Designing LinguaBytes:
A Tangible Language Learning System for Non- or Hardly Speaking Toddlers
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PROEFONTWERP

ter verkrijging van de graad van doctor aan de Technische Universiteit Eindhoven, op gezag van de rector magnificus, prof.dr.ir. C.J. van Duijn, voor een commissie aangewezen door het College voor Promoties in het openbaar te verdedigen op woensdag 28 september 2011 om 16.00 uur

door

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geboren te Vlaardingen
De documentatie van het proefontwerp is goedgekeurd door de promotoren:

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“It is our choices, Harry, that show what we truly are, far more than our abilities.”

J.K. Rowling, Harry Potter and the Chamber of Secrets, XVIII.245
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Preface

Apart from being a designer-researcher, I am a bass player, but before I was a bass player, I was a drummer, or at least thought I was. When I was about six years old I made a contraption of laundry detergent boxes, added dinner trays for cymbals, used rulers for sticks, and started playing. Two years later when my drumming ambitions had proven to be unwavering the time had come to move into more serious territories: I obtained a real drum kit from a store and started taking lessons. During the nine years that followed I practiced for half an hour every day, as far as my teenage discipline would allow. However, around the time I was seventeen my love for the drums had cooled considerably. This was mostly because I couldn’t play what I wanted to play anymore; my musical ideas had outgrown my dexterity. Maybe I should have practiced more, but I think there was also another reason to which I’ll come later.

My parents suggested that I’d try my luck with the bass guitar. Apparently, they knew me better than I did, because this instrument was perfect for me. Not only went it faithfully along with whatever I tried, it also had the uncanny instinct to keep revealing alternatives. It always seemed to understand where I was in my development relative to where I wanted to be and, like a compass, indicated me where my musical north was. Not the route to north; just north. On my way there, the bass guitar disclosed a musical vocabulary that empowered me to catch up with my ambitions, and eventually allowed me to articulate my thoughts. It had taken me to this playground called Jazz. I began composing and even seriously considered studying music professionally. However, I decided to pursue another career and let music be my passion on the side. I enrolled in the Industrial Design course at the nearby university and took my bass with me.

In the years that followed I gradually came to realise that industrial design and jazz weren’t all that different: (1) Both were grounded in a set of rules that ranged from flexible to irrefutable; (2) Some rules had to be respected, others could be interpreted, bent or even broken, some were downright contradictory; (3) Learning either design or jazz merely required the learner to develop sensitivity for the various types of rules and to invest in the tools and skills that would allow him to be creative within those rules. Helpful character traits: a well-nurtured disdain for repetition and a compulsive urge to be original.

Despite the many similarities, I was struck by a major difference between the two. As an industrial designer I was being trained to develop products that could be mass-produced and then sold to a homogeneous group of more or less quantifiable users. I deliberately use the word ‘users’ instead of ‘people’ here. As a jazz composer however I quickly realised that my target group—usually the people in one of my own bands—was all but quantifiable,
highly heterogeneous and inherently unpredictable. My band-mates usually had different musical backgrounds, heroes, styles, fortes and flaws. As a result, my compositions would never sound the way I had imagined. The size of the band, the people in the band, even the type of gig or venue had a direct influence on the rendition of my musical designs.

As a designer I found this notion highly fascinating: why do we traditionally consider our designs to be the unalterable end result? Of course, people can use their coffee cup as a pen stand, or cherish fond memories with their instance of this mass produced item, but typically a coffee cup is designed simply to allow a user to drink coffee. Jazz music however exists by the grace of personal input from the musician; a composition is solely aimed at facilitating this.

This made me think: do we designers not, by uniforming the user, choose to design for no one, instead of for everyone? Should we not, now that technology enables us to do so, be designing for diversity? And if so, how?

*Designing for Diversity*

This thesis is an account of my attempt at getting a grip on this question. My research vehicle, called LinguaBytes, was a PhD-project aimed at developing a play-and-learning system that would stimulate the language development of non- or hardly speaking children between 1 and 4 years old. It was set up in a unique multidisciplinary collaboration between Eindhoven University of Technology\(^1\), Radboud University Nijmegen and Viataal R&D Sint-Michielsgestel. In many cases the delayed language development of these children is caused by retardations in their cognitive and/or motor skills due to brain damage, but other sub-groups of children can be easily identified, for example children with an autism spectrum disorder or culturally deprived children. Since the causes for a delayed language development can vary greatly, the great challenge of LinguaBytes is to develop a play-and-learning system that will be suitable for all these children, which means that it should have the flexibility to allow children of different skills to develop from their starting point into their zone of proximal development in their preferred way.

How can my experience as a designer and performer of music help me in this challenge? Let me consider my anecdotes.

As a first observation I find it interesting that, what somehow didn’t work with the drums—even though I wanted to play the drums from early on—worked perfectly with the bass. It is my strong suspicion that the ‘language’ of the drums simply did not fit my musical qualities or ambitions: in terms of language production the drums did not provide me with the vocabulary, nor the grammar to express myself; in terms of reception

\(^{1}\)The first ten months of LinguaBytes did not include Eindhoven University of Technology as a project partner, but Delft University of Technology.
the drums did not talk to me in a language I understood the subtleties of. The bass did, however, which is something that might help me in developing LinguaBytes: apparently LinguaBytes should be able to fit a child’s personal style of expression to support its style of learning. Moreover, LinguaBytes should fit the styles of many different children. This implies a high measure of adjustability.

Secondly, it can be observed that the bass somehow grew along with me where the drums didn’t; throughout my musical development the bass leniently allowed me to stumble along while I was a novice and gracefully directed me forward. While I became more adapt it kept guiding me, now through the more subtle and complex musical territories. For LinguaBytes this means that the system should grow along with the child, guiding it towards the next step in its development. This implies a high measure of adaptive system behaviour.

Thirdly, looking at jazz composition, I find it interesting that composing involves both defining structure, as well as the openness to divert from this structure. In other words, a jazz composition is a platform for personalisation. Therefore I believe that LinguaBytes should offer structure—its directive is to improve children’s language skills—but also openness to freely move around within this structure; this should keep LinguaBytes alive and interesting.

Finally, I illustrated that the openness of this ‘platform for personalisation’ consisted of multiple facets: the size of the band, the people in the band, the type of gig or venue all had an impact on a rendition of the composition. In other words, my musical design-for-diversity was undeniably embedded within a context. In order for LinguaBytes to be fully flexible it should be context-dependent; it should be able to take into account who is/are using LinguaBytes and under what circumstances and be either adaptable or adaptive to these.

What these observations tell me is that designing for diversity is a complex business; essentially they indicate that ideally LinguaBytes should be open yet structured, lenient yet in control and highly adaptive—or at least highly adaptable—to be able to grow along with the child. In this thesis I describe how I as a designer-researcher have tried to deal with this complexity.

Rotterdam, 27 January 2011
Structure of this thesis

The research described in this thesis can be roughly divided into two tracks, although these tracks are thoroughly interwoven.

Firstly, as I have described in the Preface, there is the track aimed at researching ‘how to design for diversity’. This question can be seen as ‘how to design highly flexible systems for heterogeneous user groups’. For this track I use a Research-through-Design approach, which in short can be seen as an iterative process in which scientific knowledge is generated through, and fed back in consequent cycles of designing, building, and experimentally testing experiential prototypes in real-life settings. As these real-life settings are inherently diverse and rich in subtlety and detail, doing design research in these contexts asks for developing detailed design prototypes that allow for this diversity, subtlety and richness during their confrontation with the world. Therefore, Research-through-Design relies on the generation of wealthy, experienceable prototypes.

This is where the second track comes into focus: the one aimed at developing the LinguaBytes system at a level of sufficient wealth and experienceability. This track follows a user-centred design approach, which is based on constant dialogue with the potential users during an iterative design process. Clearly, this track can be seen as Research-through-Design as well. In a both processes scientific knowledge and design have a reciprocal influence: at some moments scientific knowledge feeds design, at other moments design feeds scientific knowledge. The difference between the two tracks however is in the role of the prototype: on the one hand the prototype is the culmination of a user-centred design track aimed at developing an as optimal as possible LinguaBytes system; on the other hand it serves as a carrier of knowledge about ‘how to’ design such a system, or more broadly, how to design for diversity. These two roles are not always easy to combine as this thesis will demonstrate.

In this thesis I have tried to find a structure that reflects the reciprocity between scientific knowledge and design as naturally as possible without resulting in chaos and unreadability. I have done this as follows.

This thesis consists of four parts. Part I: The LinguaBytes interactive play-and-learning system, is devoted to describing the LinguaBytes design, the embodiment of three years of research. Therefore in Chapter 1, I describe the positioning, structure and usage of the final LinguaBytes prototype. I do not describe the rationale behind the LinguaBytes design. This will be elaborated upon in Part II and III.

In Part II: Theoretical foundations, I describe my theoretical starting points. This part consists of three chapters in which I describe how various theories have influenced the
development of LinguaBytes. The running text of these theories contains several numbers between square brackets, for example: [1], which refer to annotations in grey text blocks.

[1] These annotations describe how a specific part of theory has impacted the LinguaBytes design, or manifests itself in the LinguaBytes design. In other words, the grey blocks represent how scientific knowledge has fed design action.

In Chapter 2, I start by describing my approach towards the LinguaBytes project, based on my beliefs, skills and expertise, grounded in paradigms from philosophy, psychology and human-computer interaction. In Chapter 3, the focus lies on the LinguaBytes users and the context in which LinguaBytes was primarily developed and tested. In Chapter 4, I describe LinguaBytes from theories on learning and language development.

In Part III: The development of LinguaBytes in five Research-through-Design cycles, I describe the LinguaBytes development process. The final LinguaBytes design was developed through five consecutive Research-through-Design cycles, which are described in Chapters 5, 6, 7, 8 and 9. With the risk of being superfluous, let me emphasise here that scientific knowledge and design within a Research-through-Design process continually influence each other, which has as a consequence that the theoretical foundations continually change. Not necessarily fundamentally, but in nuances and details. This is the essence of generating knowledge through design(ing). Therefore please note that, although I divide theory and design in Part II and Part III for the sake of readability, these two were organically intertwined in reality. In Part III I will try to describe as clearly as possible how design has contributed to the scientific knowledge described in Part II.

In Part IV: Reflection, I reflect on and discuss the scientific contribution of the work described in this thesis.
Part I
The LinguaBytes interactive play-and-learning system
Chapter 1

The LinguaBytes interactive play-and-learning system

1.1 Introduction

In this chapter I describe LinguaBytes, an interactive play-and-learning system aimed at stimulating the language development of non- or hardly speaking children between 1 and 4 years old, with sometimes severe motor disability. As mentioned in the Preface, LinguaBytes was developed as a collaboration project between Eindhoven University of Technology, Radboud University Nijmegen and Viataal R&D Sint-Michielsgestel. This multi-disciplinary collaboration made that LinguaBytes could benefit from rich scientific input from industrial design, child rehabilitation, speech pathology and special education and from connections and resources.

The importance of reducing delays in these children's early language development cannot be underestimated. Since the developments of all of a child's skills—not only its linguistic skills, but also its cognitive, perceptual-motor, social and emotional skills—are fully intertwined in a child's first years, it is vital to prevent one form slowing down the other. If not, the delayed development of one skill could very well lead to retardations in other skills, thus severely hampering a child's total development.

LinguaBytes is a modular system in which language is offered to children in a physical, playful form. Using a large collection of playful materials, children can read interactive stories and do linguistic exercises, preferably together with a parent, caregiver, therapist or teacher. These social partners play an essential role in not only the child's linguistic development, but also in its social and emotional development. In short, LinguaBytes has not been developed to replace social interaction, but rather to facilitate it.

In this chapter I merely describe the structure and functionality of LinguaBytes, but not go into detail about the theoretical foundation of, or rationale behind LinguaBytes. These will be covered in Part II and III of this thesis, respectively. In this chapter I first describe the structure of the LinguaBytes system in section 1.2. Then, in 1.3 I illustrate how LinguaBytes can be used in combination with some examples of the 16 stories and 220 exercises that make up the LinguaBytes language content.

1.2 The LinguaBytes play-and-learning system

LinguaBytes is an interactive play-and-learning system. By 'system' I mean that LinguaBytes
consists of multiple elements that for their functioning are interdependent; ‘play-
and-learning’ means that LinguaBytes stimulates learning through playing; finally, by
‘interactive’ I mean that LinguaBytes holds a software component, which responds to input
from users, or provides stimuli to users to trigger actions. LinguaBytes has been developed
to stimulate the language development of non- or hardly speaking children between 1 and
4 years old through the facilitation of communication between children and their caregivers
(parents, teachers, etcetera). LinguaBytes does this by creating a shared space for interaction
and communication, as illustrated in Figure 1.1.

![Diagram of LinguaBytes system](image)

**Figure 1.1** The LinguaBytes system was designed to facilitate communication between children and their
carers. It does this by generating spaces where child and carer meet and communicate, but also by offering
materials that enable communication. Four spaces for (inter)action can be identified: two spaces where either
the carer or the child is in control, and two other spaces where they meet. The child is primarily in control
of input, i.e. of using the LinguaBytes play-and-learning materials to interact with stories and exercises. By
placing the child in control LinguaBytes contributes to its sense of independence and thus stimulates the
child’s self-esteem. The carer has primary control over the choice and timing of stories and exercises and as
such is responsible for giving structure to the child’s linguistic development. Additionally, there are two spaces
where carer and child either have shared control or joined attention; both can communicate with LinguaBytes’
collection of play-and-learning materials, and communicate about what they see happening in the interactive
stories and exercises, shown on LinguaBytes’s output module.
To facilitate child-caregiver communication LinguaBytes encompasses a set of approximately 500 core words, distributed over 16 stories and 220 exercises. The term ‘core’ means that these are the 500 most important words a child needs to learn through the use of LinguaBytes (Bacchini, Boland, Hulsbeek & Smits, 2005; Schlichting, Van Eldik, Lutje Spelberg, Van der Meulen & Van der Meulen, 1999; Zink and Lejaegere, 2002). Other words can be included in the stories or exercises, but are of lesser priority for the child’s linguistic development. To interact with stories and exercises, physical materials were developed: 16 story booklets, 236 input figures and 31 word cards. These are illustrated in the following pages.

*Input materials to use with LinguaBytes’ interactive stories and exercises*

As mentioned above there are about 500 LinguaBytes core words, distributed over interactive stories and exercises in six linguistic themes: 1. Animals; 2. In and around the house; 3. Traffic and vehicles; 4. Toys and clothes; 5. Food and drinks; 6. People and the body. Each theme contains at least two interactive stories that form the basis for follow-up exercises. The stories have been written especially for the LinguaBytes project. A story can have two forms: (1) A linear story form: this type of story has a single storyline with clear causal connections, the order of scenes is fixed; (2) a branched story form: this type of story has a fixed beginning and ending, but an open storyline in between. I use the term ‘open’ to indicate that the scenes in the story have no compulsory order.

To interact with the stories LinguaBytes includes story booklets. The forms of the stories are reflected in those of the story booklets: the linear story is a long strip of three-scene pages, folded like an organ book (Figure 1.2, left); in the branched story the opening scene, closing scene and three-scene storyline pages are separate strips (Figure 1.2, middle). To make these stories interactive all scenes have been tagged with RFID-tags (Radio Frequency

![Figure 1.2](image_url) The LinguaBytes story booklets. Top, from left to right: a linear story, a branched story and the back of a linear story with its embedded RFID-tag. Bottom: close-up of two linear stories.
Apart from these two types of booklets for reading interactive stories the LinguaBytes system incorporates physical, RFID-tagged input figures for doing exercises. There are 236 figures in total, all shaped as miniature representations of one of the approximately 500 LinguaBytes core words. For interacting with exercises, the input figures should be placed in one of the trays of the exercise module, which will be described shortly hereafter, in the section ‘The LinguaBytes interface modules’. The input figures come in different colours, one for each theme (Figure 1.3): light blue (Animals), dark blue (In and around the house), red (Traffic and vehicles), yellow (Toys and clothes), green (Food and drinks) and ivory (People and the body). This last category also includes cross-theme input figures such as letters and the shapes ‘round’ and ‘square’.

The third type of play-and-learning material is a set of 31 word cards (Figure 1.4, left). These cards contain a Picture Communication Symbol (PCS) of one of the core words, in most cases a verb. Apart from a PCS, the cards display the word in Dutch language. All cards are tagged with RFID. The back of the cards displays the colour(s) of the theme(s) in which the card can be used (Figure 1.4, right).

Apart from these input materials, LinguaBytes supports creating custom input materials through the use of programmable input labels (Figure 1.5, left). These labels contain RFID-tags to which LinguaBytes core words can be assigned. By using the label’s integrated clip or strip of Velcro the labels can be attached to objects that a child is already familiar with, e.g., his favourite plush toy (Figure 1.5, middle). Also, if placed at different locations in a room, the labels can be used to practice more abstract concepts like ‘near’ and ‘far’, or ‘high’ and ‘low’ (Figure 1.5, right). Thus, the labels can be used to create personalised input materials.

The LinguaBytes interface modules
All play-and-learning materials can be used in combination with the LinguaBytes interface, which serves as the platform for interacting with the stories and exercises. The LinguaBytes interface consists of five modules: the output module, the base module, the control module, the story module and the exercise module. The former three modules are always needed to interact with the LinguaBytes stories and exercises; the latter two are used for either reading stories or doing exercises. I describe all modules here, starting with the output module.

Then for the sake of readability I first describe the story module and exercise module, before describing the other two modules.

Output module. As illustrated in Figure 1.1, the output module is designed as the point of joined attention, which is created by offering all interactive stories and exercises in animated form through the output module (Figure 1.6, left). The output module contains a 17” flat screen display, two speakers and controls for image and sound. The module is housed in an ash wood casing with a custom designed stand (Figure 1.6, middle) with
which the screen can be placed both a horizontal and tilted position, for use on the floor or a tabletop. The stand contains four ball transfer units (Figure 1.6, right) enabling a rapid adjustment of the screen’s axial rotation. This makes it easy to optimise the child-screen-caregiver setup.

**Story module.** The story module (Figure 1.7, left) is designed for collaborative, interactive story reading. Each of the six themes comes with multiple stories. Child and adult can choose a story together, after which the corresponding booklet is inserted in the right side of the story module (Figure 1.7, middle). In the middle of the module is a viewing window (Figure 1.7, right). The scene of the booklet that is behind the window is shown in animation and audio on the output module. To move the booklet through the module the child can use two handles, one on each side of the viewing window. By moving the right handle, the story module’s book transportation system switches on and the booklet is automatically moved to the next scene. When the scene is directly behind the viewing window the transportation system is switched off and the booklet comes to a halt. By moving the left handle the booklet can be transported to the previous scene. This matches with the Western reading direction and the direction of flipping book pages.

**Exercise module.** The exercise module (Figure 1.8, left) was designed for doing LinguaBytes’ interactive exercises. These are always related to one of the interactive stories and done in combination with the input figures and word cards. The exercise module contains three trays in which a child can place these materials in order to interact with the exercises. This will be elaborately described in section 1.3. The middle tray holds an integrated speaker for audio (Figure 1.8, middle); the two outer trays come with lids (Figure 1.8, right). Typically, the middle tray is used in all games and exercises. For some types of exercises (e.g., one focused on making sentences) the middle tray is combined with the outer trays by removing the lids. The speaker can be used to place extra emphasis on the aural aspects of language, e.g., within phonological exercises.

**Base module.** Neither the story module, nor the exercise module can be used without placing them on the base module (Figure 1.10, left). This module contains three RFID-readers for identifying the play-and-learning materials and a system for determining the selected linguistic theme (Figure 1.10, middle). At the bottom side the module holds four suction pads (Figure 1.10, right) that enable fixation of the module at the optimal ergonomic position and prevent it from sliding away.

**Control module.** Lastly, we have the control module (Figure 1.11), which is to be used exclusively by the adult accompanying the child. It contains two buttons, a switch and a joystick that can be used to: (1) Select stories, games and exercises in the LinguaBytes main menu; (2) navigate within games and exercises; (3) move to a next item within exercises; (4) repeat items within exercises; (5) switch between ‘explorative’ and ‘assignment based’ versions of exercises; (6) stop exercises and go back to the menu.
Figure 1.3 The LinguaBytes input figures, belonging to the themes (left to right, top to bottom): animals, in and around the house, toys and clothes, traffic and vehicles, food and drinks, people and the body.

Figure 1.4 The thirty-one LinguaBytes word cards contain a Picture Communication Symbol on the front side (left) and a colour coding on the backside indicating to which theme the card belongs (middle). Cards can belong to more than one theme, which is reflected accordingly in the colour coding (right).
Figure 1.5 LinguaBytes input labels (left) can be used to generate additional, personalised, interactive play-and-learning materials, for example by attaching them to children’s toys (middle). Also, the labels can be used to practice abstract concepts like ‘high’ (right), as opposed to ‘low’.

Figure 1.6 The output module seen in its horizontal position (left). The output module contains an integrated stand (middle) to put the module in a tilted position. The stand contains ball transfer units (right, one of them) on which the module can freely roll around; this facilitates adjusting the axial positioning of the module relative to the child and its carer.

Figure 1.7 The story module (left), designed for reading interactive stories. Its ash wood housing contains a recess in which one of the story booklets can be inserted (middle). By using the left and right handle of the module the booklet can be moved through the interface. The scene that is located behind the viewing window (right) is shown as an animation on the output module of LinguaBytes (shown in Figure 1.6).

Figure 1.8 The exercise module (left), designed for doing linguistic exercises. The module contains a small speaker for exercises aimed at phonological awareness (middle). The lids covering the left and right trays can be removed for exercises where input materials can be combined or clustered (right).
**Thematic backgrounds**

LinguaBytes includes eight thematic backgrounds that can be placed in the base module. By placing a background, all stories and exercises available within a theme are automatically filtered and shown in a single screen menu. This reduces the time that has to be spent on child-distracting activities like going through menus. In total there are eight backgrounds (see Figure 1.12), belonging to the six themes, meaning that two themes come with two backgrounds: the theme ‘Animals’ has one background for farm animals and one for zoo animals, and the theme ‘Toys and Clothes’ has one background for toys and play activities, and one for clothes and the weather.

**Manual**

LinguaBytes comes with a comprehensive manual that gives a thorough overview of all of the themes and their stories and exercises. With each theme an overview is given of the core words and available input materials, as well as a description of the stories and exercises. For each application the manual describes which input materials can be used and provides the caregiver, therapist or teacher with helpful suggestions and strategies for interaction; both with the system as well as with the child.

**Additional hardware**

Finally, since the LinguaBytes prototype does not yet have an integrated computer with dedicated software, it uses an external Mac Mini, running MAX/MSP and Adobe Flash (see Figure 1.13). USB cables and power connections are provided as well.

**1.3 Using LinguaBytes**

Now that the elements of LinguaBytes have been described in section 1.2 I illustrate in this section how LinguaBytes can be used.

**Arranging the output, base and control modules**

LinguaBytes was designed to support different spatial arrangements of the output, input and control modules. This enables adjusting the ergonomics of the system to a child’s requirements, or to a setting with multiple children. The preferred layout of LinguaBytes will depend on several factors such as the preferences of the child and the adult. I strongly recommend a set-up that allows for making eye contact between child and caregiver.

The output module can be placed in both a horizontal and a tilted position, and can freely be moved around due to the four ball transfer units integrated in the stand. As such, the orientation of the screen in relation to its users can be adjusted at any moment, even during the interaction. The system can be used on a workspace or on the floor. In either set-up it is important not to isolate the child, but to enable eye contact with the caregiver,
teacher or therapist. The optimal viewing distance to the output module is between 40 and 50 cm (see Figure 1.9), depending on the age of the child and its vision capacity. Often the viewing distance to a screen is related to reading and calculated as \([200 \times \text{letter height}]\). However, since we are dealing with illiterate children, we can use the rule of thumb that someone’s optimal viewing distance equals the length of his arm.

The optimal position of the base module—and thus the two input modules—is between 30 and 40 cm (see Figure 1.9), in front of the child. Input materials can be placed to the left and right of the base module. Since the control module is supposed to only be used by the caregiver, we advise to keep it out of the child’s reach (see Figure 1.1).

Connecting the output, base and control modules and starting up the LinguaBytes software

After arranging the modules of LinguaBytes system, the output module, base module and control module must be connected to the Mac Mini (see Figure 1.13, left), each other and a power source using the supplied cables. Finally, the Mac Mini and output module can be switched on. When the Mac Mini has fully started up, two programs need to be started up: first the MAX/MSP patch and then the LinguaBytes Flash Player. Shortcuts to both applications are placed on the screen’s desktop and can be simply double-clicked. The LinguaBytes menu appears (see Figure 1.13, right). We are now ready to explore the world of Tom and Tes.
Choosing a thematic background and selecting an interactive story (Movie sequence 1 on the enclosed DVD, in folder ‘Chapter 1’)

In order to access the LinguaBytes content it is necessary to select a theme. For this one of the thematic backgrounds should be inserted into the base module’s slot. Keeping in mind that the goal of LinguaBytes is to stimulate a child’s linguistic development, choosing a theme is a first opportunity for caregiver-child communication. Therefore, it is advisable to let the child choose a thematic background and talk about it, or to choose collaboratively.

When a background (and thus a linguistic theme) has been selected, it should be inserted in the base module’s slot. When the background is properly inserted, all available stories and exercises within the selected theme are revealed in the menu on the output module (see Figure 1.13 right). Using the control module, the caregiver can select one of the available stories from the menu and load it, as follows: (1) Using the joystick, the caregiver can move the menu’s selector to the desired location. Moving the joystick to the left or right results in switching columns; moving the joystick forward and backward enables moving within a column; (2) Pushing the repeat button loads the selected story.

Figure 1.10 The base module (left) contains three RFID readers, seen here as the three darker areas. At the far end of the module a slot is located with four switches (middle, one of the switches) that determine the play-and-learning theme, in combination with the thematic backgrounds, see Figure 1.12. At the bottom of the module, four suction pads (right) prevent the module from sliding away when positioned in front of the child.

Figure 1.11 The control module. This module is to be used by the child’s carer (a parent, therapist or other familiar adult) to control the LinguaBytes stories and exercises. The module contains two buttons and a joystick for selecting and controlling exercises, and a toggle switch for setting the mode of the exercises to either ‘explorative’ or ‘assignment based’.
Figure 1.12 The eight thematic backgrounds can be placed in the base module’s slot (see Figure 1.10, middle). The four switches in the slot detect the pattern of cutaways of the backgrounds and thus determine which theme is selected.

Figure 1.13 The LinguaBytes software runs on a Mac Mini (left). On the right the LinguaBytes four-column start-up menu is shown, headed by Tom and Tes, the main characters of all stories and exercises.
Listening to interactive stories (Movie sequence 2 on the enclosed DVD, in folder ‘Chapter 1’)

It is recommended to always start with interactive story reading, before moving to the exercises. To ‘read’ interactive stories, the story-reading module should be placed on top of the base module. Using internal magnets, the module positions itself automatically. Also, the story booklet of the selected story has to be retrieved from the box. The story booklet can now be used as a traditional picture book or in combination with the story reading module. In the former case a caregiver reads the story, in the latter case the output module reads it.

To read the interactive story, the physical booklet of the story should be inserted into the right side the story module, either by the child or caregiver. In the case of a linear story this is pretty straightforward. In the case of a branched story, the first part to insert is always the part that contains the opening scene. This part can be recognised by being a transparent strip, with only one scene on the right side (see Figure 1.14). When the selected story is loaded, its first image appears showing the story’s thematic context or scenery, along with LinguaBytes’ recurring main characters Tom and Tes, a three-year old boy and girl.

The child can then move the booklet into the story module, using the right flipper. This switches the story module’s transportation system on and pull the book to the left, into the module. When the story’s first scene is located behind the module’s viewing window, the transportation system is switched off. The scene is then displayed on the output module, along with its audio. The module’s flippers are automatically switched off until the scene has ended. Then the child can choose to go to a next or previous scene. To go forward in the story, the child uses the right flipper, to go back it uses the left one.

If the selected story is a linear one, the story is read from the first to the last scene. In the case of a branched story, a child chooses a new branch—a new three-scene—page at the end of the previous one. A child can choose the order of pages freely, or even repeat the same page. A branched story always has a separate end page. At the end of a story, or when the caregiver decides that story-reading time is over, the stop button on the control module is pushed. This closes the story application and show the starting menu again. Then the story module can be taken off the base module.

Choosing and doing exercises

After reading a story, LinguaBytes can be used to do linguistic exercises. There are three types of exercise, focused on three language aspects:

- Phonological awareness: listening to songs, rhymes and sounds (e.g., of animals or vehicles), finishing rhymes, practicing the coupling of sounds and letters, and stimulating auditory discrimination;
- Semantics: doing peek-a-boo guessing games, stimulating context-awareness (e.g., a cow can be found at the farm, an airplane usually not), relational classifications (e.g., fruit versus vegetable) and word associations (e.g., airplane-pilot), and spatial
relations (front, middle, back);

- Syntax: practicing forming one-word, two-word and three-word sentences, the use of adjectives and adverbs, and distinguishing shapes (square and round) and colours (red, yellow, blue and green).

Each of these exercise types has its own column in the LinguaBytes menu (the yellow, pink, green and blue columns shown in Figure 1.13 right). To select an exercise, the caregiver can use the joystick of the control module to move the menu selector on the screen, as described earlier in step 5. There is a significant difference however between the interactive stories and exercises: most of the exercises can be done in two ways: (1) Assignment-based: in this setting a child gets assignments with right and wrong answers, for example: “what do you buy from the baker?” with possible answers like ‘bread’ or ‘cookies’, but not ‘apples’; (2) Explorative: in this setting the exercise is in free-play mode; in this mode a child can simply explore his options and learn from the provided feedback. To choose either of these modes, the caregiver can use the toggle switch on the control module (the left-bottom switch in Figure 1.11). Setting it to ‘expl.’ loads the explorative version of an exercise, ‘opdr.’ the assignment-based version. If an exercise is only available in one of the two versions, this version loads automatically.

So, using the control module’s controls, the caregiver can navigate to an exercise, select the mode of the exercise, and load it. Then, the exercise module should be placed on the input base module. Using the manual, the available input figures can be collected from the box and placed around the exercise module, within view and reach of the child.

In the following I go through a few exercise examples of each to illustrate how to use LinguaBytes.

Example 1: listening to songs (Movie sequence 3 on the enclosed DVD, in folder ‘Chapter 1’). One thing that young children like is listening to songs. There are thirty-five songs included in the LinguaBytes prototype. To listen to songs the selector in the LinguaBytes menu has to be moved as described earlier in ‘Choosing a thematic background and selecting an interactive story’ to ‘Liedjes’ (= Songs) and loaded using the repeat button. The exercise automatically starts in explorative mode, since this is the only one available with this type of exercise.

Let us assume that the background ‘clothes’ is inserted in the base module’s slot. In that case, the opening screen of the ‘clothes’ song application is displayed: a room with clothes scattered around. Using the manual, the input materials of the available songs should be retrieved from the box: the wellington boots, coat, hat and shoes. The child can now place one of the input materials in the middle tray of the exercise module, for example the wellingtons. Immediately, the song associated with ‘wellington boots’ is triggered and accompanied by an animation. Removing the boot from the tray immediately ceases the song and ends the animation. The child can choose to place any of the available clothes in
the tray, for example the shoes.

A caregiver can respond to a child’s actions by asking it questions like “Who do you see there?”, “What is she wearing?”, etcetera. This can stimulate the child’s communication skills and vocabulary. If a child loses attention or is not in the mood for clothes in the first place, it is easy to switch to another theme; simply replacing the thematic background with another suffices. It is not necessary to return to the LinguaBytes menu. At the end of the exercise, hitting the ‘stop’ button on the control module ceases the application and shows the LinguaBytes menu again.

**Figure 1.14** The strips belonging to the branched story ‘Tom and Tes go to the supermarket’, in the theme ‘Food and Drinks’. The first part of the branched story is a transparent strip that only contains the standard opening scene of the story. This part is shown above. The middle parts of the story, seen here on the back, contain three-scene sequences that can be read in random order. The final part, shown below, contains the standard two last scenes.

**Figure 1.15** LinguaBytes includes 17 letters: a, b, d, h, j, k, l, m, n, oo, p, r, s, t, v, w and z.
Example 2: creating personalised input material (Movie sequence 4 on the enclosed DVD, in folder 'Chapter 1'). LinguaBytes is aimed at being a highly flexible play-and-learning system. Therefore, it even includes the option to create personalised input materials. The only restrictions are that the word that will be represented by this personalised input material is part of the LinguaBytes core word list, and that the personalised input material can be used similar to the LinguaBytes input materials, i.e. by bringing them in close proximity of the input base module's RFID-readers.

To create personalised input material you need to take an RFID-label from the box, shown earlier in Figure 1.5. Each LinguaBytes prototype comes with three of these labels. Then, the background of the theme in which the word is clustered should be placed into the base input module. Let’s stick with the word ‘shoes’. Using the control module, ‘RFID-programmer’ should be selected from the LinguaBytes menu. This loads the application for programming the RFID-labels in the right theme. One RFID-label should be placed in the middle tray of the exercise module. Using the joystick, the word selector can be moved through the list of core words, in this example to the word ‘shoes’. Pressing the repeat button assigns the word to the tag. The assigned word is displayed on the screen. Pressing the ‘stop’ button returns the user to the LinguaBytes menu.

Now the RFID-label can be attached to a real shoe, a toy shoe, a photograph of a shoe, a drawing or any other representation of a shoe that a child understands. The label can be attached by using the clip or Velcro. The newly created input material can now be used like the included LinguaBytes input materials, for example within the application described in Example 1.

Example 3: coupling sounds with letters (Movie sequence 5 on the enclosed DVD, in folder 'Chapter 1'). Learning to read is not part of the pre-school curriculum. However, introducing young children to the existence of letters is a good preparation for early literacy. Therefore, LinguaBytes includes exercises that stimulate the distinction of the sounds of 17 letters: a, b, d, h, j, k, l, m, n, oo, p, r, s, t, v, w and z (see Figure 1.15). In the following I describe how to use these letters in one of the dedicated exercises.

Firstly, of course, a thematic background should be inserted in the base module in order to access the LinguaBytes menu, for example the one representing ‘food and drinks’. We’ll assume that the exercise module is still placed on the base module. In this exercise the following letters are practiced, as can be seen in the manual: k, m, n, p, s. These can be collected from the box and placed along the input module in a way that the child can clearly see and reach them. Using the control module’s joystick, the selector should be moved to ‘koppeling klank - teken’ (coupling sound - character) and the toggle switch flipped towards the assignment-based mode. By pressing the repeat button on the control module the exercise is loaded. On the output module a kitchen setting is displayed. There is a kitchen table in the foreground. A voice-over asks a question, for example: “Which
letter do you hear? Pan, the P of P-an, Pan”. The word ‘pan’ is displayed, with the first letter highlighted.

A child can now choose the correct answer from the five available letters in front of him. If a caregiver observes that the child has difficulties choosing, the number of options can be reduced, e.g., by suggesting two alternatives: “Do you think it is this one or this one?” holding up the p and the k. The child places his selection in the middle tray of the exercise module. If the answer is correct, pear is displayed on the kitchen table and the voice-over congratulates the child, saying “Yes! Well done! The P of P-an, Pan”. If the answer was not correct, the table stays empty and the voice-over urges the child to try again. The question is repeated.

At this point there are several options for the caregiver. Firstly, she can help the child by repeating the question, by pushing the repeat button on the control module. Each time the button is pushed, the question is repeated. Secondly, she can choose to go to another question, by moving the control module’s joystick to the right. The voice-over now asks a different question, for example “Which letter do you hear? Porridge, the P of P-orridge, Porridge”. The word ‘porridge’ is displayed instead of pan. Thirdly, she can choose to switch to the explorative version of the exercise by flipping the control module’s toggle switch to explorative. In this version of the exercise, the child is not asked any questions but can instead freely explore the available letters.

Let’s stick with this last option. If the child now places the letter p, this results in a pear appearing on the display’s kitchen table, along with the voice-over saying “Pear, the P of P-ear, Pear”, or in a bowl of porridge with the corresponding audio, or in a pan with the audio “Pan, the P of P-an, Pan”. Placing the letter k results in a cookie (Koek), the n in nut (Noot), the m in knife (Mes) and the s in soup (Soep). In this way, a child can playfully get accustomed with the sounds of different letters and practice the ones he finds difficult.

When the caregiver has the impression that the child’s has become more aware of the letter sound of the letter p, she can choose to switch back to the assignment-based mode, by flipping the toggle switch to assignment-based. This results in a new question to the child, for example “Which letter do you hear? Pear, the P of P-ear, Pear”. Now, there are again two options: (1) the child and caregiver can continue doing this exercise until the child’s attention span or performance starts to slacken. Then, by pressing the stop button, the exercise is terminated and we return to the LinguaBytes menu; (2) another option is to change themes, for example to show other words that start with the letter p: paard and poes (horse and cat) in ‘Animals’, pop and pen (doll and pen) in ‘Play activities and toys’, and pet (cap) in ‘Clothes and weather’.

When exercising is over, we can return to the LinguaBytes menu by pressing ‘stop’.

Example 4: semantic associations (Movie sequence 6 on the enclosed DVD, in folder ‘Chapter 1’). The previous examples were focused on phonology, so let’s try something else.
A second aspect of language is semantics. The next example describes an association exercise in which children learn to cluster types of food in a semantic network.

Let’s stick with the ‘Food and drinks’ theme. The exercise mode is still set to assignment-based. We use the joystick to select ‘woordassociaties’ (word associations) from the middle column, and the repeat button to load the exercise. A supermarket’s grocery department appears. The greengrocer is standing behind the counter, smiling. The voice-over says “What can you buy from the greengrocer?”.

Using the manual the available input materials can be retrieved from the box by the caregiver: the correct figures representing ‘lettuce’, ‘carrots’ and ‘tomatoes’, and alternatives from other supermarket sections, like ‘bread’, ‘cookies’, ‘cake’, ‘meat’, ‘fish’ and ‘chicken’. If the child places one of the correct alternatives (e.g., lettuce) in any of the exercise module’s trays, the accompanying food appears in crates in front of the greengrocer’s counter and the voice-over says “The greengrocer sells lettuce. The lettuce is put in a crate”. If the child places incorrect food (e.g., cake), the voice-over says “The greengrocer doesn’t sell cake, but why don’t you try again?”. The child can place up to three types of vegetable-related items in the three crates in front of the counter.

By moving the control module’s joystick to the right another supermarket section can be selected: the cold cuts section, or the bread section. When practicing food associations is over, the caregiver can press the stop button on the control module to return to the LinguaBytes main menu, for example for choosing an exercise for a third language aspect: syntax.

Example 5: making sentences (Movie sequence 7 on the enclosed DVD, in folder ‘Chapter 1’). For a 1-year-old, one word is a sentence. However, by the time a child is four years old it has learned to combine multiple words into meaningful three, or sometimes even four-word sentences. To practice this, LinguaBytes includes exercises to stimulate syntax. Here I describe how these exercises can be used.

The ‘Food and drinks’ background is still in the slot of the base module. On the output module, in the right column of the LinguaBytes menu, we see the menu item ‘tweewoordszinnen’ (two-word sentences). Using the toggle switch the exercise mode is set to explorative for free play, and with the joystick and repeat button we select and load the exercise. In order to do this exercise we remove one of the lids from the exercise module. Depending on whether a child is right-handed or left-handed, either one of the outer trays can remain closed. This is detected by the base module.

Using the manual the available input materials can be retrieved from the box: the figures of Tom and Tes and the verb cards ‘eating’, ‘drinking’ and ‘licking’. These verb cards can be easily found using the colour coding on the backside, see Figure 1.4. All cards that can be used within the theme ‘Food and drinks’ have green on the backside. The child can now
freely explore the materials in front of him by placing two of them in the two open trays. Placing Tom or Tes results in them appearing on the output module, combining Tom or Tes with a verb card results in them doing the verb.

The role of a caregiver now comes into focus: since LinguaBytes is about stimulating language skill development, a caregiver can start to communicate with the child, for example by asking questions or making up stories together: “Who’s hungry?”, “Who is thirsty?”, “What should Tom do when he is hungry?”, “How can we make Tes less thirsty?” or “Who is also hungry?” are all good questions to ask a young child.

When a child shows interest in using more words, a caregiver can try out if a child is also capable of making a three-word sentence. For this, it is necessary to remove the remaining tray lid. This is detected by the base module and automatically loads the exercise ‘Driewoordszinnen’ (Three-word sentences). It is not necessary to do this via the LinguaBytes menu. Using the manual, the caregiver can now retrieve the materials used in this exercise from the ‘Food and drinks’ compartment: French fries, cookie, apple, banana and pancake for the verb ‘eating’, coffee, lemonade, milk and chocolate milk for ‘drinking’, and a lolly pop and an ice cream for ‘licking’. Now a child can combine a subject and verb with an object, for example: ‘Tes’, ‘Drinking’ and ‘Lemonade’ results in Tes drinking a glass of cool lemonade on the output module, while a voice-over says “Tes…drinks…lemonade”. Similar as described earlier a caregiver can now try stimulating the child’s imagination and linguistic sensitivity by asking questions like: “Who else likes lemonade?”, “Tes is getting thirsty from all this food. Can we help her somehow?”, etcetera.

Some of the sentence-building exercises are also available in assignment-based mode. These can be accessed by flipping the toggle switch to ‘assignment-based’. Flipping this switch during the exercise automatically loads the assignment-based version without going back to the LinguaBytes menu. A voice-over now says: “Tom drinks lemonade. Can you show Tom?”. The child is now supposed to place the subject Tom in the left tray, i.e. at the beginning of the sentence. If the child places Tes, the voice-over encourages the child to try again, saying for example “I think you need another one”. If necessary a caregiver can press the repeat button to repeat the full sentence and question. As soon as the child places Tom, he appears on the output module and the voice-over cheers “Very well done! Now, can you make Tom drink?”. When the child places the verb card ‘drinking’ in the middle tray, the proper place in the sentence, Tom starts to drink and the voice-over says “Yeah, great! Tom…drinks. Now, can you make Tom drink lemonade?”. The child places the lemonade-jug-figure in the right tray, and Tom is shown drinking a nice cool glass of lemonade. The voice-over cheers “Good! Tom…drinks…lemonade”.

The caregiver can now move the control module’s joystick to the right to go to the next assignment, or press the ‘stop’ button to go back to the LinguaBytes menu.
Rounding off
The scenario described in this section will probably have spanned half an hour. Appealing though LinguaBytes may be, the attention span of some children will have started to falter by now. These children can wave Tom and Tes—smiling widely at them in the LinguaBytes menu—goodbye for now and start looking forward to a next encounter.
Part II
Theoretical foundations
Chapter 2
Starting points for this research

2.1 Introduction
In this chapter I describe the starting points for the work described in this thesis. First in 2.2 I describe a preliminary study by Van Balkom, De Moor & Voort (2002) and a follow-up study by Hummels, Van der Helm, Hengeveld, Luxen, Voort, Van Balkom & De Moor (2006), on which this research was based. In 2.3 I describe the theoretical and methodological foundations of my research. These foundations are the underpinning of my work, as they largely correspond with my own beliefs as a designer. I illustrate these in section 2.4.

2.2 Preliminary study by Van Balkom, De Moor and Voort, and its follow-up ‘ExploraScope’

A child’s linguistic development is not a stand-alone process but is an integral part of a child’s total development. The continuous interaction between the linguistic, cognitive, perceptual-motor and social-emotional developmental domains makes that these are highly interdependent, especially in the first few years of a child’s life: disturb one and the others will follow. In a child’s linguistic development the first years form a biological crucial period. This is the main period in which the brain develops the speech and language areas (Goorhuis & Schaerlaekens, 2000). It is therefore vital to minimise the delayed linguistic development as early in a child’s life as possible. For example, research has shown that non- or hardly speaking children with multiple disabilities benefit from professional help in the form of speech- and language training programmes, possibly in combination with speech therapy (Downing, 2005). This could also reduce the negative effects on the other developmental domains.

In recent years many early intervention programmes have been instigated to stimulate the language development of preschool children (children under 4 years old). Often these programmes are based on linking language to a child’s own sensory-motor experiences. A trend within these programmes is a growing demand for supporting educational materials, especially those that encourage the child’s need to explore and take initiatives. Many researchers have been investigating the role of new technology in this, and a variety of products and systems have already become commercially available. I describe some in
section 4.4. The work described in this thesis builds on a study performed in 2001 by Hans van Balkom, Jan de Moor and Riny Voort, who identified a growing need for interactive material that would support the language development of non- or hardly speaking toddlers with multiple disabilities. These children are confronted with both cognitive as well as perceptual-motor challenges resulting in a delayed language development. Based on their observations Van Balkom et al. (2002) performed a study in which they addressed two questions: (1) is there a need for an interactive program that stimulates the language development of toddlers with multiple disabilities in the Netherlands, and; (2) if so, what could be its form, its content and the desired interaction? These questions were approached through a literature study and an expert consultation using the Delphi-method (Turoff & Hiltz, 1996). This is a method for obtaining judgments from a panel of independent experts. The invited experts (2 linguists, 5 educational psychologists and speech therapists working with toddlers with multiple disabilities, 3 computer scientists, 3 special education teachers and 1 industrial designer) were asked to react on propositions based on the literature study, in two subsequent phases (36 propositions in the first phase and 27 propositions in the second phase) via the Internet. The results of the preliminary study confirmed the first question that there was a need for an interactive program that stimulates the language development of toddlers with multiple disabilities in the Netherlands.

To answer the second question—what could be form, content and desired interaction of such an interactive program—an explorative prototype was built: a computer program telling the interactive, nine-scene story of a boy preparing to go to sleep (see Figure 2.1). Interacting with the computer program was based on the traditional PC input devices (mouse, trackball, etcetera). By clicking one of the navigation icons at the bottom of the screen, the toddler could stop the story, go to the next or previous scene or replay the current scene.

The program was presented in a plenary meeting to, and evaluated with the experts that participated in the preliminary study. This evaluation resulted in two impacting conclusions: (1) to optimise the interaction for each individual child the program should be adjustable to the developmental level—both cognitive as well as perceptual-motor—of the child, and; (2) the program should be more toy-based than a PC-based.
**ExploraScope**

To research what such a product could look like, what its content could be and how it could be used, the LinguaBytes follow-up project was started. A first explorative design was the ExploraScope or E-Scope (Hummels et al., 2006).

The E-Scope (see Figure 2.2) is a wooden ring-shaped toy with various integrated sensors and actuators, a computer with a wireless station, and a monitor. The E-Scope and the computer communicate through radio transceivers. All sensors, actuators, and batteries are built into the ringed layers of E-Scope. E-Scope can be used in different configurations to suit a child’s preferred interaction style. With the E-Scope a child can listen to stories or play educational games by rolling it over pictures that are lying on the floor. Each picture triggers a matching one-scene story. The buttons can be used for further deepening of the linguistic concepts within the scene. For example, within a scene about a goat at the farm, pushing a button can trigger auditory output (e.g., the sound the goat, the word “goat,” a song about the goat) or visual output (e.g., a different picture of a goat), or be used to highlight parts of the goat (legs, belly, tail, etcetera).

The E-Scope was tested with three children and three therapists at rehabilitation centre St. Maartenskliniek in Nijmegen, the Netherlands. The outcome was that the overall concept of the E-Scope—enabling young children to learn simple concepts through

![Figure 2.2](image.png)  
*Figure 2.2 The E-Scope in its various configurations: (1) On the floor with pictures (top-left), (2) On a table with an integrated screen (bottom-left, mock-up), (3) With a separate screen (middle), and 4. With an additional input device (right).*
physical interaction and play—was useful and promising. The children were excited by the stories and graphics and showed good concentration. The therapists were positive about the toy-like design and its playful sensorial character. They were enthusiastic about the diversity in interaction styles but encouraged further adjustability for a more personal fit. The product should make more use of physical objects that could be adjusted more to the skills of the child.

The results of the preliminary study by Van Balkom et al., as well as those from the E-Scope formed the point of departure for the work in this thesis.

2.3 Theoretical foundations

My research is inspired by the philosophical school of phenomenology—most prominently the contribution of Maurice Merleau-Ponty—and by Gibson’s ecological approach to visual perception. These approaches have in common that meaning, defined as ‘information for action’, emanates from interaction with the world. This makes these theories highly interesting for designers, as ‘interaction with the world’ is something that can be designed: design is about creating information for action for the body-that-acts-in-the-world, and the corresponding human skills and not in the first place the ‘mind’ (Designing Quality in Interaction, 2010).

In the next sections I outline the philosophical school of phenomenology and Gibson’s ecological approach to visual perception and illustrate how these have found their way into the design of everyday things and the interaction design paradigms of ‘tangible interaction’ and ‘embodied interaction’. These paradigms have highly influenced my approach to the LinguaBytes project. For one, much of the following discussion of phenomenology connects to the foundations of embodied interaction as described by Paul Dourish (Dourish, 2001). The paradigm of embodied interaction is described later in this section.

Phenomenology

The philosophical school of phenomenology was introduced by Edmund Husserl (1859-1938), who criticised how the science of the world had distanced itself from everyday experience. Instead of trying to explain the world like many of his scientific contemporaries, Husserl turned to “the things themselves”, toward the world as it is experienced in its felt immediacy (Abram, 1996: p. 35). He set out to uncover the relationship between how we observe the phenomena of our everyday world and how we experience these phenomena.

Husserl’s ideas were developed further by his student Martin Heidegger (1889-1976), who stated that the meaning of the world is the product of our being-in-the-world; it is the result of the way in which we exist in the world, actively participate in and interpret the world. Heidegger states that the world is not merely something that surrounds us and that we act upon, but also that we can act through; the world is the medium through which we
can accomplish our actions. Heidegger distinguishes two ways in this: the world ready-to-hand or present-at-hand (‘zuhanden’ or ‘vorhanden’, in Dourish, 2001: p.109). To clarify these, let me consider the bass again, as I did in the Preface. When I play music through my instrument it becomes an extension of my body allowing me to express myself effortlessly: it is ready-to-hand. However, when I get tired I start struggling with my bass: it becomes present-at-hand, my action is directed towards the musical tool itself.

The LinguaBytes play-and-learning system should of course ideally allow children to use it in such a way that it becomes ready-to-hand for each and everyone of them [1].

Although Heidegger already made a move away from the Cartesian mind/body duality it is Maurice Merleau-Ponty (1908-1961) who gives the body a pivotal role in phenomenology. Merleau-Ponty sees the body not as something that you have, but something that you are (Merleau-Ponty, 2008). To clarify his concept of le corps propre Merleau-Ponty uses the psychological concept of the ‘body schema’, which is basically the non-conscious understanding of our own, lived body. According to Merleau-Ponty the body schema is dynamic and open: clothes, tools, prosthetic limbs, new motor skills, all can be freely added to our body schema, causing it to automatically change. Fact remains that the relation we have to our environment is determined at the most primordial level by the possibilities our bodies have to handle specific situations. According to Merleau-Ponty objects are meaningful to us because we have a (prereflexive) bodily relation to them: “being-in-the-world [...] has to be understood in terms of [...] a free space which outlines the possibilities available to the body at any time” (in Dourish, 2001: p. 114) [2].

[1] Essentially this ready-to-handness of LinguaBytes is an argument in favour of the conclusion of Van Balkom, De Moor and Voort to make the play-and-learning system more toy-based than PC-based. In order for LinguaBytes to be successful it needs to fit the skills, needs, requirements and goals of the child, in the same way that a chain saw will not likely become ready-to-hand for a brain surgeon. As PCs have been developed to support office work they are simply less suitable for children whose interaction style is more playful and explorative. LinguaBytes allows for playful interaction through the use of physical toy-like materials, offering not assignment-based content but also explorative content. The physicality of the interaction allows children control over LinguaBytes in a form they can master.

[2] LinguaBytes’ goal was exactly this; to offer a child a platform which outlines participatory possibilities, as well as restrictions in the structured form of stories and exercises, in combination with their accompanying physical modules and input materials.
process. We start by making expressive sounds and gestures and only later start adopting a fixed rule set. Our early sounds and gestures don’t just represent an emotion or feeling but are emotion and feeling. Therefore, according to Merleau-Ponty, we learn language bodily, not mentally (Abram, 1996: p. 75). As an experiment: try to read a text without any intonation or affection. This will be more difficult than you think.

An interesting thought originating from phenomenology with regard to LinguaBytes is the following: as meaning results from the way we exist in the world, children with multiple disabilities will probably give a different meaning to the world than their able-bodied peers. For example, the concept ‘high’ will probably mean something different for a child in a wheelchair than for a child that can freely move around. Consequently, since LinguaBytes is aimed at stimulating the linguistic development of these children—language being a verbal representation of meaning—I should be alert to offering them language concepts in a form that fits their being-in-the-world [3]. This will require a great deal of empathy from me as a researcher and much fine-tuning. I will come back to this at the end of this chapter, when I describe my research method.

[3] To correspond with a child's cognitive skills LinguaBytes offers stories, exercises and games at various difficulty levels. Additionally, the interaction is playful and explorative, which corresponds to how most children interact with the world. More about this is described in Chapter 4. To fit children with different perceptual-motor skills I designed LinguaBytes to match their ergonomic requirements. These are addressed in detail Chapter 3. Also, the interaction with LinguaBytes was designed to address a child's perceptual-motor skills (rather than their cognitive skills alone), while keeping in mind that many LinguaBytes children have restricted motor skills. To help these children in a subtle and unobtrusive way, the LinguaBytes design includes physical restrictors to help these children aim. These design aspects are described in detail in Part III of this thesis. To support a child's emotional being-in-the-world the stories, games and exercises were thoroughly researched by my fellow researcher Riny Voort and tailored to a child's interests. Additionally, the fact that LinguaBytes allows children with sometimes severe motor limitations to more or less independently use a highly physical system will contribute to these children's sense of self-esteem. With regard to a child's social being-in-the-world I want to emphasise that I distinctly designed LinguaBytes to be usable by multiple children at once, for example by making the output module's orientation highly adjustable and by making use of physical input materials: these allow shared control, contrary to many 'traditional' interfaces that are typically suitable for single users only.

A final interesting aspect of phenomenology with regard to LinguaBytes comes from the work of Alfred Schutz (1899-1959), who extended phenomenology from the individual experience of the world—which had the focus in Husserl’s and Heidegger’s
work—to the common experience of the world between different individuals. According to Schutz, people need an understanding of each other’s subjective experience of the world in order to understand the world. In other words, being-in-the-world incorporates social understandings as well: we need to understand how our actions in the world are interpreted by others and vice versa. Schutz argues that this intersubjective understanding is achieved only by our assumption that we share a common reality and all act rationally in this reality, and that to interpret actions as rational, we are required to see them emerge within a pattern of goals, causes, requirements and motivations (in Dourish, 2001: p. 110-112).

Translating these thoughts to LinguaBytes means that its design should allow children and their communication partners to make themselves understandable; to express their views, ideas and motivations in such a way that the other can understand them and that you can understand that the other understands them. In short, LinguaBytes should be a platform for shared meaning [4]. This looks more trivial than it actually is. Please keep in mind that LinguaBytes is aimed at children that need to learn to communicate, need to learn social interaction. Consequently, LinguaBytes as a ‘platform for shared meaning’ should provide (1) appeal to children in order to stimulate them to take initiatives in interaction and communication; (2) provide the flexibility for them to create meaning; and (3) provide sufficient structure in order for caregivers to understand the child and respond to it, while maintaining didactic integrity.

[4] To create this platform, LinguaBytes was developed as a mediator between child and caregiver, as was illustrated by Figure 1.1, the figure we have seen earlier in Chapter 1. By offering a wide range of materials and content LinguaBytes creates opportunities for both communication partners to create a shared language. Children can grab or point at any input material or things happening on the screen, possibly using additional sign language. A caregiver can respond to the child’s expressions, confirming that these are understood and offer stimuli to which the child in turn can respond.

Gibson’s theory of direct perception and affordances

A second prominent theoretical foundation of the research described in this thesis is the theory of direct perception of psychologist James Gibson (1904-1979). Gibson’s theory explains perception from an ecological perspective, emphasising the reciprocal relationship between animals and their environment. Contrary to the then-conventional psychological approaches to perception, Gibson stated that seeing and acting are fundamentally connected. According to Gibson perception is not the combination of ‘optics’ and ‘brain’, but rather a dynamic dialogue between an animal (in our case the animal ‘human’) and its environment: we perceive the environment in terms of what we can do with it. In other words, according to Gibson our knowledge is in the world, not in our head.
In this light Gibson introduced the term *affordance*. “The affordances of the environment are what it offers the animal, what it provides or furnishes, either for good or ill” (Gibson, 1986). In other words, affordances can be seen as an action possibilities that are determined by the capabilities of an animal (again, in our case a human being) in combination with its environment. The crucial factor here is the term ‘combination’: this means that affordances do not belong to the environment only, but also not a human only. Affordances are not meaningful when measured in physical terms, but only when specified relative to a human individual. For example, to an adult a fence door may afford climbing over, while for a child it may afford crawling under or squeezing through [5].

[5] The interaction with LinguaBytes highly depends on affordances for the simple reason that the LinguaBytes target group consists solely of illiterate, preschool children. The alternative, semantic approach will most probably be a route to failure and frustration, as this is already the case with adult users of intelligent systems (Djajadiningrat, 1998; Djajadiningrat, Wensveen, Frens & Overbeeke, 2004). Consequently, I designed (the interaction with) LinguaBytes relative to the child’s bodily capabilities. For example, all measurements, weights and required actions are tailored to the ergonomic specifications of children between 1 and 4 years old. This was not a first-time-right process but required multiple iterations, which are described in Part III: Research-through-Design cycles.

Since affordances communicate action possibilities—behaviour—they are not only linked to our capabilities, but also to our intentions. For example, when you are hiking in the mountains and get tired any tree stump corresponding with your sitting height becomes a chair; to you it affords the perceptable action of sitting and your intention to take a break. A prickly shrub corresponding with your sitting height will most likely not become a chair. However, it may provide nesting opportunities to a bird. In other words, the information that specifies affordances is personal to the animal that perceives it (Michaels and Carello, 1981: p. 53). The potential purposeful behaviors of an animal are called its ‘effectivities’ (Shaw and MacIntyre, 1974; after von Neumann, 1966).

Donald Norman rooted the term affordance in the world of design. In his book *The Design of Everyday Things* (Norman, 1988, originally published as *The Psychology of Everyday Things*) Norman argues that designers have the power to incorporate instruction in the design of the product itself by capitalising on the understanding we have of the world. Designers can make use of the fact that we form conceptual models of the products we encounter, using these models to simulate their operation. Critical in this process are an efficient mapping of our conceptual models to the visible structure of these products. Norman identifies three aspects in this structure: affordances, constraints and mappings. Affordances convey action possibilities (e.g., the holes in a pair of scissors afford sticking
your fingers through), constraints limit the number of alternatives (e.g. the size of the holes limits the number of fingers per hole) and mappings combine affordances and constraints with functionality (moving the blades of the scissors with our fingers while moving it through paper will result in a predictable cut) [6].

[6] I here describe some examples of Norman's affordances and constraints in LinguaBytes. I do not describe mappings.

- The trays of the exercise module were designed to afford the placement of the input figures. The behaviour of almost all children participating in our user tests seemed to confirm this affordance, i.e. by automatically doing exactly that. To emphasise the connection between the trays and the input materials both were made of the same material: white plastic. The trays were constrained to house one input figure only—in most cases—since the RFID-readers could only recognise one RFID tag at the same time;
- The handles of the story module clearly afford flipping and are both constrained in their movement: they can only move inward. Moving the handles in the right direction would be rewarded with the sound of the DC motors switching on;
- The dimensions of the story module's track in combination with two narrow slots affords the placement of story booklets;
- The base module's slot affords inserting the thematic backgrounds, due to their corresponding width and depth. Moreover, the dimensions of the slot were designed so that a child cannot insert a background but a caregiver can. This was done to protect the vulnerable micro-switches within the slot;
- The dimensions of the story module and exercise module correspond with those of their position on the base module. The integrated magnets confirm proper placement;
- The base module's suction pads show its proper orientation on a work space;
- All input materials afford grabbing by a child since their dimensions and weight have been designed to correspond with the dimensions of a child hand and the weight they can comfortably lift.

In Part III of this thesis I describe the rationale behind the details in the LinguaBytes design.

The big difference between Gibson's ecological affordances and Norman's perceived affordances is that Norman defines his affordances as “the perceived and actual properties of the thing, primarily those fundamental properties that determine just how the thing could properly be used” (Norman, 1988: p. 9), which implies that affordances are part of the object, i.e., can be designed. Since in Gibsonian terms affordances are the result of the combined properties of a human and its environment it is reasonable to say that they cannot be designed (Frens, 2006). Although I believe that for this research it is not critical
to participate in this discussion, I can see the contribution this research could make to it. Let me regard Norman’s definition again. For LinguaBytes, the critical part in his definition lies in ‘properties that determine just how the thing could properly be used’, and most prominently the word ‘properly’. This word assumes that, since we are all humans, we share the same skill sets and intentions—the same effectivities—and that all are in sync. This is however not the case for the children of the LinguaBytes target group. These children can have severely disturbed perceptual-motor skills, which makes that what may afford grabbing, turning or sliding for ‘normal’ children does not for them. Consequently these children’s intentions may be different as well. These considerations together make that I am inclined to agree with Frens and to say that affordances cannot be designed. They can be used as inspiration for design, as the concept “suggests that products can be designed so that they are intuitive, not by simplifying, but through expressive, meaningful form. It suggests [...] that it might be possible to design products that can be gradually explored, that need skills beyond memory” (Frens, 2006: p. 180).

**Tangible Interaction and Embodied Interaction**

This automatically brings us to interaction design. As said in 2.1, the to be developed play-and-learning system would be an *interactive* one. This essentially means that LinguaBytes would contain a certain amount of hardware and software that would allow it to respond to the actions of the people using LinguaBytes, and vice versa. Designing LinguaBytes therefore would not just be about the design of the toy-like, adjustable product itself but also about how to design the interaction: the action possibilities and responses of both the product and the users.

There are many approaches to do this. However if we look at the history of interactive products (e.g., in McCorduck, 1979), it can be seen that the design of their interfaces has moved away from our being-in-the-world, relying more on our cognitive skills than our perceptual-motor, social and emotional skills. This is due to a change in what people interact with: where we used to interact with predominantly mechanical products, we nowadays more and more interact with computers: cars, laundry machines, coffee machines, telephones and many other products all contain a computer. Of course this isn’t necessarily a bad thing, but it does reduce the understandability of many products: in an old car a malfunctioning headlight could be easily traced back to the bulb or wiring, in new cars you often need to replace the whole light armature or part of the circuit boards.

Another example of how interactive products have come to rely more on our cognitive skills is the CD player, admittedly a close to archaic device but a good example nonetheless. The CD player shows many similarities with the predecessor it replaced, the record player: both use a spinning disc that holds the sound waves of a recording—be it in the form of a groove or a pattern—and a miniscule reader that moves along the radius of the disc.
However, the way we interact with these two devices is very different. With the record player we could see by the mechanics what was going on: the needle could be placed freely on any location of the record or taken off when desired, and place of the needle showed us the relative location in the recording. With the CD player however the CD itself is hidden from view; playing or stopping the CD can be achieved by pushing one of the many similar-looking buttons on the front of the device or on a remote control, after which a written message on a display reassures you that the CD is playing even if you hear nothing; the play location is represented by a number on the display.

A third example of how interactive devices mainly appeal to our cognitive skills is the Graphical User Interface (GUI) we have become so used to. For example, let me consider the PC, as a representative for single-user GUIs: (1) using the PC requires us to learn an abstract language of graphical representations and metaphors in the form of menu structures, windows, icons and command options; (2) our perceptual-motor skills are reduced to typing and manually moving a cursor; (3) we are often sitting behind our PCs in relative social isolation, since they were not designed for collaborative use; (4) we are hardly allowed to adopt a personal, individual style in interaction, which reduces our natural expressiveness severely. These four aspects show clear reasons why the second conclusion of Van Balkom, De Moor and Voort was that the interaction with LinguaBytes should not be based on that of the PC: PCs tend to reduce users to cognitive beings only, whereas a child's linguistic development is the product of the interplay between its cognitive, perceptual-motor, social and emotional skills, as I have said in 2.2. Apart from this, it is my strong belief as a designer to approach the user of my design as a complete human being, respecting all of the aforementioned skills. I will come back to this in section 2.4.

Probably the main reason why many well-known forms of Human-Computer Interaction (often called HCI) is so different from Human-Product Interaction—here a product means a product without embedded computing—is that (1) how computers operate does not correspond with how humans operate and; (2) the design of the computer interface has long been determined by the computer's characteristics instead of the human's. Over the past two decades however, approaches to interaction design have emerged that attempt to redress this balance and approach HCI from a phenomenological point of view. I will describe two here: tangible interaction (Ishii and Ullmer, 1997) and embodied interaction.

**Tangible interaction.** Tangible interaction is an approach to interaction design that builds on our familiarity with the physical world and is based on a direct coupling between physical representation and digital representation (Ullmer and Ishii, 2000). Inspired by the work of Mark Weiser who predicted that miniaturisation would one day lead to a world in which the computers would be seamlessly interwoven with our everyday environment
(Weiser, 1991), tangible interaction moves away from the traditional setting of a user sitting behind his computer. Instead, in tangible interaction computing can be distributed over different locations and devices. A famous example of a tangible interface is the marble answering machine of Durrell Bishop (Poynor, 1995), in which messages are represented by physical marbles, rather than by a number on a display. When a message is left on the machine, a marble rolls down a slide into a compartment of received messages. Thus, the owner of the answering machine can see in a glance how many messages he has received, simply by counting the marbles. Messages can be played by placing a marble on the designated area, after which the user can decide to keep the message/marble or put the marble back into the machine for re-use [7].

[7] In analogy, LinguaBytes uses physical input figures to represent core words, and to trigger and combine digital information in any of the exercises. Additionally LinguaBytes includes story booklets to represent corresponding animations and thematic backgrounds to select digital content and thus manipulate the digital LinguaBytes menu.

Many researchers believe that this capitalising on our familiarity with the everyday physical world could be highly suitable for learning, based on the view within education that hands-on activity can be of educational benefit. Marshall (2007) identifies various possible learning benefits of tangible interfaces, based on an analysis of research projects:

• Using physical materials in a learning task might change the nature of the gained knowledge relative to that gained through interacting with virtual materials [8];
• It is possible that, because tangible interfaces often utilise concrete physical manipulation, they might support more effective or more natural learning;
• Assuming that interaction with tangible interfaces is more natural for children than with the traditional PC-interface, these tangible interfaces might be more accessible to young children, people with learning disabilities or novices, as tangible interfaces lower the threshold of participation [9];
• Tangible interfaces might be particularly suitable for engaging children in playful learning [10];
• Novel links between physical action and digital effects might lead to increased engagement and reflection [11];
• Tangible interfaces might be particularly suitable for collaborative learning, as they can be designed to create a shared space for collaboration. Thus they might allow concurrent interaction, sharing control between the collaborating learners, and increase the visibility of other members’ activity.
[8] The story booklets are a good example of this:

- By offering a physical booklet a child can literally see the ‘length’ of the story;
- Additionally, when being moved through the story-reading module the story is divided into three segments: one on the left of the module (past pages), the one behind the viewing window (the current page) and one on the right of the module (the remaining pages). This offers both clear feedback and feedforward, as well as valuable meta-information about story linearity and storyline causality.

More about this is described in Chapter 7.

[9] LinguaBytes was designed fully as a platform for participation. By offering children physical representations of words along with opportunities to explore these words and play with them freely, as such LinguaBytes could serve as an alternative means of communication; to a large extent, children can create their own language, a channel for expression. Indications of this could be seen during our evaluations of the intermediate and final LinguaBytes designs. These are described in detail in Chapters 5 through 9. See also [2] and [4].

[10] In the development of LinguaBytes I have tried to exploit the element of engagement, based on the assumption that engagement (indicated by factors such as a child’s attention or initiative) increases the chance that children actually learn; the longer you have the child’s attention, the more opportunities there are for interaction and thus, learning. I do this by making as much of the system as possible, part of child-caregiver interaction. The mechanism I use is allowing the child to take initiatives through physical action: choosing input materials, selecting a thematic background, help moving the storage box, etcetera. As such, many elements of LinguaBytes can also be used ‘offline.’ The story booklets are a good example of this:

- By being physical, the story booklet can be used both within the system as well as outside the system, e.g., for anticipating on the story or assessing the child understanding of the story in retrospect;
- Finally, by offering a physical booklet the child can have an alternative communication means: children can handle the booklet similar to a traditional book, or point to details to convey specific words.

[11] The physical and digital stimuli in LinguaBytes were designed to serve as starting points for caregiver-child communication. This automatically implies increased reflection, not only by the child but by all its communication partners.

However, Marshall also points out that, although many researchers claim these benefits, few of them are based on empirical evidence. This is particularly the case when it comes to
educational tangible interfaces for non- or hardly speaking children between 1 and 4 years old—the LinguaBytes target group. Often, related research is focused on older children (e.g., Brederode, Markopoulos, Gielen, Vermeeren & De Ridder, 2005; Sluis, Weevers, Van Schijndel, Kolos-Mazuryk, Fitrianie & Martens, 2004; Li, Fontijn & Markopoulos, 2008) and/or typical developing children (e.g., Antle, 2007; Lund, 2005; McNerney, 2004; O’Malley, 2004; Zuckerman, Arida & Resnick, 2005) or children with an autistic spectrum disorder (ASD, e.g., see Van Rijn & Stappers, 2008).

Although I agree with Marshall’s criticism, there is something else that worries me more: many of the current tangible interfaces appear to be focusing merely on the direct coupling between physical representation and digital representation, overlooking the phenomenological aspects of tangibility. The designs of these tangible interfaces appear to be driven by ‘what happens inside’ i.e., what happens computationally, rather than on ‘what happens outside’, on a behavioural level. This is not the true value of tangible interaction, which in my opinion has been well articulated by Djajadiningrat et al. (2004): “Rather than viewing tangible interaction as physically represented or manipulated data flow, what we value in physical objects is the richness with which they address human perceptual-motor skills. […] Physical objects offer rich action possibilities with inherent feedback to exploit the refinement of human motor skills.”

Embodied interaction. A second approach to interaction design that is closely related to tangible interaction is embodied interaction (Dourish, 2001). At its core embodied interaction is based on the argument that “we find the world meaningful primarily with respect to the ways in which we act in it” (Dourish, 2001: p. 125), a statement which shows great similarity with phenomenology and the work of Gibson. Dourish introduces the term embodiment, which he defines as “the common way in which we encounter physical and social reality in the everyday world” (p. 126). Dourish argues that this ‘embodiment’ has disappeared from our interaction with computers, thus making interaction with them inherently meaningless: “despite the fact that computers are so radically different from the computers of twenty years ago, and that their capabilities are so vastly different, we interact with them in just the same way” (p. 27). What embodied interaction proposes is to capitalise more on our understanding of the everyday physical and social world in the design of human-computer interaction. According to Dourish embodied interaction is aimed at creating, manipulating, and sharing meaning through engaged interaction with artifacts (p. 126). In this respect Dourish gives an example from aviation: he shows how air traffic controllers use physical flight strips not only to manage aviation activity, but also as a social medium of shared understanding with their fellow air traffic controllers. Design for embodied interaction should therefore be aimed at creating interactive artifacts that allow for this creation, manipulation, and sharing of meaning [12].
Since meaning is inherently contextualised Dourish argues that the only way to design interactions for a social context is to thoroughly research this context using methods from sociology, such as field materials and observational studies [13]. This brings me to the research method used in this thesis.

[12] Analogue to the flight strips, children can use LinguaBytes’ input materials not only in combination with the interactive stories and exercises, but also outside the system, as an alternative means of communication. As such, LinguaBytes can be used as a platform for the creation of shared meaning.

[13] Throughout the development of LinguaBytes I have maintained close ties with the targeted user group and context of use. From the earliest phases of the project I have performed field studies to increase my understanding of the design context, I have interviewed therapists and teachers and used their input as design guidelines, and I have tested all intermediate prototypes in situ, with the LinguaBytes children and their caregivers. Two of the final three prototypes are currently being tested for over a year.

**Method**

As I have illustrated in the explanation of the structure of this thesis (p. 15), this research has roughly two interwoven tracks: on the one hand there is the one aimed at developing the LinguaBytes system; on the other hand there is track aimed at researching ‘how to’ design a system such as LinguaBytes, or in more general terms, how to design for diversity, which according to my jazz analysis in the Preface entails designing highly flexible systems for heterogeneous user groups. The reason why I emphasise the double-tracked character of this research again is because of the role the prototype plays in these tracks, which I explain here.

Earlier in this chapter—in the ‘phenomenology’ section (p. 46)—I mentioned the reliance of this research on empathy. I said that, since LinguaBytes is aimed at improving the linguistic development of children with multiple disabilities, language concepts should be offered in a form that fits their perception of the world, moreover, in a form that fits how they are in and give meaning to the world. Considering that I am not a toddler with multiple disabilities myself, this means that I somehow need to learn to understand these children; I need to acquire relevant knowledge that will help me develop a successful LinguaBytes system. For this I use a user-centred design approach, which is based on constant dialogue with the potential users during an iterative design process (Markopoulos, Read, MacFarlane & Höynsniemi, 2008). The aim of this approach is to propose, evaluate, repurpose and reevaluate the design long enough until a design is reached that satisfies the development team’s criteria well enough to be implemented. The goal of the user-centred
design track within this research is to develop a prototype that is tuned as much as possible to the LinguaBytes users and context of use. In this research, children do not serve as ‘design partners’ per se, but rather as design informants (Scaife and Rogers, 1999).

Parallel to this track is the question ‘how to’ design a complex, highly flexible system such as LinguaBytes; a question that does not address the prototype itself, but the process leading to the prototype. For answering this question I use a method known in my circles as Research-through-Design, although there is no uniform definition of Research-through-Design in the HCI community.

Often Research-through-Design is associated with Bruce Archer’s ‘research through practice’ (Archer, 1995), which can be seen as an iterative transaction between design and research, meaning that it is a process in which scientific knowledge is generated through, and fed back in consequent cycles of designing, building, and experimentally testing experiential prototypes in real-life settings. This somewhat contrasts the traditional view of research (or science) and design being separated or even opposites, the former generally being perceived as seeking to understand the world and finding explanations for this understanding, the latter as establishing a working effect in a possible future, in a world that does not yet exist (Stappers, 2007). However, Stappers suggests that the two disciplines are fundamentally not so different: both are characterised by an iterative process of generating ideas about the world and confronting them with the world. What can differ is the form of these ideas and consequently how their confrontation with the world takes place (Stappers, 2007).

I, like many of my colleagues, strongly believe in using design as a method for this confrontation, and thus for generating scientific knowledge. I see the craft of designing not merely as a matter of applying knowledge but also of investigating how to apply knowledge. Moreover, Erik Stolterman (2008) argues that the main reason that interaction design research aimed at this ‘how to’ question has not (always) been successful is that it has not been guided by a sufficient understanding of the nature of design practice (Stolterman, 2008; Wakkary, 2005). According to Stolterman this lack of understanding is due to a fundamental difference in the way science and design deal with the complexity of the world. Science can be seen as focused on ‘regularities, mechanisms, patterns, relationships, and correlations with the attempt to formulate them as knowledge [...] that is valid and true at all times and everywhere’ (Stolterman, 2008: p. 60). Designers on the other hand are typically placed in a position in which they are exposed to unlimited information sources, presented in the form of diverse technical possibilities, constantly changing contextual factors and societal preconditions, fickle clients, etcetera. These “messy situations” (Schön, 1983) can never be accurately modeled (Wakkary, 2005), thus a reductionist approach to addressing them would fail (Zimmerman, Forlizzi & Evenson, 2007). This makes that designers have to act on a a complex design situation with a regard for all of its richness and
complexity, and in a way that is appropriate for the specifics of that situation—they have to act ‘designerly’, which according to Stolterman should not be mistaken with fuzzy, intuitive, subjective or even irrational\(^1\). To act designerly requires a designer to be fully immersed in the context of the case and to make sense of that context based on an understanding of the particular situation, and then to create an appropriate approach for the specific design task at hand (Stolterman, 2008: p. 61). Consequently, Stolterman argues that asking ‘how to’ questions in (interaction) design research requires a similar designerly approach—a rationality of design—in order to respect the complexity of the design context [14].

As these contexts are inherently diverse and rich in subtlety and detail, doing design research in these complex contexts asks for developing detailed design prototypes that allow for this diversity, subtlety and richness during their confrontation with the world. Therefore, Research-through-Design relies on the generation of wealthy, experienceable prototypes—in my case developed in a user-centred design process—and an evaluation in situ in a physical, human and experiential sense (Wakkary, 2005)[15]. This will consequently result in equally contextual scientific results, leading more to conditional regularities instead of general laws (Hummels, 2000). The prototype is the physical, experiential manifestation of this; the carrier of integrated, contextualised knowledge.

\[^1\] I personally do not mind design being viewed as fuzzy, intuitive, subjective or irrational. On the contrary, in my view it would be a mistake to omit fuzziness, intuition and subjectivity from the craft of designing.
This brings me back to the opening of this section. Within this research the prototype serves two purposes. On the one hand it is the culmination of a user-centred design track aimed at developing an as optimal as possible LinguaBytes system; in other words, this track has a focus on usability. On the other hand it serves as a carrier of knowledge about ‘how to’ design such a system, or more broadly, how to design for diversity. The user-centred design track will probably be easy to follow in this thesis, as I will clearly describe each user test in Part III of this thesis. The ‘how to’ track however makes this a difficult thesis to write, most prominently because doing research in a ‘designerly’ way implies by definition that not everything can be justified on the basis of non-designerly rationality. Written language is in essence a reductive communication means and in my opinion not optimal for design research theses. I will however try to be as rich in detail and respectful to the complexity of the design process as possible.

*Research-through-Design and children.* Before rounding off this section I consider it necessary to emphasise that LinguaBytes was aimed at, from the perspective of interaction design, very young children. Many researchers have already been investigating the ins and outs of interactive systems for children, of which I already mentioned some earlier in this chapter. However, not so much related work can be found where the focus is on toddlers between 1 and 4 years old. There is compelling work on interactive technology designed for and/or with children by, e.g., Druin (1999a, 2002), Bekker, Beusmans, Keyson & Lloyd (2002), Brouwer-Janse (1997), Plowman & Stephen (2003) or Bruckman & Bandlow (2002). Also, there are very comprehensive books by e.g., Druin (1999b) or Markopoulos et al. (2008). All of these provide valuable techniques and guidelines for researching interactive technologies for and with children. However, only few works include the youngest children, the children from the LinguaBytes target group.

This relative scarcity of related research was for me both a handicap and a blessing. I was forced to be inventive in my research, maybe even slightly opportunistic, sometimes having to alter validated techniques before applying them; this may sometimes appear haphazard, but I hope to provide convincing rationales to counter this. On the positive side, this improvisational aspect of my research also automatically placed me in the beautiful position that I could try to assess whether the available methods and techniques could be applied to preschool children and/or to create new techniques. In Part III of this thesis I will therefore try to be as thorough as possible in describing how LinguaBytes was developed, using which techniques, and whether or not these techniques were suitable. As such I hope to make my scientific contribution to the palette of methods and techniques for designing interactive systems for, and evaluating them with children.
2.4 My approach to LinguaBytes, based on my design beliefs.

In the previous sections I have described how the starting points of my research have been shaped by preliminary studies, and by the theoretical and methodological foundations of the research group in which I did the majority of my work. There is however one final factor that has greatly influenced the LinguaBytes project: the researcher himself. Me.

I joined LinguaBytes in 2006. My role was to build on the two aforementioned conclusions of Van Balkom et al. and the findings of the E-Scope study in order to develop the LinguaBytes interactive play-and-learning system. My focus was to be on the design of the system, encompassing the 2D, 3D and interaction design, while my fellow researcher Riny Voort would be developing the linguistic content and structure. Our joint end target was to develop three fully functioning prototypes that could be longitudinally tested in 2010.

Of course there are multiple ways to Rome in a PhD project. However, a global direction is often shaped by the personal beliefs, skills and expertise of the PhD candidate. As my expertise is covered in the CV at the end of this thesis and my skills will hopefully become apparent in Part III of this thesis, entitled ‘Part III: Research-through-Design cycles’, I will here only describe my design beliefs. These correspond largely with the theoretical foundations I have described in the previous section, but allow me to articulate them in my own words.

Let me start by saying that I believe that everybody is different; we are all unique individuals with our own lives, backgrounds, skills, needs, goals and beliefs. In addition—or perhaps in consequence—I believe that people should in principle have the possibility to have control over his or her own life, and to live it to its full potential [16]. This makes design a highly complex discipline: designing entails by definition to intervene in an intricate structure of dynamic individuals in a context that is also dynamic: over time we all change, as does the world in which we live. In my opinion the only way in which this intervention can be done responsibly is to take on a holistic approach; people and their contexts cannot be isolated from each other but only seen in relation to each other. Consequently, design should not reduce people to instances of each other, but be respectful to human diversity and aimed at allowing people to be themselves [17]. This especially holds for the children from the LinguaBytes target group, who typically experience a highly restricted control over their lives, due to cognitive and/or motor limitations. I will describe these children in more detail in Chapter 3, but here I can already say that having worked with these children for three years strengthens me in believing that, due to the way their body works, they (1) probably do not experience the world as I do, and consequently; (2) will not give the same meaning to the world [18].
Based on my beliefs I interpret the two conclusions of Van Balkom et al. as follows:

1. To optimise the interaction for each individual child the program should be adjustable to the developmental level—both cognitive as well as perceptual-motor—of the child: each child has his own perception of the world, based on how he or she is in the world. This involves a child’s personal as well as his contextual characteristics. In order for LinguaBytes to be suitable for each child it should be adjustable to their skills, needs and beliefs. It may even adjust itself;

2. The program should be more toy-based than a PC-based: the world of a child is a world of play and exploration, not a world of office machines. LinguaBytes should benefit from the possibilities of computing in a form that fits the interaction style of children.

I integrated this interpretation into the following proposition: in order for LinguaBytes to be successful, it is crucial that it respects the individual skills (perceptual-motor, cognitive, social and emotional), needs and beliefs of non- or hardly speaking children between 1 and 4 years old. Therefore, LinguaBytes should fit the way in which these young children perceive and experience the world, understand the world and give meaning to the world and provide the flexibility to support this diversity.
With this proposition I end this chapter. In the next two chapters I describe how the development of LinguaBytes was shaped by the effect of the user and user context, and by theories on learning.

2.5 Conclusions for the final LinguaBytes design

In this chapter I have described my starting points for the development of LinguaBytes, based on the preliminary study by Van Balkom et al., theoretical foundations from philosophy, psychology and (interaction) design research and my own design beliefs. Here I briefly summarise the most important conclusions.

The preliminary study by Van Balkom et al., including the ExploraScope, was the basis for the research described in this thesis. I used the conclusions of the preliminary study as the starting point for the first, explorative Research-through-Design cycle as described in Chapter 5.

Based on the theoretical foundations described in section 2.3 I have decided to capitalise on our familiarity with our everyday world in the design of LinguaBytes. This familiarity includes all our human skills, i.e. perceptual-motor, cognitive, social and emotional. I build on the tangible and embodied interaction design paradigms, with an emphasis on their phenomenological aspect. I largely rely on ecological affordances. I will use a Research-through-Design approach to conduct my research.

Based on my design beliefs I state that LinguaBytes be respectful to the individual skills, needs and beliefs of non- or hardly speaking children between 1 and 4 years old. Therefore, LinguaBytes should fit the way in which these young children perceive and experience the world, understand the world and give meaning to the world and provide the flexibility to support this diversity. Getting a grip on this diversity and establishing ways to support it will have a prominent focus within my Research-through-Design process.
Chapter 3

The LinguaBytes user and context of use

3.1 Introduction

In Chapter 2 I have described how the development of the LinguaBytes has been influenced by the preliminary studies leading up to this research, by the theoretical foundations of the Designing Quality in Interaction research group and by my design beliefs. In this chapter I describe how the users of LinguaBytes and the context of use have influenced the design. In 3.2 I start by elaborating on the anticipated users of LinguaBytes: non- or hardly speaking children between 1 and 4 years old. In particular I focus on children within this age range with Cerebral Palsy. In 3.3 I describe the influence of the LinguaBytes primary context of use on the design: the context of speech therapy.

3.2 Non- or hardly speaking children between 1 and 4 years old

The goal of LinguaBytes was to develop a play-and-learning system that would improve the linguistic development of non- or hardly speaking children between 1 and 4 years old. Various subgroups of children fit this global target group definition, for example children with multiple disabilities, children with an autism spectrum disorder or culturally deprived children. But many other subgroups can be identified as well.

Researching—and designing for—many subgroups at once holds some risks. For one, it is very difficult to design for everyone, since everybody is different in their needs, skills, desires or requirements: usually designs for everyone turn out to be a perfect fit for no one. But more importantly, within a four-year PhD research there is simply not enough time to research everybody. It is sometimes smarter to start focused and try to extrapolate the results. Therefore it was decided to first limit the focus of the LinguaBytes project to children with Cerebral Palsy (CP), for two major reasons.

Firstly, this subgroup of children is characterised by diversity: children with CP are typically limited by multiple disabilities, both mental and physical, in any combination. In some cases children may be mentally fine but be ‘trapped in their body’, in other cases it may be the other way around. This makes that the subgroup of children with CP is very heterogeneous. It was decided that taking this subgroup as a starting point would probably cover most of the range of non- or hardly speaking children, including some of the most difficult ones to design for: the children who are severely physically challenged. The
reasoning was: ‘make LinguaBytes suitable for these children and adapting it to the rest will be easy’.

Secondly, within the group of children between 1 and 4 years old with multiple disabilities, this subgroup of children makes up the majority.

Children with cerebral palsy
Bax, Goldstein, Rosenbaum, Leviton, Paneth, Dan, Jacobsson & Damiano (2005) define Cerebral Palsy as follows: “Cerebral palsy (CP) describes a group of disorders of the development of movement and posture, causing activity limitation, that are attributed to non-progressive disturbances that occurred in the developing foetal or infant brain. The motor disorders of cerebral palsy are often accompanied by disturbances of sensation, cognition, communication, perception, and/or behaviour, and/or by a seizure disorder.”

Bax et al. annotate elements of this definition, of which the following are particularly relevant for LinguaBytes (Bax et al., 2005):

1. ‘a group’ – there is general agreement that CP is a heterogeneous condition in terms of types and severity of impairments. Several groupings are possible and may show overlap [1];
2. ‘disorders’ – this refers to conditions in which there is disruption of the usual orderly processes of child biopsychosocial development. The disorders are persistent [2];
3. ‘movement and posture’ – abnormal motor behaviour (reflecting abnormal motor control) is the core feature of CP. It is characterised by various abnormal patterns of movement and posture related to defective coordination of movements and/or regulation of muscle tone [3];

[1] Since children with CP are diverse due to the nature and severity of their disability, providing flexibility is the central element to the design of LinguaBytes.

[2] As the usual orderly processes of a child’s development are disrupted, they cannot be predicted. Therefore, LinguaBytes does not prescribe a single route through the developed stories and exercises, but provides a framework within which many routes are supported. The LinguaBytes manual suggests ways in which LinguaBytes will probably be most successful, but in the end it is left to the child and caregiver to find the best learning strategy.

[3] To compensate for a child’s defective coordination current interactive applications for children with CP often make use of special input devices, as traditional ones are typically too demanding; children with CP often have difficulties controlling a mouse regardless of the
sensitivity, and they will certainly press multiple keys at once on a keyboard. Buttons are used extensively, in a wide variety of forms and locations, depending on the remaining functions of the child. Many keyboard-based input devices use so-called ‘key-guards’: perforated plastic keyboard overlays that help children position and keep their fingers area above a key.

These key-guards have inspired the design of the exercise module, which contains three trays in which the tangible input materials can be placed. Similar strategies were adopted in the story module: story booklets can be easily placed in the extruded track and slid towards the viewing window. The track automatically positions the booklet in its proper orientation. When it can be slid no further the booklet can be transported into the module with the two handles. Each handle can move in one direction only and can be grabbed, pushed or pulled.

4. ‘activity limitation’ – the World Health Organization’s International Classification of Functioning, Disability and Health speaks of ‘activity’ as ‘...the execution of a task or action by an individual’, and identifies ‘activity limitation’ as ‘...difficulties an individual may have in executing activities [4];

[4] For example, children with CP can have slow responses, resulting from the time they need to get from point A to B (see Figure 3.1). Some children even stiffen under stress: they try so hard to control their movements and want to perform so eagerly that tension takes over and the children just freeze. Asking quick responses from these children would be highly demotivating. Therefore, in the LinguaBytes exercises children can take as much time as they need without being rushed by the system. If a child takes so much time to respond that it has forgotten the assignment, a therapist can push the control module’s repeat button.

Figure 3.1 Schematic impression of hand movements (from A to B) for different motor disorders (after Bilo and Voorhoeve, 1990).
5. ‘accompanied by’ – in addition to the disorder of movement and posture, people with CP often show other disorders or impairments. These may be caused by the same disturbances as those that caused CP and/or represent indirect consequences of the motor impairment and/or be caused by independent factors (hence the term ‘accompanied by’ as opposed to ‘associated with’) [5];

[5] One example of accompanied behaviour is that children with CP can drool due to their medication. This is arguably one of the reasons why current AAC systems are often made of sturdy plastics. In my opinion other materials can be used as well, as long as they can somehow be cleaned or washed. Since LinguaBytes makes use of integrated electronics, electrical insulation is critical. After exploring textiles in the second Research-through-Design cycle (see Chapter 7) I decided to use wood in later prototype generations.

6. ‘sensation’ – vision, hearing, and other sensory modalities may be affected [6]. With regard to vision, it is generally recommended to keep backgrounds static (e.g., SchoolTV, 2004), because toddlers need more time to process visual information [7]. Secondly, because the eyes of small children are most sensitive to bright colours, LinguaBytes uses colours with a high saturation. Rydland, Griffiths, Simpson, Millwood, Ramondt & Chapman. (1999) showed that children prefer the use of multiple colours instead of a single colour, and recommends five colours as a minimum [8];

[6] Two design decisions were made based on children’s hearing problems: firstly, I placed the output module’s speakers at the high end of the module instead of the low end. In this way the sound source is located at a child’s ear height, and the sound is obstructed less by the thematic backgrounds in the base module. Secondly, I included a repeat button in the control module, which enables a therapist to repeat a sound fragment as often as is necessary.

[7] To keep the overall image in the LinguaBytes animations as less distracting as possible while maintaining visual pleasantness, moving animations are mostly used to clarify dynamic concepts such as verbs. This was one of the recommendations originating from the preliminary study by Van Balkom, De Moor and Voort (2002).

[8] In LinguaBytes I use six theme colours and a family of twenty colours in the drawings and animations. All colours are highly saturated, but not the typical ‘My First Sony’ colours. There are plenty more aesthetic alternatives available than the three primaries. All drawings are outlined in a darker shade to increase the contrast between colours.
7. ‘cognition’ – both global and specific cognitive processes may be affected, including attention’ [9] and [10];
8. ‘communication’ – expressive and/or receptive communication and/or social interaction skills may be affected [11];
9. ‘perception’ – the capacity to incorporate and interpret sensory and/or cognitive information may be impaired both as a function of the ‘primary’ disturbance(s) to which CP is attributed, and as a secondary consequence of activity limitations that restrict learning and perceptual development experiences [12].

[9] Since cognitive processes may be affected LinguaBytes incorporates a range of stories, games and exercises aimed at children with a developmental age between 1 and 4 years old. There is no prescribed order in which these need to be offered to a child.

[10] To catch a child’s drifting attention a caregiver can use the control module’s repeat button to repeat sounds within an exercise or a story, e.g., the current story scene, a song, rhyme or question.

[11] Limitations in a child’s communication are LinguaBytes’ raison d'être.

[12] LinguaBytes was developed to create opportunities for learning, not only by offering children interactive stories and exercises but also by providing them with materials that they themselves can use to take initiatives. Thus LinguaBytes allows children with activity limitations to create their own platform for communication.

Typically subgroups of CP are classified according to the nature of the motor disorder and/or localisation in the body, although recently the classification system has slightly changed. The most prominent subgroups classified by the nature of the disability are: spastic, dyskinetic and ataxic. Two subgroups can be identified in the classification by localisation: unilateral and bilateral. This is somewhat different than in the traditional classification, in which a distinction was made in: monoplegic, triplegic, or quadriplegic, for one, three or four limbs respectively; diplegic, usually referring to both legs being affected; and hemiplegic, for one side of the body. These are illustrated in Figure 3.2. Bax et al. (2005) recommend using unilateral versus bilateral motor involvement only, and to describe the motor impairment and functional motor classification as accurately as possible when diagnosing a child.

To measure a child’s fine and gross motor abilities two systems are used: the Gross Motor Function Classification System for the key function of ambulation (GMFCS, Palisano Rosenbaum, Walter, Russell, Wood & Galuppi, 1997) and the Manual Ability Classification
System for assessing arm and hand function (MACS, Eliasson, Krumlinde-Sundholm, Rosblad, Beckun, Arner, Ohrwall & Rosenbaum, 2006). Both classifications use a 5-point scale. A level-1 child on the GMFCS scale can walk without support and manipulate objects in a sitting position; a level-5 child has restrictions in all areas of the motor functioning. A level-1 child on the MACS scale can manipulate objects effortlessly; a level-5 child is severely disabled [13].

[13] Since for LinguaBytes a minimal hand function is required, the choice was made to aim for all children that have a GMFCS and MACS from 1 to 4, which represents the large majority. Making LinguaBytes suitable for the level-5 children was postponed.

Negative effects of cerebral palsy on language development
In many cases (in children with spasticity: 52%; in children with dyskinetic disorder: 89%; in children with ataxic disorder: 85%) the part of the brain that controls speech is affected. In these cases children can have trouble talking clearly or are not able to speak at all. This seriously impedes their language development: not being able to speak means a reduction in communication opportunities and thus learning opportunities; these children will simply receive less lingual information [14].

[14] LinguaBytes makes use of tangible representations of words to provide non or hardly speaking an alternative means of communication. Children and their caregivers can use these representations to generate their own agreed language.

But not only damage to the brain’s speech centre forms an obstruction to early language development. Other factors can be identified as well. Firstly, children with CP experience a restricted access to their environment, due to their motor dysfunction. They have relatively less freedom to explore their environment, which results in an impoverished experiential base for language development (Light, 1997). This is especially relevant for abstract concepts that are by definition embodied, e.g., ‘near’, ‘far’, ‘high’, ‘low’, etcetera [15].
Secondly, the facial and gestural expressions of toddlers with CP are usually not what we are used to, due to their diminished muscle control. Therefore, the expressions of children with CP can be hard to interpret by a caregiver, making it difficult to understand what the children are trying to communicate. Consequently, because communication with non- or hardly speaking children is highly dependent on non-verbal expressions, these children receive less communicative reactions than normal developing children, or only reactions that are less rich in information. This leads to further impoverishment of the child’s opportunities for language development.

Thirdly, children with CP require much physical care, which means that less time and attention remains for caregivers to spend on social interaction and communication. Again, this further restricts the already diminished opportunities for learning (Basil, 1992) [16].

[15] For this reason I have included the programmable RFID labels in the LinguaBytes design. These can be attached to warm and cold objects, or be spatially distributed.

[16] Because children with CP need much physical care and time is limited I have tried to keep LinguaBytes’ set-up time as limited as possible. I come back to this later in this chapter when I describe the context of speech therapy.

Children between 1 and 4 years old
Before describing the LinguaBytes context of use in the next section one more aspect of children with CP should be made clear with regard to their age. When dealing with children with a mental disability, we have to distinguish two ages: the child’s calendar age and its developmental age. In the case of typical developing children these are more or less the same, but with children with multiple disabilities the developmental age almost always lags behind the calendar age. This means that a child with a developmental age of 4 years might very well have a calendar age of 5 years. This should be taken into account to properly dimension LinguaBytes. If not, it will not be possible to tailor the ergonomic settings of LinguaBytes to the individual child. For example, children can be extremely left or right-handed, which severely restricts their reach. Vision problems can contribute to this restriction even further. Also, children with CP often need special furniture to stabilise their work posture [17].

Additionally, it should be taken into account that one-year-olds and four-year-olds are at different stages in their cognitive, perceptual-motor, social and emotional development. For example, where one-year-olds generally play solitary, four-year-olds are more socially aware and show a different, more collaborative playing style [18].
[17] I designed LinguaBytes to fit within the reach envelope visualised in Figure 3.3. This figure shows the reach envelopes of two-year-old females (left-handed and right-handed, inner blue dashed line) and five-year-old males (left-handed and right-handed, outer blue dashed line). Combining these it could be determined that the smallest envelope is 45 centimetres wide and 32 centimetres deep, using Table 3.1.

![Figure 3.3](image)

**Figure 3.3** Reach envelopes of children with a calendar age between 2 and 5 years old determine the maximum dimensions and positioning distance of the interface modules. In the right figure the base module (32x18 cm) is shown within the smallest reach envelope.

<table>
<thead>
<tr>
<th></th>
<th>1-2 yrs</th>
<th>2-3 yrs</th>
<th>3-4 yrs</th>
<th>4-5 yrs</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Male</strong></td>
<td>Not available</td>
<td>401 (35)</td>
<td>432 (36)</td>
<td>450 (33)</td>
</tr>
<tr>
<td><strong>Female</strong></td>
<td>Not available</td>
<td>387 (31)</td>
<td>420 (32)</td>
<td>443 (36)</td>
</tr>
</tbody>
</table>

Table 3.1 Arm length of children between 1 and 5 years old, in millimetres (standard deviation between brackets). Source: Steenbekkers (1993).

Keeping in mind that the LinguaBytes interfaces should best be located directly in front of the child, the section defined by the smallest envelope (darker blue) describes the maximum dimensions of the LinguaBytes interface modules; the larger section determines the maximum location distance. Also, since children with CP can have stiff or rigid hands the input materials were designed so that they could be grabbed between the palm of the hand and the fingers.

[18] The LinguaBytes design is aimed at stimulating social interaction. Therefore, although children can use LinguaBytes solitarily, I recommend that LinguaBytes be used by at least two people. Most often this will be a child and a caregiver, but two children and their caregiver can also use LinguaBytes. This is described in Chapter 8.
3.3 LinguaBytes context of use: speech therapy

I have argued that, in order to keep the LinguaBytes project manageable, I would focus first on children with cerebral palsy before addressing other groups of non- or hardly speaking children. In the previous section I have described how the effects of cerebral palsy have an impact on the development of these children, and consequently, how they have influenced the design of LinguaBytes. In this section I describe how the environment of children with cerebral palsy have influenced the design of LinguaBytes. I will focus on the context of speech therapy.

Typically, children between 1 and 4 years old with CP can be found in two environments: (1) the home environment; and (2) the education and/or rehabilitation environment. Language forms an integral part in both environments, manifesting itself through social interaction. In the home situation a child’s most prominent communication partners are parents and siblings, in the educational or therapeutic environment teachers, therapists and peers.

As I wanted to test LinguaBytes with as many children with CP as possible I have focused on the rehabilitation environment. The benefits of researching LinguaBytes in this environment are: (1) many children with CP visit rehabilitation centres, which makes it possible to test LinguaBytes with many children at a single location; (2) children will feel more at ease at a rehabilitation centre than in a laboratory setting, as they are in a familiar environment, surrounded by their familiar people; (3) children are familiar with the nature of therapy, which is typically more structured and directed than for example the home environment. This will probably put the participating children in the right mood for testing, especially those parts of LinguaBytes that are based less on free play; (4) many other relevant groups of non- or hardly speaking children between 1 and 4 years old attend rehabilitation centres as well, which creates the possibility to test LinguaBytes with them too.

In the rehabilitation environment, the context that is most language-centred is that of speech therapy. This type of therapy has as its goal to research and treat problems concerning the communicative skills of people (MedTerms, 2010). This encompasses any written, oral or non-verbal problems related to the voice, language, speech, swallowing (eating and drinking) and the hearing. Speech therapists have a wide scope of skills from treatment and intervention, to establishing Augmented or Alternative Communication (AAC) techniques, counselling, instructing relatives and more. Most importantly for LinguaBytes, speech therapy is centred on the dyadic interaction between child and therapist with language as a medium. Therefore, we decided to use the speech therapy context as the most influential for the development of LinguaBytes, but include people from related disciplines (e.g., occupational therapy, physiotherapy) in the evaluation of our designs.
Speech therapy typically takes place in the form of 30-minute sessions during which the therapist works with one or multiple children. Although it is difficult to define a ‘baseline’ session as the goals of speech therapy are manifold, a speech therapist follows approximately this programme during this half hour:

1. He or she has to review the long-term goals that were defined for the specific child as well as the progress so far. Often speech therapists determine a set of 20-30 new words a child should learn to understand and use (e.g., in the form of symbols or signs) as the long-term goal for a child and log the child’s progress after each session. Results from previous sessions are consulted before the next so that the child’s progress can be re-assessed;

2. Then the speech therapist sets the short-term goals for that session and retrieves suitable learning materials from a cupboard or shelf. Sometimes speech therapists make their own custom materials to fit special needs of individual children [19]. This makes that the cupboards and shelves can be quite full [20];

3. After that the child should be retrieved from somewhere, but often the child is simply dropped off at the speech therapy room by a parent, teacher or group leader. Some older children can arrive semi-autonomously;

4. When the child has arrived the speech therapist places the child at a preferred therapy location, e.g., the workspace or the floor and into a good ergonomic position. In some cases, e.g., in the case of highly spastic children, a physiotherapist is involved in this. The location and the position can differ between children [21];

5. After these five minutes of preparation and setting-up, the therapist starts working with the child. As said in step 2., typically a speech therapist prepares in advance which activities should be done with a child and selects supporting materials accordingly. These materials can be books, toys, symbols, or other tangible, non-interactive items. The fact that these materials are generally low-tech makes that much of the initiative lies with the therapist [22]. Over the next twenty minutes the therapist observes the child and keeps focused on any communicative initiative or reaction of the child. Indicators of initiative taking and communication by the child are making eye contact, pointing at language referents, grabbing materials, making utterances, using sign language, grabbing the therapist, and more non-verbal expressions [23]. In response the therapist tries to offer the most appropriate ‘scaffold’ for learning [24];

6. Meanwhile the therapist tries to keep the child motivated for the full session, which for the younger children can be quite long. This appeals highly to the therapist’s professional improvisational skills [25];

7. The last five minutes remain for dismantling: the therapy is rounded off, the child is
gently removed from the especial furniture and prepared for its next activity;

8. Then, before the next child arrives, the speech therapist has to log all her observations with regard to the goals of the day, and we return to step 1. Logging is generally done on paper. Sometimes additional notes are taken during therapy or at the end of the day.

These steps are repeated for each child. At the end of the day the speech therapist spends some time on administrative duties, cleans up and leaves the room, ready for the next day.

[19] LinguaBytes is designed to be as flexible as possible to the individual needs and skills of different children, by offering a wide range of easy to handle interactive materials, in combination with a variety of interactive content. As a consequence, most children will be able to actively use LinguaBytes.

[20] To not add to this fullness, LinguaBytes comes in an own box that can be used as a bench. The additional advantage of having all LinguaBytes materials close is that it makes it easier for a speech therapist to make rapid changes in topic or activity. This used to be quite disruptive as it meant an interruption of the session.

[21] LinguaBytes can be used on a work surface (e.g., a table or desktop) as well as on the floor. To support this diversity the LinguaBytes output module can be placed both in a tilted as well as a fully horizontal position and be freely rolled around on four ball transfer units.

[22] One of the novelties of LinguaBytes is that it puts more initiative with the child and provides starting points for communication to both partners.

[23] In the final LinguaBytes design a small camera is included to allow therapists capturing a child’s behaviour on video. These video clips can be used to review a child’s progress, for example in its use of sign language. This functionality is not yet in operation at this time.

[24] To assist the therapist in the scaffolding process LinguaBytes provides stories, games and exercises, as well as story booklets, input figures, thematic backgrounds and word cards. All these materials can be used to keep the communication in motion.

[25] LinguaBytes’ wide offer in content and physical materials offer speech therapists tools for improvisation.

It should be clear from this scenario that 30 minutes is not a lot of time and that there are a number of factors that can thoroughly disrupt the therapy session. For example,
keeping the child motivated throughout the session is crucial. This starts in the set-up phase: during set up the child needs to be kept involved and motivated to start therapy on the right foot [26]. But also during therapy it is essential to be able to immediately change tactics when you observe that things are not going well: the child might have a cold or be tired, might not understand the learning material, might not be interested in dolls but in boxing, etcetera. Situations like these require rapid action [27] in order to keep the child's attention and keep the child motivated [28]. With regard to interactive learning materials this means that hardware and software settings should be adjustable in minimal time [29]. An important thing to acknowledge here is that only very few speech therapists are ‘the programming kind’; all therapists I have interviewed expressed no positive feelings towards using the PC or learning “how to operate a program”[30].

[26] To keep a child’s attention from the very beginning of a session, LinguaBytes is designed to engage children in collaborative activities as much as possible. For example:

- Children can help move the LinguaBytes box as it is mounted on swivel casters and approximately dimensioned to correspond with a child’s pushing height. In other cases the child might like sitting on top of the box;
- Children can help retrieve input materials or play with some while the therapist retrieves the rest;
- Child and therapist can choose a thematic background together, which makes LinguaBytes' software setup more inclusive.

[27] In the design of LinguaBytes I have tried to focus on minimising the amount of time required for setting up LinguaBytes or changing settings. I use two strategies: one is to make the setup phase part of the therapy, which I have described above; the other is to keep the setup procedure as simple and intuitive as possible. One way is through clustering and coding of the six themes. Each theme has a designated colour that recurs throughout the entire system. In this way it is easy to quickly find the theme’s available materials even when they are haphazardly stored in the box or lying scattered around.

   Additionally, LinguaBytes has a simple, single-layer menu structure: there is only one menu screen for selecting applications. Using the thematic backgrounds, the therapist can filter out the available applications with each theme in a direct and tangible way. Selecting an application will automatically load it within the selected theme and mode (explorative or assignment based). To change a theme or mode, it is not necessary to go back to the menu: a therapist can replace the background or flip the toggle switch mid-exercise. Thus it is less likely to lose the child’s attention, moreover: switching backgrounds can even be turned into part of the therapy itself; simply let the child choose a background.
Most often speech therapy takes place in dedicated rooms within the rehabilitation centre. These rooms contain:

- Special furniture: a workspace or table of which the height can be adjusted to the ergonomic requirements of the child, and chairs that can be tailored even more meticulously. Often the workspace contains some ready at hand materials like tissues, since children with CP can drool due to their medication. Also, there are often some mirrors available for the therapist to observe a child from different angles;
- Sitting furniture for the therapist, like a chair, a stool, a bench or a sitting mat. This furniture can also be used by parents or visitors (e.g., physiotherapists, teachers);
- Therapy materials, stored in cupboards, on shelves and in storage containers. These materials include toys, musical instruments, books, games, as well as auxiliary materials such as Velcro, which is often used for attaching communication symbols to objects (e.g., the symbol ‘drinking’ on the water tap);
- More and more rehabilitation centres acquire a Nintendo Wii, which is usually placed in a separate therapy room;
- Professional materials for children with special needs. These can include eye-gaze tracking scanners (although these are very expensive), AAC devices such as speech
output computers, and communication symbol systems;

- A workspace for the therapist: usually this is a desk with a PC and office materials. Most of the speech therapy rooms have fluorescent lighting;
- Sometimes the room contains a separate PC for working with interactive materials with the child. This can be in combination with available interactive systems for children with special needs. Often, many types of buttons and switches are available in the room;
- In some cases children bring their own materials, e.g., a walker or a special bicycle to move around independently. Therefore, it is important to keep the floor clear of obstacles so that children can manoeuvre themselves to the workspace. The walkers need to be parked somewhere in the room. Finally, it can even be the case that multiple children receive therapy at the same time. In short, speech therapy rooms are usually scarce on space [31].

[31] The main requirements stemming from the speech therapy context are that LinguaBytes should be easily retrieved and stored, and that it should occupy limited space. Therefore a storage box was made for each prototype, containing all the individual elements. The box is further described in Chapter 9.

3.4 Conclusions for the final LinguaBytes design

In this chapter I have described how the LinguaBytes user and context of use have impacted the design of the final LinguaBytes prototype. Here I briefly summarise the most prominent conclusions.

Based on the children with whom I primarily intend to test LinguaBytes (i.e., children between 1 and 4 years old with cerebral palsy) the focus is on designing LinguaBytes to be as flexible as possible. For example, there is no prescribed route through the LinguaBytes content and response time is not a performance factor. Furthermore, LinguaBytes is focused on creating opportunities for learning and communication, by offering children a wide collection of materials. These materials can be used as alternative communication tools. RFID-labels enable generating custom input materials. To help children place input materials, LinguaBytes learns from the so-called key guards. Further, LinguaBytes takes various impairments due to CP into account, such as hearing impairments, vision impairments. The LinguaBytes target group was limited to children with a GFMCS and/or MACS from 1 to 4.

Based on the context of use in which I intend to test LinguaBytes (i.e., speech therapy) I have decided to involve children as early as possible, when using LinguaBytes. That means that the interaction with LinguaBytes should as much as possible be part of, or create opportunities for social interaction with the child.
Chapter 4

Learning theories and current materials aimed at stimulating early language development

4.1 Introduction

In this chapter I describe how the design of LinguaBytes has been influenced by learning theory, by the negative effects of cerebral palsy on a child's language development, and by the lessons we can learn from current materials aimed at stimulating early language development or reducing the negative effects of being non- or hardly speaking. I start with describing constructivist learning theory and social constructivism in 4.2. In this section I also illustrate the negative effects of cerebral palsy on a child's language development in the light of these two learning theories. In 4.3 I describe current materials aimed at reducing these negative effects or at improving early language development and the lessons we can learn from these materials.

4.2 Learning theories: constructivism and social constructivism

There are three main learning theories: behaviourism, cognitivism and constructivism. Where the former two theories respectively approach learning as a process of behavioural conditioning, or as a process that is predominantly brain-based, constructivism takes on a more holistic approach. Constructivism sees learning as a process of active participation in that what is learned. This approach to learning puts more value than the other two on the individuality of children and the idea that knowledge about the world cannot be separated from actual bodily experiences in the world. Learning does not only involve cognition, but all of a child's skills and is influenced by experiences and environmental influences, which contribute to the acquisition of new knowledge and skills (and values, worldviews, etcetera) as well as to the refinement and adjustment of these with each new experience. As such constructivism corresponds best with my view on the role of LinguaBytes as I have described it in Chapter 2. I describe constructivism in this section, as well as the related theory of social constructivism.

Piaget's constructivist learning theory

Jean Piaget (1896-1980) was one of the most influential developmental psychologists of the twentieth century and has laid the foundations for constructivist learning theory.
According to Piaget children acquire knowledge through experience in the world [1], with each experience contributing to the generation of new knowledge or the refinement or replacement of existing knowledge. This is a two-step process of assimilation and accommodation: first, children assimilate what they encounter in the world, forming their mental representation of it; then they gradually accommodate their mental representation to what they encounter [2].

[1] Children acquire knowledge through experience in the world. This means that, for LinguaBytes should enable a child to explore the world. In LinguaBytes I try to support exploration through active participation, by offering the child an interactive platform for initiative taking.

[2] The process of assimilation and accommodation is supported through offering exercises in two modes: explorative mode for assimilation, and assignment-based mode for accommodation.

Piaget has described the development of a child as being a sequential process of developmental stages. Although the speed with which a child progresses through these stages may vary, the route is consistent (Fallen and Umanski, 1985; Hodapp, 1998). Two developmental stages are relevant for this thesis: the sensorimotor stage and the preoperational stage. These two stages cover the development of a child between 0 and 7 years old, which includes the age range of the LinguaBytes target group. Throughout these stages, Piaget considered that children primarily learn through imitation and play [3]. Here I describe the stages briefly.

[3] As mentioned in Chapter 2, many researchers believe that tangible interfaces are particularly suitable for engaging children in playful learning and collaboration, which facilitates imitation. This is one of the reasons that I chose to focus on physical input materials.

Sensorimotor stage. In the sensorimotor stage (0-2 years old) children start reflecting on sensory information, developing their fine and gross motor skills [4]. Two important developments in this stage are the understanding of cause and effect relations and of object permanence. The former, cause and effect, means that the child learns that it can evoke responses from its environment through its own actions [5]. The latter, object permanence, means that a child learns that objects keep on existing even though they are not always visible.
The fact that in this phase the gross and fine motor skills start to develop has reinforced the decision to make the interaction with LinguaBytes tangible, even though these developments may be disturbed in the children from the LinguaBytes user group.

Cause and effect relations need to be reinforced by clear and direct feedback (Strommen, 1998), which should always be positive (Malone and Lepper, 1987). In order for children to learn (Bruckman and Bandlow, 2002; Strommen, 1998; Beck, 2002) and stay motivated the interaction with LinguaBytes should be clear and unambiguous. This is especially relevant since the users of LinguaBytes can have reduced motor skill and have to invest much effort into taking initiatives to begin with. In other words, for these children cause and effect relations do not only imply well designed feedback, but also clear feedforward. I do this by capitalising on physical affordances: the story module’s handles afford moving, the exercise module’s trays ask the child for placing input materials. Additionally, the story module’s handles can move in one direction only, thus providing clear action states: either a handle is in its vertical, self-assumed position or the tilted child-imposed position. Similarly, the exercise module’s trays provide two clear action states: input materials are either inside or outside the tray. Only materials placed within a tray triggers feedback in the form of animation and sound on the output module. Removing the input material immediately causes the animations and audio to stop. In the case of the story module, feedback is provided by the sound of the DC-motors switching on, and the movement of the booklet in the corresponding direction of the handle’s movement. Additionally, the result is animation and audio on the output module.

The preoperational stage. The transition to the preoperational stage (2-7 years old) is marked by major developments in the child’s representative thinking: children start to learn that an image can represent a real-life object [6]. The inclination of children to point at and touch familiar objects in picture books is a manifestation of this [7].

Before this transition children have more difficulties with unfamiliar representations. For this reason LinguaBytes also supports custom, alternative input materials through using the programmable RFID-labels; these enable turning any object into input material, tuning LinguaBytes to the developmental level of the child.

This is another factor reinforcing the decision to make the interaction with LinguaBytes tangible; tangible materials can be pointed at and grabbed, thus helping children—especially those who are hardly or non-speaking—communicate their thoughts in a way that fits them.

The preoperational stage is characterised by:
- **Egocentrism**: a child in this phase is very self-centred, which also manifests itself in
language through monologue [8] and repetition [9]. The child talks while it plays and thus learns the synthesis of doing, verbalising and thinking:

- **Centring on one aspect only**: a child is not yet capable of weighing multiple factors in problem solving; it focuses on one aspect only. For example, a child will be able to sort objects by colour, but not by colour and shape [10];
- **Inability to induce**: logical thinking needs induction and deduction, i.e., drawing general conclusions from specifics, or drawing specific conclusions from the general, respectively. Toddlers in the preoperational stage of their development are not capable of inducing [11];
- **Logical thinking**: a child begins to learn logical thinking. It will start realising that objects can have similarities and differences in function, physical characteristics and the relation to other objects [12].

[8] LinguaBytes supports a child's urge for monologues by allowing the child control over the pace of the interaction. Thus, time is created for children to vocalise what they are doing or, if the child is non-speaking, for a therapist or parent to do this 'verbal mediation' for the child.

[9] A child's craving for repetition is supported similarly. Since most of the interaction is tangible it is reversible: input materials can be removed from the tray. As such, a child has control over the duration of the content.

[10] Because children in the preoperational stage cannot yet sort objects by colour and shape simultaneously these classifications are offered through two separate exercises. Also, for this reason the input materials for the shape exercise have similar colours, and for the colour exercise similar shapes.

[11] I have been as consistent as possible in the use of characters and objects in the LinguaBytes applications: for example, the car is always the same car, both on screen as well as physically. There are a few exceptions: for example, Tom and Tes appear in all sorts of clothing—mostly in their usual attire, but also wearing swim suits or winter clothes—but are always the same in their physical version. This was done for the practical reason that it would make it easier for a parent or therapist to retrieve the right input materials from the box. Having multiple Toms and Tesses might have made this a more timely matter, where I specifically set out to reduce the necessary set-up time.

[12] To stimulate logical thinking through LinguaBytes, children are allowed to make unusual three-word sentences within the theme 'animals'. Children could place 'cow', 'eating' and 'duck'
Social constructivism
A closely related theory to constructivism is that of social constructivism, commonly associated with Lev Vygotsky (1896-1934). This theory connects to Piaget’s work by seeing learning as an active, participatory process, but extends it by giving a pivotal role to a child’s social environment. According to Vygotsky (1978), cognitive development results from a process whereby a child learns through problem-solving experiences shared with someone else, usually a parent or teacher, but also siblings or peers. Initially, the person interacting with the child assumes most of the responsibility for guiding the problem solving, but gradually this responsibility transfers to the child itself [13]. Language plays an important role in this process: at first it is the dominant form of interaction through which adults transmit knowledge and skills to the child but as learning progresses, children begin to use internal language to direct their own behaviour [14].

[13] In LinguaBytes a shared space for communication is created, as illustrated earlier in Figure 1.1 in Chapter 1. This shared space is accessible to both the child as well as its caregiver, who can both take initiatives—and thus share the responsibility—for interaction, communication and consequently learning.

[14] LinguaBytes offers children the child physical materials as an adaptable, external representation of their internal language.

In this context, Vygotsky is generally associated with: (1) the Zone of Proximal Development (ZPD); and (2) the concept of scaffolding. The ZPD is the distance between what a child can achieve independently (his actual development) and what a child can potentially achieve under guidance of an adult or in collaboration with more capable peers (his potential development) [15]. These adults—or more capable peers—can informally share their experiences with the developing child and thus provide the help it needs to progress in his ZPD. This is called scaffolding. Social constructivists argue that, since much of what a child learns comes from the people in its social environment and much of the child’s problem solving is mediated through an adult’s help, it is wrong to focus on a child in isolation [16]. Advancement through a child’s ZPD is a joint accomplishment, the result of the dyadic interaction between the child and the skilled partner.
[15] LinguaBytes is designed as an adaptable platform for caregiver-child communication. Within this platform children can take initiatives, but also be assisted by more capable people. As such LinguaBytes provides a tool that can be adjusted to a child’s ZPD.

[16] Currently many interactive play-and-learning materials are designed to replace a parent or teacher, where it would be better if they would have a more facilitating role, mediating between parent and child. Therefore I decided to design LinguaBytes as an interactive platform for participation, a meeting point for parents and children. The child’s parents or caregivers are not excluded from the interaction but are part and parcel of it: caregiver and child choose a theme together by physically picking a thematic background, they choose a story together and insert it together in the story module, they handle the input materials together during exercises, etcetera. But always it is the child that ‘completes’ the interaction: the child moves the booklet through the module and selects and places the input materials. Thus, the child has the sense of being responsible for LinguaBytes’ response. This was considered as a small but crucial motivational factor by the participating speech therapists throughout this research.

Social constructivist learning and early language development
Just as a child’s early development relies highly on social interaction (most prominently with parents and peers), the foundations for language acquisition are laid in early parent-child interaction (Snow and Ferguson, 1977; Snow, 1986). Through interaction with the parents or other caregivers, children are exposed to language and communication from birth on, in a form that is tailored to their perception of the world, their skills and preferences, their developmental stage, their interests and their needs. In interaction with their child, parents offer the child opportunities to actively participate, which is highly important for its language development (Beukelman and Miranda, 1998). However, this is not the case with the children from the LinguaBytes user group as described in Chapter 3, who can hardly speak or not speak at all. This highly disturbs parent-child communication. But also other factors severely limit these children’s opportunities for learning, which I will explain in the following section.

Factors that impede the language learning process of the LinguaBytes user group
Children from the LinguaBytes user group—primarily defined as children with cerebral palsy in the previous chapter—often experience retardations in their linguistic development. These retardations can be caused by several factors, either as a direct result of a brain injury, or as the indirect result of the repercussions of this brain injury on parent-child communication. Two prominent direct results of brain injury can be identified: (1) damage to the speech centre of the brain: the part of the brain responsible for speech can be affected, which is highly disruptive for the transition between linguistic developmental
phases (Paul, 1997); (2) damage to other parts of the brain: other parts of the brain can be injured as well, resulting in limitations in the child's perceptual-motor and/or cognitive skill developments (Fallen and Umanski, 1985; Lewis, 2003), which can heavily disrupt parent-child communication. For example, if a child is spastic its movements can be really difficult to interpret: intentions of the child become unclear, feelings or emotions can be hard to identify. As a result, these children receive fewer communicative responses than regular children (Blischak, Loncke and Waller, 1997).

Whereas these first two components describe the direct results of brain injury, the following pair represents the indirect repercussions on the child’s daily situation: (1) reductions in learning time: because children with CP often require much physical care from a parent or carer, less time and attention is left for communication. As a result, a child receives less linguistic information and is less communicative; (2) subordinate role for the child: research has shown that, in parent-child communication with hardly or non-speaking children, the adults take on a too dominant and interpretive role (Van Balkom and Welle Donker-Gimbrère, 1988). This has negative effects on the child's active communication participation [18].

[18] These two aspects—reductions in learning time and the subordinate role for the child—were taken into account in LinguaBytes by limiting the time needed for setting up the system and changing settings, and by putting the child in control of much of the interaction, respectively. I will clarify both.

Many current applications with a dominant software component aimed at early language development use extensive, time consuming menus. These not only slow down the time for setting up the system, but also disturb the flow of the interaction when something needs to be changed. Additionally, going through menus is typically a procedure for adults, leaving the child excluded from interaction. This can result in losing the child’s attention, which should at all times be avoided. LinguaBytes was therefore designed so that setting up the system can be the start of parent-child communication: by collaboratively choosing a thematic background and a story, the child is involved from the start and actively participating in communication.

Also, in many current applications the software often dominates the interaction: typically a child has to wait until the computer says ‘yes’ and has nothing to do in the meanwhile.

Another observation is that current applications often use ‘traditional’ input devices like a keyboard, mouse or trackball, or special buttons. Many of these input devices do not connect to a child’s explorative interaction style, either because they are too limited—a button can be in two states only: pressed or not—or because they only allow on-screen explorations: a trackball can only be used for browsing through on-screen intangible hotspots. Young children are still much oriented towards physical exploration, despite any motor disability. Therefore the interaction with LinguaBytes was designed with an emphasis on opportunities for physical
interaction and a dominant role for the child: because all interactions with LinguaBytes are based on physical actions by the child, the child has control over the speed of the interaction and, in LinguaBytes’ explorative mode, over the content. The child can physically choose the input materials (s)he wants to use, guided—not dominated—by a parent or therapist. This gives the child the feeling that it is in control, even though it needs help from an adult for some actions, e.g., inserting a story booklet.

Social constructivist learning and the LinguaBytes user group

Regarding all these impediments one could question whether any considerations should be raised on social constructivism learning theory’s fit to the children from the LinguaBytes user group, given the fact that (1) the LinguaBytes children are non- or hardly speaking and sometimes severely limited in their motor abilities, and; (2) social constructivism relies on active participation. Not much research is available to answer this question. Studies by Letto, Bedrosian & Skarakis-Doyle (1994) show strong, albeit preliminary, support for the use of Vygotskian developmental theory in the context of language acquisition in children with severe speech impairments and physical challenges. Their work is based on Bruner’s notion of scaffolding, which involves the caregiver’s efforts to adjust the environment in order to permit participation in a communication event of which the child would otherwise not be capable (Letto et al., 1994). In this light my role as designer-researcher can be seen as ‘creator of scaffolding material’. LinguaBytes should provide opportunities for ‘environment adjusting’, not only for the child but also for the caregiver.

4.3 Current materials aimed at improving delayed language development

Since the direct results of the brain injury cannot be solved—in CP the injury is non-progressive but irreversible—most energy is spent on improving the indirect repercussions.

For example, much is invested in offering the child alternative forms of communication. These can include sign language or graphic symbols (Van Balkom and Welle Donker-Gimbrère, 1994), which then serve as so-called Alternative or Augmentative Communication (AAC). AAC is aimed at enhancing a person’s communication skills or at offering alternatives when a person’s communication is temporarily or permanently impaired and inadequate to meet a person’s communication needs (ASHA, 2005). AAC comes in many forms, from unaided (i.e., without the use of external aids, e.g., sign language) to aided, and from low-tech (i.e. non-electrical) to high-tech [19]. Frequently

**Figure 4.1** Symbol sets include PCS (left and Bliss (right). Here depicted the word ‘fish’. 

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used aided AAC systems are graphic symbol sets (for example, PCS or Bliss, see Figure 4.1) and speech output devices. Which type of AAC is suitable for a specific person depends on his or her current skill set. Generally it is assumed that starting with AAC should begin with concrete referents, thereafter moving towards two-dimensional referents such as photos, images and graphic symbols. A person’s age naturally plays a role in this [20]. After this, a step can be made towards using speech output devices. There are about 50 different symbol systems for alternative communication, such as PCS and Bliss (see Figure 2). Much software is available that helps children learn these symbols or sign language. Many of these programs support active learning, which is known to facilitate a child’s understanding, recognition and recollection (Hetzroni and Belfiore, 2000).

[19] LinguaBytes is positioned within the high-tech, aided AAC category.

[20] In the LinguaBytes design I support the use of different referents by enabling the parents or therapists to make customised input materials through the use of the programmable RFID-labels. As such, it is possible to address a child at its developmental level at all times.

Also, many materials have been developed aimed at interactive story reading. This is no surprise, since scholars agree that stories offer a meaningful context for language (Bus and Jong, 2006; King-DeBaun, 2006; Teale and Sulzby, 1986) and thus facilitate both the learning process and the integration of new knowledge of the child in its existing knowledge [21]. To do this, a child should have the opportunity to actively participate in story ‘reading’, e.g., by pointing at images or flipping pages (Bus and Jong, 2006). Thus a story does not only expand the child’s vocabulary, but also contributes to early literacy because a child learns to recognise the linearity and length of a story [22]. Over the last two decades we have seen a number of interactive story reading applications appear, both in research and on the commercial market, e.g., interactive CD-ROMs or, more recently, online storybooks and literacy adventure games. Additionally, interesting interactive toys for early language development have made it to market such as the earlier mentioned V-Tech® computers (VTech, 2010) and LeapFrog® Tag Junior Books (LeapFrog, 2010), all specifically developed for pre-school children. The HCI research community has gone even further, exploring the possibilities of tangible interaction (see Chapter 2, e.g., Fontijn & Mendels, 2005) and augmented reality (e.g., Billinghurst, Kato & Poupyrev, 2001).

[21] LinguaBytes uses interactive story reading as the starting point for exercising. I decided to capitalise on physicality within interactive story reading, since early communication is not limited to verbal information, but involves many bodily elements: when reading stories to a child, the child points at details in the book, grabs the parent and makes eye contact.
uses facial expressions to convey emotion, along with a variety of other expressive and communicative gestures and movements. The physicality of the book itself plays a facilitating role in this: children can flip through pages themselves, either backward or forward, prevent flipping pages or simply throw the book away if they’re fed up with the story.

[22] Physical books convey important linguistic meta-information to the child outside the storyline: the length of the story is conveyed through the thickness of the book, the position in the story through the relative thickness of the book before and behind the current page, and thus the concept of story linearity. Therefore, interactive story reading in LinguaBytes is supported through physical, RFID-tagged story booklets. These booklets represent the real-world component of story reading. By inserting the booklet in the story reading module the virtual-world component is disclosed through the output module. This introduces children to the concept of computing in a very low-threshold way.

The story booklets move through the module in such a way that they are read from left to right, which corresponds to Western reading. The booklet can be moved through the module with the two handles that have a movement corresponding with page flipping. Through these design aspects several elements from traditional book reading are incorporated in LinguaBytes: (1) by offering a physical booklet a child can literally see the ‘length’ of the story; (2) additionally, when being moved through the story-reading module the story is divided into three segments: one on the left of the module (past pages), the one behind the viewing window (the current page) and one on the right of the module (the remaining pages). This offers both clear feedback and feedforward, as well as valuable meta-information about story linearity and storyline causality; (3) by being physical, the story booklet can be used both within the system as well as outside the system, e.g., for anticipating on the story or assessing the child understanding of the story in retrospect; (4) finally, by offering a physical booklet the child has an alternative communication means: children can handle the booklet similar to a traditional book, or point to details to convey specific words.

I developed both linear and branched stories, with the latter looking like a cut-up version of the former. Adding the branched stories has a few advantages: (1) since children have to choose a new branch after every three scenes, more opportunities for parent-child communication are introduced; (2) additionally, the child has more control over the story and is thus more involved and more concentrated, and; (3) cutting up linear stories into parts opens up the possibility of training an additional linguistic skill: thinking about the right order of causally related scenes.

Finally, more and more interactive educational toys are becoming commercially available, both for typical developing children as well as for children with an atypical language development. I describe some successful ones here.
Software aimed at stimulating early language development. In the field of educational software design a major player is IntelliTools (IntelliTools, 2010). Their most successful software product is Classroom Suite, which is an extensive collection of instructive software that covers math, reading, talking and more. Classroom Suite can be easily combined with switches, trackballs or other alternative interfaces for children with special needs. An additional feature is that Classroom Suite can also be used to create custom, personalized applications. Therapists can add images, sounds, transitions, animations and more, comparable with, but more extensive than e.g., PowerPoint. Often Classroom Suite is used in combination with IntelliKeys, a touch-sensitive interface (A4 size), comparable to the touchpad of your laptop. IntelliKeys can be used to make custom touch interfaces by simply printing an interface marking hotspots and sliding this into IntelliKeys. The therapist can make as many hotspots as necessary and assign them a range of actions.

Another company that offers a very broad suite of educational software is Laureate Learning. Their software product ATLAS is a very complete suite of software aimed solely at language acquisition. The suite consists of dozens of separate programmes aimed at very specific language aspects. A major benefit of ATLAS is that it is adaptive to individual users: it keeps track of the student's linguistic strengths and weaknesses and adapts its content accordingly. There is an extensive logging functionality for teachers or therapists, and a helpful intake assessment tool.

The strong points of both Classroom Suite and ATLAS are the broad offer of exercises and their flexibility and adaptability. Weaknesses are the huge time load of creating original material (especially by non-designers), the lack of real unity in the separate software products, and the overall design, which is rather old-fashioned and unappealing for very young children [23].

[23] In comparison with Classroom Suite and ATLAS the strategy for LinguaBytes was clear: learn from the strengths of these suites and get rid of the weaknesses. LinguaBytes was designed as a suite as well, offering a range of more than 200 stories and exercises. However, learning form the drawbacks of Classroom Suite and ATLAS, I decided to invest in a coherent visual style and to leave this style intact. In other words: the people using LinguaBytes are not able to generate their own visual material. This will save time (see also the next chapter) and will give most guarantees for understandable learning material. So in short, what happens inside LinguaBytes stays inside LinguaBytes. However, what goes on outside LinguaBytes is more open for adaptation, using the programmable RFID-labels. These allow parents or therapists to create customised input materials, thus facilitating the translation between a real-world concept and its linguistic counterpart.

One software developer with, in my opinion, very tastefully designed language stimulation
software is SEMERC. SEMERC’s software connects to a trend in AAC to move towards so-called Visual Scene Displays (VSDs). Where visual information in AAC used to be grid-based, VSDs weave language in a contextual visual scene, a coherent image in which multiple linguistic concepts are shown in an—for a toddler—understandable, dynamic context [24]. Drager, Light, Curran-Speltz, Fallon & Jeffries (2003) have showed that: (1) toddlers prefer a schematic scene over an iconic system, and; (2) 80% of the toddlers organise words according to their contextual function, rather that to the semantic meaning. In addition, Shook and Coker (2006) have argued that: (1) VSDs therefore impose a lower cognitive load on the toddler; (2) VSDs correspond more with the way in which toddlers process visual information and organise words, and; (3) VSDs offer more starting points for parent-child communication.

[24] In LinguaBytes a contextual scene is provided through the thematic backgrounds, and words are materialised in input materials. As such LinguaBytes offers a three-dimensional VSD. The effects of a child’s exploration of the 3D VSD are reinforced on the output module. The value of this was clearly illustrated when a boy who participated in the testing of the KLEd prototype (see also Chapter 5) created the two-word sentence ‘the woman hugs’, triggering the animation of a lady hugging a baby. Seeing the baby, the non-speaking boy grabbed the tangible figure of the baby and placed it next to the verb card, creating ‘the woman hugs the baby’. This was a clear sign that the boy was in the transition from the two-word phase to the multiple-word phase.

Toys aimed at stimulating early language development. Apart from educational software, many interactive educational toys can be found on the market. A large manufacturer of interactive educational toys for children between 1 and 9 years old is V-Tech (V-Tech, 2009). V-Tech develops toys in close collaboration with panels of educationalists, parents, children and toy specialists. These provide valuable information about the needs and desires of a child at a specific age. The products of V-Tech use various integrated technologies such as RFID and embedded displays. A nice example is the Smartville train station, which uses tagged characters for role-playing games, letter and word games, music and sound games, and shape and colour games. Another nice example is TOM by Platus Learning Systems (Platus, 2009). TOM consists of an RFID reader that can be connected to your PC via USB. Using a collection of physical tagged materials children can do all kinds of exercises, such as spelling and semantic classifying. Both of these examples allow an explorative interaction style because of their tangible character, but in my opinion still offer children only a limited assortment of tactile experiences. Also, TOM only offers assignment based exercises and no explorative games.
Criticism on existing materials aimed at stimulating early language development

However, commercially successful though these examples may be, research suggests that there is much room for improvement in the design of play-and-learning materials for non- or hardly speaking children. For example, Light and Drager (2002) argue that early intervention is more likely to be effective if AAC systems are more appealing. They argue that young children, using AAC systems that appear to be interesting and fun, may be viewed more positively by their peers, making it easier to start communication with these peers. Additionally, Light and Drager argue that children who need AAC may view themselves more positively if they perceive that their AAC systems are considered ‘cool’ by their typical developing peers. This idea is backed by Gielen, Oorschot and Berg (2003), who argue that the design of play materials for children with special needs often emphasises the child’s disability rather than focuses on a child’s abilities. This makes that these toys are often perceived as stigmatising. Moreover, Gielen (2005) argues that the danger exists that badly designed toys can result in an aversion towards playing (and thus learning). Gielen argues that the design should contribute to a child’s confidence and positive self-image.

Light, Drager and Nemser (2004) compared features of 43 AAC toys with 60 successful toys for children between 2 and 5 years old, with the aim of identifying design aspects that might improve the appeal of the AAC systems. The toys and AAC systems were systematically analyzed with respect to colour, materials, shape, size, weight, movement or action, sound or voices, lights, and themes. The research yielded interesting guidelines for the design of more appealing AAC materials for young children [25]:

- Use bright glossy colours and translucent colours;
- Incorporate multiple colours in a single AAC system;
- Use plastics with bright glossy finishes;
- Facilitate easy change of colour, e.g., through snap-on covers;
- Use colour to designate different operations or functions;
- Explore the use of other materials in AAC systems;
- Develop AAC systems in a variety of shapes and appearances;
- Consider AAC systems that can be transformed into different configurations e.g., through snap-on parts;
- Develop modular AAC systems that can be built up and taken apart into individual units;
- Develop light-weight systems that can be easily carried/moved by young children;
- Develop small systems proportionate in size to young children;
- Incorporate various moveable parts that support multiple movements/actions;
- Provide immediate explicit feedback for actions;
- Incorporate a library of sound effects Incorporate songs, music, sounds of musical instruments;
• Include animal sounds;
• Include the voices of popular children's characters;
• Use lights as feedback for actions;
• Include lights as possible visual effects to add interest;
• Incorporate popular children's characters as decorations on system hardware;
• Incorporate children's characters into AAC symbols;
• Include the voices of children.

[25] I will describe here how these guidelines have been incorporated in the design of LinguaBytes, or, if not why not.

Use bright glossy colours and translucent colours and incorporate multiple colours and use plastics with bright glossy finishes: bright colours are used both in LinguaBytes’ graphics and in the input materials. The choice of colours will be described in Chapter 5. Using translucent colours in the LinguaBytes design showed no added value;

Provide multi-coloured snap-on covers to facilitate easy change of colour and use colour to designate different operations or functions: LinguaBytes doesn’t use snap-on covers or major colour customisation options. The main reason for this is that in the design of LinguaBytes colours or materials were assigned to clusters of LinguaBytes components: all input materials are plastic, coloured per theme, all interfaces are wood with white plastic accents to highlight where the action is. Allowing customisation of colours would disturb this clustering, leading to incoherences in the design. This would not benefit the visual unity that I was aiming for;

Explore the use of other materials in AAC systems: Rydland et al. (1999) showed that children prefer soft materials to rigid materials, which was partly the reason for me to explore other materials than plastics in earlier prototypes, such as wood, cardboard and textiles. I will elaborate on this in Chapter 5. The final LinguaBytes design only uses plastics and wood, and of course any material to which the programmable RFID-labels are attached. Altogether this will better cover a child’s need for different tactile sensations than only using plastics;

Develop AAC systems in a variety of shapes and appearances and consider AAC systems that can be transformed into different configurations and develop modular AAC systems that can be built up and taken apart into individual units: LinguaBytes is a modular system consisting of 5 interface modules and about 300 input materials;

Develop lightweight systems that can be easily carried/moved by young children: I am afraid that LinguaBytes is not as lightweight as this guideline suggests: the output module is heavy and the movements of all modules are limited by the many cables. However, the input materials are lightweight and easily manipulable by children with multiple disabilities. In our view this contributed more to a child’s independent use of LinguaBytes than the relative immobility of the modules;

Develop small systems proportionate in size to young children: the dimensions of LinguaBytes
were tailored to the ergonomic requirements of the LinguaBytes target group. I will elaborate on this in Chapter 4;

  Incorporate various moveable parts that support multiple movements/actions: this is a rather ambiguous guideline. In my opinion it is not about moveable parts but about the possibility of moving parts. With LinguaBytes, children have ample opportunity for using their body and manipulating materials: they can freely explore the tangible input materials, and the interaction with both the interactive stories as well as the exercises is by definition based on movement;

  Provide immediate explicit feedback for actions: I have described the use of feedback extensively in [4];

  Incorporate a library of sound effects like songs, music, sounds of musical instruments and include animal sounds: LinguaBytes involves many exercises aimed at stimulating phonological awareness. These exercises include rhymes, songs and sound effects;

  Include the voices of popular children’s characters and incorporate popular children’s characters as decorations on system hardware and incorporate children’s characters into AAC symbols and include the voices of children’s characters: I haven’t followed this guideline. Popular characters are legally protected, and using popular voices would surpass our budgetary capacity. I personally recorded all of the required 2100 audio clips;

  Use lights as feedback for actions and include lights as possible visual effects to add interest: as I have described in Chapter 2, I rely more on Gibson’s affordances that appeal to a person’s perceptual-motor skills, than on blinking lights to attract attention. I have explained earlier in this section how the affordances of the story and exercise modules provide inherent feedforward and feedback to the child, and how a child’s actions triggers reactions from LinguaBytes. I believe that these suffice, and that if not, I would rather place the responsibility for engaging the child with the parent than with a blinking light. Apart from this, lighting conditions are not always optimal for using lights to attract attention; also, many of the LinguaBytes children have vision problems and might not even notice a blinking LED.

4.4 Conclusions for the final LinguaBytes design

Here I briefly summarise the most significant conclusions with regard to the final LinguaBytes design.

The design of LinguaBytes is based on the learning theories of constructivism and social constructivism. This means that the interaction with LinguaBytes will be focused on (1) learning by doing, i.e., active participation of the child, and; (2) on providing opportunities for scaffolding. LinguaBytes should by a tool that can be flexibly adjusted to a child’s Zone of Proximal Development.

In comparison with existing materials aimed at improving a delayed language development, LinguaBytes will capitalise more on the richness of physical materials, such as story booklets. Also, contrary to many software suites LinguaBytes will not provide
possibilities to create own stories or exercises. Creating custom input materials is supported.

LinguaBytes offers 3D contextual scenes, thus connecting to the trend in AAC of so-called Visual Scene Displays. In addition, the design of LinguaBytes will take the guidelines into account, established by Light et al. (2004).

In the next part of this thesis, Part III: Research-through-Design Cycles, I will describe how the theoretical foundations described in the past three chapters were used in developing the final LinguaBytes design.
Part III
Research-through-Design cycles
Chapter 5

First Research-through-Design Cycle: explorative 3D sketches

5.1 Introduction

As described in Chapter 2 the LinguaBytes project was based on a preliminary study performed by Van Balkom et al. (2002). The two main conclusions of this study were, that:

1. to optimise the interaction for each individual child LinguaBytes should be adjustable to the developmental level (both cognitive and perceptual-motor) of the child, and;
2. LinguaBytes should appear to be more toy than PC-based computer program.

My working interpretation of these conclusions was the following: ‘In order for LinguaBytes to be successful, it is crucial that it respects the individual skills (perceptual-motor, cognitive, social and emotional), needs and beliefs of children between 1 and 4 years old with multiple disabilities. Therefore, LinguaBytes should fit the way in which these young children perceive and experience the world, understand the world and give meaning to the world and provide the flexibility to support this diversity’.

The first Research-through-Design cycle was aimed at gaining empathy for the LinguaBytes users, and at determining design strategies and a global positioning for LinguaBytes, in relation to existing products and systems aimed at stimulating early language development. For this, several actions were undertaken including a literature search, field studies and expert consultations. Based on the insights gained from these actions, I developed and evaluated a first set of experienceable 3D-sketches, which have the focus of this chapter.

5.2 Literature search, field studies and expert consultations.

To get up to date with the state of the art in comparable interactive play-and-learning materials—of which some have been described in Chapter 4—and to identify opportunities for LinguaBytes I undertook the following actions.

Firstly, I did an extensive literature search. The most prominent topics were: (1) language development and early literacy; (2) children with disabilities, in relation to language development and early literacy; (3) the role of interactive technologies in the development of children, their language development in particular; (4) the status quo in assistive technologies that are especially aimed at providing children with multiple disabilities alternative or augmentative communication; (5) design for preschool children:
literature encompassed developments in product design, toy design, graphic design in children’s books and cartoons, as well as in interaction design. Key sources from this literature search and the implications for LinguaBytes have been addressed and cited in Part II of this thesis.

Secondly, I attended the world’s largest conference on assistive technologies—CSUN International Technology and Persons with Disabilities Conference—to analyse existing systems, get up to date with the latest developments in assistive technologies and identify possible partnerships.

Thirdly, I consulted various experts in the Netherlands, in the fields of (interactive) storytelling, educational games, television programmes and software, toy design and design for special needs. I even became quite an expert myself in toddler television programmes as I watched hours of Teletubbies, Dora the Explorer, Bob the Builder and more. All in the interest of science, of course;

Finally, I visited several special schools and child rehabilitation centres where children from the LinguaBytes target group and their caregivers could be observed in action, and where teachers and therapists could be interviewed.

The preliminary findings from these actions show that current applications aimed at LinguaBytes’ target group can be organised using two characteristics (see Figure 5.1):

1. **The presence in the physical and/or virtual domain.** In general, physical application types benefit from the richness of the real world, whereas application types in the virtual domain benefit from the opportunities created by computing and audiovisual media;

2. **The prominence of language: foreground or background.** In some application types language is prominently present, for example in software aimed at rehearsing letters. In these types of applications language has a role in the foreground. In other applications, for example in many toys language play a secondary role in the background: language ‘happens’ as a side-effect of a child’s imagination.

I envisioned LinguaBytes to be dynamically positioned in the space defined by these two characteristics. By dynamic I mean that LinguaBytes’ design should allow for adjusting the balance between its physical and virtual characteristics, as well as the prominence of language in order to make it suitable for children of different ages and developments: for some children LinguaBytes should be a game, for others an exercise. This means that LinguaBytes will optimally be positioned in the middle of Figure 5.1, with the flexibility to make small migrations in any of the four directions.
5.3 Explorative field study with four sketch models

In addition to the actions described in the previous section, I prepared a field study to get more first-hand experience with the potential LinguaBytes users. For this study I designed and built four interactive sketch models. These are preliminary, cardboard models aimed at simulating a context of experience in a quick and easy way. These sketch models—or 3D sketches—can help mimic interactivity but do not function autonomously; they are by no means final designs. However they can be helpful tools for a designer for:

- **Observing the target group in action.** Observing how the intended users behave when they interact with your own designs can help a designer get a grip on part of their drives and goals;
- **Determining responsibilities.** While observing users in action you as a designer can try to determine how you can influence the situation you are observing, and if you should influence it in relation the design goals. In this process, the added value of using your own designs is, that when the user is interacting with your work you can get a grip on how your expectations—your design rationale—match or mismatch with the expectations of the user. This is very valuable information since it can help you identify flaws in your own rationale, and identify possibilities for changing the rationale of the user so that expectations match better in the future.

In short, testing with sketch models helps create empathy.
Design of the sketch models

I designed four sketch models. Through these sketch models I wanted to get more grip on the limits of the dynamic position of LinguaBytes in the middle of Figure 5.1. Therefore the four sketch models varied in their physical-virtual ratio and foreground-background language ratio. Please note that this was done on an intuitive basis, as this is a preliminary exploration. Had I wanted detailed information on these ratios, I had needed more detailed prototypes. I describe the four sketch models here (see Figure 5.2).

Sketch model 1: story booklet with audio. The first sketch model consists of cardboard story booklet of the story developed for the ExploraScope (see Chapter 2), with the photo of a scene glued on each right page and a PCS (Picture Communication Symbol, pictorial communication cards, see Chapter 4) of the corresponding core word glued on the left page. Turning a page automatically triggers the audio of that scene. When the child touches the PCS, the accompanying word sounds through a speaker. I developed two versions: one with an adult narrator and one with a child narrator (a 7-year-old girl) as I wanted to determine the users’ preference for either. For the same reason, I created a second version of the booklet in which drawings were used instead of photographs (see Figure 5.3). Thirdly, the narrative was recorded in first-person and third-person versions.

![Sketch model 1: story booklet with audio.](image1)

**Figure 5.2** The four 3D sketch variants. Top left: a cardboard story booklet with accompanying audio, telling the story ‘Jitte goes to bed’; top right: a matrix of PCS communication symbols, used to control an on-screen version of ‘Jitte goes to bed’; bottom left: a visual scene with accompanying audio highlighting parts of the going to bed routine; bottom right: a visual scene with physical objects, to control an on-screen animated variant of the third 3D sketch variant.
Sketch model 2: matrix of PCS communication symbols. The second sketch model is a PC-variant of the same story, combined with a matrix of PCSs. In this variant the child is given an overview of all PCSs in the story. The symbols are ordered following the storyline: from left to right and from top to bottom. Whenever the child touches one of the symbols the corresponding scene from the story is shown on the vertical display in front of the child and narrated. At the end of each scene the symbol of the most important core word is shown and pronounced. Like the first model, this second sketch model is offered in combination with two different narrators.

Sketch model 3: visual scene with audio. This variant consists of a graphic scene with tangible PCS cards. The visual scene contains drawings of all core words. Together with an adult a child can select a PCS and look for the corresponding core word within the visual scene. When the child touches the correct object in the visual scene, audio of the core word is played through an external speaker.

Sketch model 4: visual scene with physical objects. In this fourth sketch model two versions of the same visual scene are shown: a ‘complete’ on-screen version and a physical version in which core words were missing. Of these missing core words tangible objects are lying in front of the child. A child can choose one of the objects and place it on the empty scene. As a result the corresponding object is animated in the on-screen version. The core word sounds through the internal speakers. Also, the PCS of the core word appears on-screen. As long as the object is placed on the empty scene the animation continues; when it is removed, or when a new object is placed the animation stops.

Evaluation setup
The sketch models were tested in a Wizard of Oz set-up (Dahlback, Jonsson and Ahrenberg, 1993). In this technique, participants have the impression that they are interacting with an autonomous, interactive prototype although in fact they are not; instead the interaction is mediated by a human operator, the wizard, who observes the actions of the subjects
and responds as he would want the system to respond. As a consequence, the participants can be given more freedom of expression. One particular forte of using a Wizard of Oz setup is that it can provide the empirical basis for the development of the software for a particular application, without having to invest time and effort in elaborate prototyping or programming. Of course you cannot expect to gather all the information you need for the perfect design of the system by means of Wizard of Oz studies, but for finding out application/context specific characteristics it is a valuable technique.

The evaluation setup is shown in Figure 5.4: the evaluation took place in the children’s usual speech therapy room. The participating children often sat in a special chair at a large workspace, with a speech therapist sitting on a stool or bench next to the child. I (RESEARCHER 1 in Figure 5.4) sat at some distance of the child. In this position the child’s interaction with the 3D sketches and with the speech therapist could be well observed. A digital video camera was placed next to RESEARCHER 1. My fellow researcher Riny Voort (RESEARCHER 2 in Figure 5.4) who also took notes and photographs, operated the video. I was typically observing the child and trying to respond as satisfactory as possible using a separate keyboard and a list of the shortcut keys needed to trigger the right software reactions. Occasionally, parents or a second (type of) therapist was present at the evaluation, typically taking place behind the child and therapist.

The evaluation of the 3D sketches took place in two back-to-back 30-minute speech therapy sessions with two children. The speech therapists were instructed to try out all four variants within his 30-minute session.

Participants
The evaluation was executed with two children at the early intervention department of rehabilitation centre St. Maartenskliniek in Nijmegen, the Netherlands. CHILD 1 was a girl with a calendar age of 2 years and 6 months and a developmental age that was probably lower (although untested). She was diagnosed with hydrocephalus, along with additional minor diagnoses. She had no major vision or hearing problems, but had motor retardations: she could not walk but could sit and drag herself around on her buttocks. Her fine motor skills were slightly hampered: she had trouble gripping objects. Cognitively and linguistically she was within the required developmental stages for these sketch models, but she had a short attention span and limited concentration. She did not speak, but communicated by pointing and grabbing. She liked books and being read to.

CHILD 2 was a boy with a calendar age of 2 years and 7 months and a developmental age that was probably lower (at 26 months his developmental age was 13 months). He had spastic tetraplegia (see Chapter 4), more on the right side of his body than on the left side. He was very visually oriented, did not like loud noises and only occasionally responded to sounds. His gross motor skills were more limited than CHILD 1’s: he could only walk under
guidance; he could crawl and use a wheelchair. His fine motor skills were similar to CHILD 1’s: he could grab objects with his left or right hand but placing these objects at a certain position would often take tremendous effort. Cognitively and linguistically CHILD 2 was well within the required developmental level: he could make the connection between a PCS and an object and used approximately 120 PCSs. These were organised in a folder, into the following subgroups: ‘At home’, ‘Food and drinks’, ‘Toys’, ‘Traffic’, ‘People’, ‘Animals’, ‘Outside’, ‘Feelings and emotions’, and ‘Celebration’. Additionally, CHILD 2 used 5 to 10 sign language signs. CHILD 2 liked cars and trains and playing with tactile things like macaroni (uncooked).

Findings
Both children used all four variants. Our observations and the speech therapists’ feedback provided interesting insights, despite the preliminary character of the 3D sketch models. I will illustrate these insights here. Please note that I will not evaluate the individual 3D sketches. They were not intended to be full-fledged LinguaBytes designs; they are vehicles for gaining empathy for the user and identifying design opportunities and responsibilities.

The added value of physicality. Almost all 3D sketches bordered on CHILD 2’s maximum fine motor capabilities. This was most apparent with the second and third variant, where
the child was required to point at—for him—small pictures. This proved to be difficult, both for him and me, to which I will come back in 5.5.

In contrast, it could be observed that the three sketch models using physical materials for interaction (variants 1 and 4, and to a lesser extent variant 3) allowed children more control, especially over the pace and timing of the interaction. I identify two critical elements in their success of these materials: (1) they were three-dimensional, and; (2) they were manipulable. As such they provided clear action possibilities, affordances: the book pages afforded turning, the PCS cards and toys grabbing and moving.

Additionally, in comparison to the versions that offered less sensory stimuli, the two children seemed more engaged in the interaction, and showed more active behaviour when they were offered visual, auditory and tactual stimuli at the same time. It should be noted that children were also more easily distracted when offered multiple stimuli.

However, attributing these positive effects to physical materials in general would be oversimplifying, since differences could be observed between the appeal of the three designs: the cards used in sketch model 3 seemed to be quickly boring whereas manipulating the materials used in sketch model 4 was so satisfying in itself that it claimed all of the children’s attention. In short, the benefits of physical interaction materials were evident, but future materials would need to be designed thoughtfully; the challenge would be to find the optimal design between boring and over-stimulating.

The added value of a screen. It could be observed that in general the two children found the two sketch models without animations far less interesting than the two other variants. The speech therapists preferred the variants with animations as well. They indicated that the animations helped keeping a child’s attention, provided the child with appealing rewards for its actions and last but not least, provided nice starting points for communication with the child.

This information argued in favour of using a screen within LinguaBytes, although there were also significant counterarguments. Firstly, since LinguaBytes is aimed at very young children, on-screen information could be too abstract for some of them (Anderson and Evans, 2001). Secondly, using a screen would severely reduce the flexibility of LinguaBytes since screens are typically require strong power sources and are heavy. Smaller, portable screens would probably be unfit for children with vision problems, but this could be considered in the next Research-through-Design cycle. Thirdly, screens can be very dominant. I should be aware of this, especially because one of the goals of LinguaBytes is to address children on more than their sense of vision alone. Fourthly, I should investigate if and how LinguaBytes could be made suitable for multiple children simultaneously, to

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1 Please note that the variants with animations were deliberately evaluated last, as we expected that the non-animated variants would not stand a chance otherwise.
stimulate peer-peer communication. A major breaking point here could be how multiple children—possibly with vision problems—can make use of a single screen\(^2\). Also, I should investigate what the pros and cons are of a screen in a horizontal position. The participating therapists indicated that alternative screen orientation this would be highly appreciated since in some cases it is preferred to sit on the ground with a child during therapy.

The positive effects of a screen however, are evident. Therefore I decided to keep including a screen in future LinguaBytes designs, but keep my mind open for screen-less possibilities.

**Distribution of action locations.** The two children seemed to have difficulties with switching their focus between the input location—i.e., the location where they could act—and the output location where the system would respond. Often children did not see the link between their actions and the resulting reaction, or be so immersed in their action that they had no attention for feedback to begin with.

It would be premature to attribute these difficulties to specific aspects in the designs of the four variants, but I see connections with the work of Wensveen et al. (2004) and Djajadiningrat et al. (2004) who identify six factors that, when showing unity between action and feedback, can strengthen the coupling between action and feedback:

1. **Unity in time:** the product’s reaction and the user’s action coincide in time.
2. **Unity in location:** the reaction of the product and the action of the user occur in the same location.
3. **Unity in direction:** the direction or movement of the product’s reaction (up/down, clockwise/counter-clockwise, right/left and towards/away) is coupled to the direction or the movement of the user’s action.
4. **Unity in dynamics:** the dynamics of reaction (position, speed, acceleration, force) is coupled to the dynamics of the action (position, speed, acceleration, force).
5. **Unity in modality:** The sensory modalities of the product’s reaction are in harmony with the sensory modalities of the user’s action.
6. **Unity in expression:** the expression of the reaction is a reflection of the expression of the action.

Looking at the four 3D sketch variants I can identify that only in ‘time’ action and feedback show unity. In future iterations I could design for more unity on the other five factors as well, although it could be argued that some are less easily applicable to the more severely disabled children using LinguaBytes, e.g., unity in direction, dynamics or expression. These aspects can be very distorted due to the impact of cerebral palsy on a child’s motor control.

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\(^2\) I could also choose to use multiple screens, one per child. However, that would probably result in parallel learning instead of collaborative learning, which was deemed undesirable. Therefore it was decided to use a single screen.
An interesting suggestion of one of the speech therapists was to investigate including auditory feedback within the physical materials themselves. This could contribute to more unity in location between action and feedback. However, this idea was abandoned later in the project for insurmountable practical reasons.

*Photographs or drawings?* The children seemed to show a slight preference for photographs over drawings, but this could not be indecisively ascertained. I suspect that, because photographs are less abstract than drawings, the children could relate to them more easily. However, photographs can also hamper the interaction. For example, although Child 1 did not really interested in the picture books one scene earned his appreciation: the one in which the Jitte brushes her teeth. The reason for this was that she wore pyjamas with the boy’s favourite book character, Lucy Cousins's *Maisy Mouse*. However, as soon as he spotted *Maisy Mouse* the boy lost his remaining interest in the story line.

Another drawback of using photographic material is that it is more difficult to use within animations, especially when LinguaBytes would allow importing personalised photographs. There are examples of how this can be done, for example as seen on the website *Elf Yourself* (OfficeMax, 2009), on which you can take a picture of your face with a webcam, and place it on the standard animated body of a Christmas elf. However, this technology is technically challenging. Additionally, where the strength of *Elf Yourself* lies in that you can only adjust the face of the elf, I would probably need photographs of a child’s body and limbs as well since the main reason to allow using personalised photographs would be to make the LinguaBytes content accessible for children who are not yet able of understanding more abstract representations. This would demand considerably more from the LinguaBytes software, but more importantly also from the caregiver who needs to generate the photographic materials.

Thirdly I find it my responsibility to ensure that the visual content is of a quality that supports the goal of LinguaBytes to stimulate language development. This requires coherence in structure and aesthetic quality. Therefore I have decided to focus first on providing well-researched and professional animations. Especially since the 3D sketch tests provided no compelling arguments to use photographs.

*Narrator.* It was difficult to draw conclusions with regard to using a child's voice or an adult voice, nor with regard to telling a story in the first or third person. However, the speech therapists indicated that they preferred the adult narrator because adults generally articulate better.
5.4 Conclusions for the next prototype

Here I briefly summarise my conclusions for the next prototype.

*Positioning* – LinguaBytes should be flexible enough to capitalise on the benefits of either the physical or virtual domain, and be able to alternate between foreground or background prominence of language.

*The added value of physicality* – I should capitalise more on the advantages of physicality in the interaction with LinguaBytes. For this I will need to focus on play-and-learning materials that are three-dimensional and manipulable.

*The added value of a screen* – LinguaBytes will make use of a screen for providing as many starting points for communication as possible. I should investigate if and how LinguaBytes can be made suitable for multiple children simultaneously, and what the pros and cons are of a screen in a horizontal position.

*Distribution of action spaces* – In future LinguaBytes designs I should couple action and feedback as clearly as possible. This can be done by aiming for unity in time, location, direction, expression, modality and dynamics.

*Photographs or drawings* – In the next Research-through-Design cycle I will focus on drawn animations, but keep our minds open for including other representations.

*Narrator* – For the sake of understandability LinguaBytes will make use of adult narrators.

5.5 Reflection on this Research-through-Design cycle

Research-through-Design is a method in which design and scientific knowledge continually feed each other. In this chapter I have described how I have explored several sources based on which I have developed a first set of explorative designs. In this section I reflect this first Research-through-Design cycle. I address the following topics: (1) interaction design for and with non- or hardly speaking preschool children, and; (2) designing for diversity: the interpretative and lenient nature of adaptive behaviour.

*Interaction design for and with non- or hardly speaking preschool children*

As I have described in the final section of Chapter 2, LinguaBytes is aimed at, from the perspective of interaction design, very young children. Moreover, LinguaBytes is aimed at very young children who are non- or hardly speaking and can have severe motor limitations. These factors profoundly impact my research, as many research methods rely on language. During this first Research-through-Design cycle it became quickly apparent that within LinguaBytes I have to rely on the following information sources:

- *Expert input from the children's caregivers*: these are the people that know the children best and can make the most reliable estimations of the effects of LinguaBytes on the
child. I can use language-based evaluation methods here;

- My own observations: to be able to understand how to synthesise the formative evaluation results it is essential that I understand the particularities of the LinguaBytes users and context of use. Through observation I can learn to interpret a child’s behaviour and (body) language and get a feeling for how I can offer support through design.

I can imagine that people may consider the latter information source (my own observations) hardly reliable, especially when reading words such as ‘interpret’ and ‘feeling’. However, I believe that interpretation and relying on one’s gut feeling or intuition are integral parts of design research, for the simple reason that designing involves designers. These are people trained in making decisions based on incomplete, ambiguous or even contradictory information, and often rely on their tacit knowledge and professional judgment. We should therefore not be dismissive of the designerly skill of interpretation. I elaborate on the role of the designer in research in Chapter 10.

Additionally, we should keep in mind that this research is not only aimed at developing LinguaBytes but also at the question ‘how to design for diversity’. Consequently, my observations as designer-researcher are also not only aimed at improving the design, but also on gaining first-person experience as a ‘designer for diversity’.

Designing for diversity: the interpretative and lenient nature of adaptive behaviour

The most important lesson from my observations in this first Research-through-Design cycle has to do with the question how to design for diversity. Even though only two children participated in the 3D sketch tests these children already showed immense differences. Being the Wizard of Oz made me realise how difficult it would be for the LinguaBytes system to be able to interpret the diverse behaviours of these equally diverse children. Currently the system’s behaviour was effectively my own, as I myself observed the children working with the 3D sketches and interpreted their intentions and actions—their input for my (i.e. the system’s) reactions. This turned out to be more difficult than I anticipated, due to the fact that the two children were non-speaking, but even more due to the diminished motor control of a child with cerebral palsy. I will explain this.

Almost all of the 3D sketches bordered on the maximum fine motor capabilities of Child 2, the child with the more severe motor disability. For example, pointing at one specific PCS in the matrix of symbols in 3D sketch variant 2 was too difficult: he would either overshoot, going in the right direction but missing the end target, or the target would be only touched very briefly making it difficult for me to discern if it was an intentional action. This made me realise why buttons are being used so much in AAC: buttons are discrete, either pressed or not. However, I was also confronted with an alternative behaviour: Child 2 would unintentionally touch all PCSs in the matrix on his way to the
targeted one. Had I played a ‘system with buttons’ I would have had to react to all these accidental actions, which would have certainly resulted in a highly unmotivated child within minutes.

I chose to play a more lenient system, observing Child 2 meticulously and interpreting his intentions. This involved looking closely at the child’s face, gaze and movements and trying to find their interrelations, coupled to the most likely action scenario: for example, if a scene in the story incorporated a bear it would be likely for Child 2 to touch the bear PCS. Also, I tried to estimate what this child’s typical motor behaviour was in order to filter seemingly intentional movements—which I like to call suggestures—out of the ambiguous noise of seemingly unintentional movements. Whenever I observed Child 2 making a pressing movement I tried to interpret from his facial expression and gaze whether the movement should be system input or not. If so, I (i.e., the system) had to react immediately, since feedback latency is a motivation killer. This required me to press the right button on my keyboard to trigger the proper animation or audio. This demanded a lot from my multitasking abilities, since I had to divide my attention to various sequential tasks in parallel. Knowing that this is what computers excel in this did not worry me for the future LinguaBytes system, but something else did: much of my (i.e. the system’s) leniency depended on my interpretation of the child’s behaviour, which in turn depended largely on my social skill and experience. I was doubtful how I could implement these, in my view profoundly human qualities, in LinguaBytes.

My conclusion was the following. My behaviour as the Wizard of Oz was essentially adaptive: I adjusted the rules on which I based my (i.e., the system’s) reactions, based on the immediate situation I observed, my previous experiences with similar situations and likely future situations. In order for me to be able to design this amount of adaptivity in LinguaBytes, it would be good to: (1) get more insight in the situated factors to which LinguaBytes should become adaptive; (2) find strategies that will help me design and implement this adaptive behaviour in future LinguaBytes designs.

I decided to approach these questions through a brainstorm in the second Research-through-Design cycle.
6.1 Brainstorm aimed at determining strategies for designing adaptivity

**Brainstorm goal and topics**

In section 5.5 I described how much the success of LinguaBytes would depend on its ability to be adaptive. I decided to try to get more grip on adaptivity to a specific user group, and on promising design strategies for making LinguaBytes adaptive, through a brainstorm. Brainstorming, a term coined by advertising consultant Alex Osborn (1963), is a group creativity technique aimed at generating a large number of ideas, often solutions to a problem. I typically use it to get new perspectives on a situation, in this case on how I could tackle the limitations, posed by the specifics of children between 1 and 4 years old with cerebral palsy, on interaction design through adaptability or adaptivity.

Based on the definition of cerebral palsy as proposed by Bax et al. (2005, see Chapter 3) and my observations during the first Research-through-Design cycle, I identified ten typical behaviours and described these in layman's terms, to serve as starting points for the brainstorm. In this way the brainstorm would appeal more to the participants' sense of empathy rather than on their ability to learn terminology. The ten behaviours were related to gross motor disability, fine motor disability, visual defects, oromotor disability, learning disability, or other factors such as 'not being able to read' or 'having a short attention span'. Considering the fact that most HCI is based on textual and symbolic representations, these are factors that severely impact the form in which a designer can offer information.

**Brainstorm setup**

The ten behaviours were addressed by re-contextualising them in a different setting. By re-contextualising a situation you often get ideas that are admittedly not always useful, but highly inspiring. And as the obvious solutions will surface anyway, I feel it is better to invest in the less obvious ones. Examples of re-contextualised behaviours are the following:

- **Moving involuntary**: “Oh dear, you are not in luck: the location where you organise a chess tournament lies at a notorious fault line. Every other minute the whole venue shakes so much that not only the chess pieces topple, but the players as well. It is too late to relocate or cancel. How can you prevent the chess games at the tournament from going to pieces?”

- **Only being able to make unrefined movements**: “At your latest barbecue you sustained light burns to your hands due to a peer-pressure incident. As a consequence, you find your
them bandaged up to your arm pits, which severely hampers you in the execution of your prestigious job: cutlery straightener at the Ritz-Carlton. Quitting is not an option. How do you maintain your high standards in cutlery straightening?”

The brainstorm was done with five designers, moderated by myself. The most promising results of the brainstorm were selected using five personas I based on the two children from my observations during the first Research-through-Design cycle and on the participating children in the ExploraScope research (see Chapter 2). Personas are fictional characters that describe a user in a compelling and succinct way, making it possible for members of a design team to rely on a shared understanding of the needs and goals of this persona (Markopoulos et al., 2008). Personas are often used to make a design problem less abstract, which helps designers make design choices. I asked all brainstorm participants to consider for each of the ten brainstorm topics which ideas they found most promising for these personas, and to explain why. The explanations were discussed further as a group, thus trying to get to the core quality of the selected brainstorm results.

**Brainstorm findings**

The brainstorm resulted in two important realisations. Firstly, the ideas generated in the brainstorm all shared the strategy of adjusting the re-contextualised situations. This is essentially what designers do. Roughly the ideas could be organised by using two criteria: (1) Are the adjustments made to the user or to what he or she is using? In other words, is the user being made suitable for what he or she is using or the other way around? (2) Who does the adjusting, the user or what he or she is using? In other words, does someone do the adjusting or are the adjustments automated?

The former criterion is pretty straightforward: in future LinguaBytes designs I can choose to either design things that change the way children function to help them interact with the world around them, or to adjust the world itself with the same purpose. A combination of the two is of course also an option. The latter criterion is far more impactful, as it is more difficult to have a product or system adjust itself than to have a user adjust the product or system. I call these two situations ‘adaptivity’ and ‘adaptability’,

![Diagram](image-url)

**Figure 6.1** When a product or system can adjust itself to a user, this is called adaptivity. When a user can adjust a product this is called adaptability.
respectively (see Figure 6.1). More about this can be read in (Hengeveld, Hummels, Overbeeke, Van Balkom, Voort & De Moor, 2007a).

The second realisation was a strategic one. By identifying the two aforementioned criteria the brainstorm provided me with tools that could help me start small. I could approach adaptivity via the less complex adaptability. In other words, I decided that I should start by making LinguaBytes highly adaptable first, which could help me acquire guidelines for making it highly adaptive later.

Therefore, the goal for this Research-through-Design cycle is to develop a first fully functional LinguaBytes prototype, i.e., one that would not use a Wizard of Oz set-up; an adaptable starting point for future, more adaptive designs.

6.2 Explorative designs

Language components that should be addressed through LinguaBytes
The four sketch models of the previous Research-through-Design cycle were based on a global positioning for LinguaBytes. In this cycle I used language as a second starting point.

My fellow researcher Riny Voort determined which language aspects LinguaBytes should support, based on the linguistic development of most children. This development follows a more or less predictable route (see Figure 6.2). Words are stored in a child’s memory as so-called semantic networks (Aitchison, 1994; Goldberg, 2003). This means that one word can have multiple distinctive components, for example the meaning of the word (semantics), the sound of a word (phonology) or its use in a sentence (syntax). Other components are morphology, pragmatics and meta-linguistics. However, since semantics, phonology and syntax are the components that develop furthest between the age of 1 and 4 (Figure 6.2, grey area) LinguaBytes will be focused on these three only. With regard to syntax it should be noted that children between 1 and 4 years old move through several developmental phases, i.e. the one-word phase, two-word phase, multiple-word phase and differentiation phase. During these phases a child progresses from using single word utterances to constructing more elaborate and difficult sentences that gradually approach the use of proper grammar.

As described in Chapter 4, there is general agreement that story reading forms a good foundation for early language development. Therefore, the LinguaBytes prototype should use interactive stories as the starting point for exercises.

Explorative designs
I made several explorative designs, of which I illustrate three briefly here: the PictoCatcher, the ObjectSlider (Figure 6.3) and KLEEd.

PictoCatcher. The PictoCatcher (see Figure 6.3, left) is an interactive marble course where each marble with an enclosed PCS serves as tangible system input. A child and
Figure 6.2 The order in which the linguistic development of children between 0 and 10 years takes place (vertical blocks) and the parts that are relevant for LinguaBytes (grey area); these encompass most of phonology, semantics and the early stages of syntax.

Figure 6.3 PictoCatcher (left) is an interactive marble course where each ‘marble’ with an enclosed PCS symbol is related to a story and triggers additional movies when entering the wooden casing; ObjectSlider (right) starts or alters an animation by placing the related tangible objects next to the screen.
caregiver can choose a marble together and lay it on the track’s starting position. This triggers a movie of a story scene on a small screen integrated in the track’s casing. At the end of the scene the child can push the marble, which rolls down the track into the wooden casing. This triggers another movie, which can be focused on any of the three aforementioned language components, for example on phonology by playing a song related to the marble’s PCS. At the end of the movie the marble rolls down a ramp out of the wooden casing. Two positive aspects of the design are that the input and output locations are brought closer together and that the set of marbles can be limitlessly extended.

I had my doubts however about the small screen—children with CP can have vision problems, see Chapter 3. Therefore I made a short animation in Flash and tested it with some children using a PDA. This immediately showed that the small screen in the PictoCatcher would not work. The PDA screen was too small for all participating children [2]. Another weakness in the design was that the interaction quickly became monotonous; it offered too little variation. I explored ways of making the track expandable, but this only made it less practical without adding real variation. This could help make the PictoCatcher adaptable to children with different levels of development. For these reasons I decided to abort the PictoCatcher and explore alternative design routes.

ObjectSlider. A second design was based more on the trend in research of interactive tabletops. In this design, which was called the ObjectSlider, children can start animations by placing tangible objects next to a tabletop projection (see Figure 6.3, right). This design was based on the fourth 3D sketch variant, with the major difference that the input and output locations are closer to each other. Although this change appeared promising, the ObjectSlider seemed too static due to its dependency on a projector. Therefore I decided to explore the possibilities of an integrated screen in a follow-up design, called KLEEd.

KLEEd. KLEEd (Hengeveld, Hummels, Voort, Van Balkom & De Moor, 2007b) stands for Kids Learn through Engaging Edutainment. KLEEd is a \( \heartsuit \)-shaped textile play rug (see Figure 6.4) that can be placed on the floor or on a table in different set-ups (see Figure 6.5). A screen for animations is located in the centre of a play rug, as a shared point of attention for children and caregivers. Attached to each side are four interactive surfaces. On these surfaces a child—or multiple children—can place objects to do linguistic exercises or control interactive stories, like in the fourth 3D sketch variant. Each surface supports one of the three aforementioned language components, plus one for story reading, which means that KLEEd is used in at least four different spatial orientations.

To test the practical implications of this—for example how it would be possible to present on-screen content in such a form that it would be understandable from different perspectives—I made a full-scale model of the design. In my experience working on a 1:1
Figure 6.4 Design sketches, among which the first one of KLEEd at the bottom right.

Figure 6.5 The first version of KLEEd.
scale has various benefits over working on smaller scales:\footnote{Of course small-scale models have their advantages over large-scale ones, too, e.g., see Frens, Djajadiningrat & Overbeeke (2003), but the decisions I describe here can be fully attributed to working on a 1:1 scale. I do not go into the benefits of small-scale models over large-scale models.}

- First and foremost, it is evident that full-scale models appeal to our perceptual-motor skills differently than smaller scale models; consequently, the only way to make valid predictions about how the design will be used is to try it out full size;
- Also, full-scale models show the exact behaviour of materials as well as the scale of the design in relation to the context of use;
- A third benefit is that making these models make you sensitive for the possibilities and limitations of materials and their fabrication techniques;
- Consequently, full-scale models force a designer to think about details that ‘disappear’ on smaller scales.

I made this version of KLEEd of blue and grey fleece with a green accent where it could be opened to take out the electronic components before washing the rug itself. The location of the screen was accentuated with a playful, brightly coloured polka dot border. I made a special stand to place the screen in a tilted position if required (see Figure 6.5, top right image). Please note that the model was a non-functional mock-up. I implemented no interaction or any functional electronics yet.

\textit{Evaluation of the KLEEd design}

Working on the full-scale model of the first KLEEd design immediately brought limitations to light.

First of all it is very difficult to present a clear and understandable visual scene to multiple people sitting around the same screen; perspective—or the lack thereof—starts causing problems. Seemingly the only way to use perspective is to adopt a birds-eye viewpoint, looking down on the scene below. However, this highly reduces the visual detail, especially that required by small children. Another way to deal with perspective issues would be to get rid of it altogether, for example by adopting the Chagall-like perspective used in play-rugs. This is the ‘perspective’ that young children sometimes use in their drawings. However, this often results in an incoherent visual scene and will probably not provide the most understandable semantic visual scene, and thus a sub-optimal basis for language. Moreover, adding animations to this perspective inevitably results in all-children-except-one looking at the scene upside-down. Finally, this type of perspective will probably only work when KLEEd is lying flat on the floor; in a typical tabletop set-up a regular screen perspective should be used. This means that the LinguaBytes should be developed so that it can be offered in both perspectives. Though challenging, this would require a
Figure 6.6 Original sketches of Tom, Tes and their grandparents.

Figure 6.7 Front, rear and ¾ views of Tom and Tes and an overview of the other characters.
disproportional time investment; given the aforementioned anticipated drawbacks, it was decided not to pursue this challenge but aim for a 'desktop perspective' first.

Secondly, another limitation of this design of KLEEd originated from the physical properties of the +-shape: the interactive surfaces attached to the left and right of the screen were in the way when using KLEEd in a vertical set-up. They tended to pull the screen down, making it slide away or fall over.

Thirdly, because each of the interactive surfaces was dedicated to one language aspect, changing between for example stories and exercises requires a change in the orientation of KLEEd, or of the people using it. This could make KLEEd impractical due to the previous remark.

On the positive side however, the last two disadvantages can be easily solved by clever design and as such do not weigh up to the friendliness of the material. The softness and playfulness of the fleece made KLEEd inviting, and the four surfaces could trigger a child’s exploration when they would more clearly show interactivity. Also, KLEEd appeared to be easily made adaptable using low-tech materials such as Velcro or buttons (not the electrical ones but those on clothes), or through advances in the textile industry, such as the use of conductive yarns. I decided to continue with the KLEEd design in this Research-through-Design cycle and investigate its advantages and disadvantages further, by adding functionality and interactivity. In the next section I describe how KLEEd was developed into the first fully functioning, Wizard of Oz-less LinguaBytes prototype.

### 6.3 KLEEd: re-design

**Prototype content**

As a start we developed content. With an eye towards the future my fellow researcher Riny Voort (who would be writing the LinguaBytes content) and I decided to design a family of recurring characters for LinguaBytes. This would have several benefits: (1) It would create a visual unity across the stories and exercises; (2) It would prevent that children would prefer some LinguaBytes applications over others, merely due to the fact that they relate to one character more than to another; this situation would not benefit the learning goals of LinguaBytes, and; (3) It would have a positive effect on the feasibility of LinguaBytes, compared with using existing, copyrighted characters.

We decided that all the LinguaBytes content would revolve around two children, a boy and a girl named Tom and Tes, both approximately three or four years old. Tom and Tes would always appear together. This would eliminate the risk that the children using LinguaBytes would only be interested in doing exercises featuring their favourite character.

Riny Voort wrote two interactive stories, both consisting of nine scenes. In the first story Tom and Tes are playing with a ball. Then daddy drops by and joins them. At an unlucky moment however, he falls and tears his trousers so he has to go home to put on
**Figure 6.8** The KLEEd prototype, with clockwise from the top left: the output module, the navigation module, the combination module, tagged input material and the hide-and-seek module.

**Figure 6.9** The output module consists of a 15” TFT-display, encased in a wooden container (left and middle), which in turn is put into a fleece sleeve (right).

**Figure 6.10** Left and middle: A stand can be used to place the output module in tilted positions. The stand can be attached to the output module's sleeve using the horizontal strip of Velcro, the angle of the stand can be adjusted using the other strip of Velcro; right: KLEEd in three different set-ups: from left to right with the story module, the combination module and the hide-and-seek module.
a new pair. The second story also starts with Tom and Tes playing with a ball, but now a 
woman with a baby appears. The children want to see the baby and give the baby a kiss. 
They sing a song for the baby. Then the baby falls asleep and the woman with the baby go 
home. By including a song the stories do not only support interactive story reading but also 
stimulate phonological awareness.

In addition to the stories, two exercises were created focusing on semantics or syntax. 
The semantic exercise was a hide-and-seek exercise that stimulated a child to guess which 
character from the interactive stories was hidden, and the syntax exercise would focus on 
teaching children two-word sentences.

**Character design**

Based on my findings from the previous Research-through-Design cycle I had concluded 
that LinguaBytes would use drawn visual material instead of photographic material. I 
designed Tom and Tes as a blond girl and a tanned boy. Tom could be foreign. As peripheral 
characters I designed a mother and father, grandparents, siblings, a friend in a wheelchair, a 
woman from the neighbourhood with a baby, and two animals: a rabbit and a dog—almost 
al all young children like animals. The characters can be seen in Figure 6.6 and Figure 6.7.

**KLEEd design**

After asking some fellow designers, researchers and speech therapists to reflect on the 
KLEEd model, I decided to detach the four interactive areas from the central screen (see 
Figure 6.8) and turn KLEEd into a modular system. This seemed to solve most of the issues 
of the -shaped KLEEd design. The design now consisted of three interactive modules— 
two exercise modules and a story module—that can be connected to a fourth module for 
output. Additionally, I designed a small set of RFID tagged input materials based on the 
content of the stories and exercises. I describe all four modules in the remainder of this 
section.

**Output module.** This module contains a 15-inch flat-screen TFT-display with stereo 
speakers. The display is mounted in a wooden holder, which in turn fits in a fleece sleeve 
that can be washed separately (see Figure 6.9). The near and far ends of the sleeve contain 
a rigid wooden strip with two magnets for the attachment of the story module or exercise 
modules. The position of the output module can be placed in both a horizontal position, 
enabling the use of KLEEd on the floor or table, and in a range of tilted positions. As such 
the screen is adaptable to the optimal learning settings of individual children. I designed a 
foldable stand that can be attached to the output module’s sleeve with two Velcro strips (see 
Figure 6.10).

**Story module and exercise modules.** The KLEEd prototype contains two stories and two 
exercises. To interact with these I have designed three interface modules, one for the stories
and one for each type of exercise. I designed a dedicated interface for the two exercise types, so that I could design each module to optimally fit the goal of the exercise. I assumed that this could make the interaction more intuitive, engaging and suitable for children between 1 and 4 years old. Each of these modules can be easily attached to the output module in different set-ups (see Figure 6.10, right), with a magnetic connection. I describe the three modules here. The one for interactive story reading is called ‘Story module’, the one for the semantic exercise ‘Hide-and-seek module’ and the one for the syntactic exercise ‘Combination module’.

**Figure 6.11** From left to right: the story module (left), the father figure placed on the story branch selection area (middle), and the handle for moving forward and backward in the story (right).

**Figure 6.12** The nine-scene story of Tom, Tes and Daddy.
The story module (Figure 6.11, left) was designed to support reading the two interactive stories. The module can be magnetically connected to the output module, which automatically starts the story. At the end of the opening scene child and caregiver can choose which other character joins Tom and Tes. They can do this by placing a wooden figure of that character on a wooden area in the story module, for example the dad-figure (Figure 6.11, middle). The story automatically continues with the dad-variant, as described in 6.3. Screen shots from this story are shown in Figure 6.12. In both stories PCSs of all core words are shown on-screen, in accordance with guidelines from recent literature that suggests that: (1) it is best to show a communication symbol at the same location as the object it refers to; and (2) it is preferred to reveal the communication symbol at the moment the corresponding audio is being pronounced. The child can go through the story by moving a handle (Figure 6.11, right) to the right for the next scene or the left for the previous scene. By swapping the tangible figure for another the story changes topic automatically.

In addition to the story module I designed two exercise modules. The aim of the first exercise was to stimulate vocabulary (words like ‘dad’, ‘mom’, ‘baby’ or ‘boy’) in a playful way, through a hide-and-seek game. In this game, three coloured contours of characters from the story would be shown on the output module’s screen (Figure 6.13). Coloured lines ran from the bottom of the contours to the edge of the screen after which they continued in a physical form on the output module’s sleeve and, after connecting it, on the hide-and-seek module’s sleeve (see Figure 6.10, right) and finally into three coloured cords. Pulling one of these a cords reveals the character in the corresponding. When revealed, audio is played, giving information about the character, for example: “This is mom, mom is a woman”. After this, the revealed character is replaced by the contour of a different character. The module was made of dark blue fleece around a multiplex shell. The three strings had beads at the end, which made them easier to grab.

The aim of the second exercise was to construct two-word sentences. In this exercise a child can combine characters from the stories with verbs, thus creating a two-word sentence. To do this I designed a set of wooden character pieces (Figure 6.14, left) of which a child can choose one and combine it with a PCS-verb card, by placing them on the combination module (Figure 6.14, middle and Figure 6.15). The module holds three input areas, from left to right: a wooden area for the wooden subject pieces, a green glossy area for the verb cards with green glossy backs, and a third unassigned area marked only by red stitching. This order corresponds with Dutch grammar. Any combination, for example “Tom” and “Sleeping”, is shown in animated form on the output module’s screen and pronounced (a narrator says “Tom sleeps”, see Figure 6.14, right). I made the combination module of yellow fleece around a multiplex core, containing two Phidgets RFID readers (Phidgets, 2006). Since this exercise was aimed at supporting building two-word sentences...
Figure 6.13 The hide-and-seek exercise, aimed at stimulating vocabulary. From left to right: (1) The speech therapist asks the child who ‘the blue figure’ could be, (2) the child pulls the blue string and (3) thus reveals the blue figure.

Figure 6.14 From left to right: (1) five LinguaBytes characters: Tom, Tes, woman, baby, Daddy; (2) four verb cards, one seen on the back; (3) a combination of Tom and ‘To sleep’ on the combination module, forming the sentence ‘Tom sleeps’.

Figure 6.15 The combination exercise. From left to right: (1) The wooden piece of the woman is selected, (2) placed on the wooden ‘subject’ area and (3) combined with the PCS verb-card ‘to cuddle’ into the sentence ‘The woman cuddles’.
this last area did not yet contain an RFID reader, but was included in the design for future three-word sentences exercises\(^2\).

All stories were animated and programmed in Adobe Flash. I used MAX/MSP to read out the RFID and other sensor values. All stories and exercises used an adult voice-over.

### 6.4 Evaluation of KLEEd

**Setup and participants**
I evaluated KLEEd (Hengeveld, Voort, Hummels, De Moor, Van Balkom, Overbeeke & Van der Helm, 2008a) with seven children with developmental ages between 1 year 5 months and 3 years 9 months, at two different locations: a day care centre and a rehabilitation centre. These were familiar environments for the participating children.

Four children had cognitive delays but no or minor motor problems. Two children had a form of cerebral palsy; the last child had the diagnosis hydrocephalus. These three children had moderate to severe problems with their arm- and hand function: they could pick up something with their hands, but were not able to pick up something with their thumb and forefinger. All seven children had a delayed language development.

For the evaluation I used questionnaires for the participating therapists of the children and video observations. The spatial set-up of the evaluations was comparable to the first Research-through-Design cycle (see Figure 5.4). The four children at the day care centre used KLEEd once, in 30-minute sessions. The children at the rehabilitation centre used KLEEd twice, in two 25-minute sessions separated by a week. The participating speech therapists were instructed to start with an interactive story, but were free to base the rest of the session on their expertise.

**Findings**
The most important findings were the following:

**General impression.** All children enjoyed using the prototype. They liked the stories and characters and kept interested in the story plot. They looked continuously at the screen and seemed interested in the story and the exercises. The therapists indicated that the concentration, speed of work and motivation of the children were at least similar or better than in working with existing materials. It was noted that the child’s motivation could be even more enhanced by offering both child and therapist more control over the content and timing of the exercises. According to the therapists the children reacted well to the design, among which the use of material, colour, graphics, animations and audio.

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\(^2\) As described in this chapter, the older children in the LinguaBytes user group will be able to make multiple-word sentences. We decided to start with two-word sentences and support three-word sentences in a later prototype. From there we would decide whether or not to support four-, five- or six-word sentences as well.
On the negative side however it could be seen that the story module, hide-and-seek module and combination module were too large to be positioned at the ergonomically optimal position.

Content. The content of the stories and exercises were considered suitable. All children seemed to like the characters in the story, as they spontaneously used the names of Tom and Tes. The therapists found the use of PCSs in the interactive stories satisfactory, but these showed weaknesses in clarity and flexibility. Firstly, as I have described earlier in this section literature suggests showing any communication symbol at the same location as the object it refers to. In the animated stories this obscured parts of the scene, making the scene unclear. This effect increased with each additional symbol. Secondly, literature suggests that it is preferred to reveal the communication symbol at the moment the corresponding audio is being pronounced. However, it could be seen that toddlers often looked away from the screen at this crucial moment, due to their diminished motor control. This raises substantial timing problems for an animator. Thirdly, in order for the scene to be as clear as possible, it was necessary to keep the symbols small, making them harder to discern, especially for the children with vision problems.

Based on these weaknesses it was concluded that in future prototypes it would be better to omit on-screen communication symbols altogether. This decision was backed by two additional arguments. Firstly, many children use a mix of the approximately 50 available symbol systems. Including all these symbols systems in LinguaBytes would be a costly business, since they are all copyrighted. Secondly, therapists indicated that they would often customise symbols or replace them in order to make them suitable for individual children, as some do not understand standard PCSs but do understand a slightly altered version. Tailoring the LinguaBytes settings so that the on-screen symbols correspond with the mixed symbol set of individual children would result in a huge amount of setup and administration time, let alone if modified symbols could be included as well. In conclusion, in future designs communication symbols will not be shown on-screen, but offered in a physical form.

A final finding related to the KLEEd content was that the therapists found it limited and indicated that more (types of) stories and exercises should be implemented. They did not give a high priority to integrating their own personalised pictures or audio in the program. This confirmed the choice to offer LinguaBytes as a closed system as I have described in Chapter 3.3.

Story module. The physical interaction needed for storytelling was not suitable. Children enjoyed moving the handle so much that it disrupted their concentration on the story and requests from the therapists. Also, placing the physical story characters encountered problems, due to the orientation of the pieces (horizontal) and the location of interaction space (behind the handle). This was problematic for the children with motor disabilities.
In addition, the handle did not provide suitable feedforward or feedback: none of the children seemed to understand that moving the handle in different directions had different results in the story. The role of the physical story characters was also unclear for the children. The story module did not communicate what the effect of placing a character was, when the character could be placed or what would happen when it would be taken away.

The sensation of the textile sleeves was very much enjoyed by the children, but the material also hampered the interaction: due to their diminished motor control, children involuntarily moved the module, frustrating the interaction.

*Hide-and-seek module.* The hide-and-seek exercise was physically difficult for the children with motor disabilities because the coloured strings were difficult to grab, despite the beads. Also, the children generally lost their attention quickly when doing this exercise. The interaction seemed not only less intuitive than anticipated, but also needed more surprising elements to keep young children engaged, according to the therapists.

*Combination module.* The interaction with the combination module was clear for all children and provided no difficulties, not even for the children with motor disabilities. All children immediately understood the interaction: after a single demonstration of their therapist they placed the wooden characters on the wooden area and the verb cards on the verb area. It was not clear if the children understood the hidden message I put in the two surfaces—wooden pieces on the wooden area and the green cards on the green cardboard area—or if they made another connection. One boy clearly appeared to make a linguistic connection: he placed the woman character, then the verb card to make her cuddle and glanced at the screen; seeing the woman cuddle a baby the boy grabbed the wooden baby character and placed it on the remaining area on the right, the one I included just in case. This made the speech therapist realise that this boy was making the transition from two-word sentences towards three-word sentences.

Most children seemed highly engaged in the combination exercise, despite the fact that they could only combine four characters with four verbs. Especially the ‘sleeping’ combinations were successful, probably due to the funny snoring sound effect I added, but maybe even more to the fact that the characters did not bother to find a bed but simply dropped onto the grass. One of the children even started shouting “Tom, wake up!” to the screen, getting up from his seat. He would then remove the ‘sleeping’ verb card causing Tom to rise and shine once more. He repeated this at least ten times, continuously making contact with his caregiver.

It could be seen that some children experienced slight problems with the characters and cards lying horizontally. Some therapists therefore suggested to enable placing the characters upright. This would make it easier for children to grab, place and remove them. The children showed to be better at removing the characters and cards than at placing them. Removing a piece would typically be done by dragging it close and picking it up when it
would tilt. Placing a piece required more motor control from the child and would have
benefited from more help in aiming.

The added value of physicality. In the previous chapter I have described the added value of physicality in the interaction with the 3D sketches (see Chapter 5.3). I identified two critical factors: three-dimensionality and manipulability. This Research-through-Design cycle has highlighted the added value of physicality in the context of this research further, especially through our observations of the interaction with the combination module:

• The children immediately understood the interaction, which in my view can be attributed to the design’s affordances;
• Despite the limited number of subject-verb combinations, all children seemed highly engaged in the interaction. According to the participating speech therapists this was due to the high measure of control children had over the exercise: they can determine the content, the timing, the number of repetitions, the order of events, and more, contrary to other existing materials. This was considered very important for these children, who typically experience a lack of control over their environment;
• Children generally showed a longer attention span than usual and more initiative. These observations were confirmed in the therapists’ questionnaires;
• Additionally, it was evident that the physicality of the interaction slowed down the interaction pace, resulting in more time and opportunity for expressions (facial, gestural and verbal) of the children, allowing them to evoke more communicative reactions of their surroundings.

These observations contrasted with those of the story module and hide-and-seek module. Although the interaction with these two modules was based on the manipulation of three-dimensional elements—a handle and three beaded strings—it could be seen that these elements seemed to be missing a decisive factor: improvisation. Bluntly put, these elements were merely playfully disguised buttons. The interaction with the combination module on the other hand allowed children to create their own rules within the structure of the speech therapy context and the exercise. To me, this structured openness is comparable to the balance in jazz between composition and improvisation, as illustrated in the Preface.

6.5 Conclusions for the next prototype

Here I briefly summarise the conclusions of this Research-through-Design cycle.

General conclusions – The fabrics should be replaced with a different but friendly material. Using separate modules seems promising, as does the high amount of control and the structured openness that is given to the child through the physicality of the system.

Content – More (types of) stories and exercises should be implemented to add to LinguaBytes’ adaptability. On-screen symbol systems will not be used, but included in the system in a physical form. The current style of visuals and audio is good.
Story module – The story module should provide better feedforward and feedback in its interaction: the link between a child’s action and the effect on the story should be clearer, both in terms of selecting a story and navigating through a story. The drawbacks of the textile sleeve should be solved.

Hide-and-seek module – The hide-and-seek module will be discontinued. The interaction and content provided too little variation, nor enough possibilities for improvisation.

Combination module – The combination module will be continued, capitalising on the advantages of its physicality and structured openness. As some children experienced slight problems with the horizontal characters and verb cards, this should be improved in the follow-up design.

6.6 Reflection on this cycle

In this chapter I have described how I have developed a first autonomous LinguaBytes prototype called KLEEd. As in the reflection on the previous Research-through-Design cycle, I believe that there are two capital lessons to be learned from this cycle. I describe these here.

Designing adaptivity through adaptability: determining the social role of LinguaBytes.

The most significant decision of this Research-through-Design cycle is the strategic one to start designing LinguaBytes as a highly adaptable system before making it adaptive. But I should emphasise here that I do not see adaptability and adaptivity as an either-or situation: LinguaBytes could and should be both, as both have their advantages. For example, adaptability will allow a caregiver more control over LinguaBytes than adaptivity. On the other hand, adaptive behaviour could make LinguaBytes less stigmatising, as children with cerebral palsy are already so dependant on adapted products. Unobtrusive, adaptive behaviour could give a child with cerebral palsy—or any child from the LinguaBytes target group—more sense of control and independence, which could benefit a child’s self-esteem.

However, designing adaptive behaviour is not trivial; it is not a matter of ‘when this happens, LinguaBytes should do that’ but requires a set of rules on which LinguaBytes can base its behaviour and a set of rules on which LinguaBytes can decide to change its behaviour. To establish these rule sets, it is necessary to determine LinguaBytes’ role in the language learning process. By this I do not only mean its functional role of providing stories and exercises, but also its social role in the triangle child-caregiver-LinguaBytes. Because if one thing has become clear through KLEEd’s evaluation, it is that LinguaBytes should not only take the needs of a child into account but also those of the child’s communication partner(s). This makes the design of LinguaBytes’ adaptive behaviour even more complex.

I strongly believe that guidelines for this adaptive behaviour can be determined through adaptability. Therefore, I will reflect on these guidelines in the upcoming Research-through-
The value of full-scale and fully functional models.

A second topic that I address here concerns the major difference between this Research-through-Design cycle and the previous one: the difference in the quality of the evaluated prototypes. Whereas I used preliminary cardboard sketch models in the previous cycle—which allowed me to draw equally preliminary conclusions—the revised design of KLEEd was of a higher level of reality, which consequently enabled me to draw more real conclusions. For example, making KLEEd out of textile not only clearly showed the disadvantages of this material, but also showed that these disadvantages weigh up to the benefits, e.g., the material’s friendliness or the other tactual sensation of textiles as opposed to that of plastics. One compelling argument against KLEEd’s material is that many children with cerebral palsy drool due to their medication. This is not a huge problem, but was considered too unpractical nonetheless. Not so much because KLEEd could not be cleaned—the electronics can be easily taken out of the textile sleeves—but more because KLEEd needs to be cleaned too frequently for comfort. Other arguments have been addressed in section 6.3.

But also the PictoCatcher, ObjectSlider and first KLEEd design yielded insightful design guidelines, despite the fact that they were not fully functional. The quality alone that they could be experienced made them invaluable physical tools for thinking, just like a pen and paper help you remember your shopping list. Realistic models thus do not only embody designs, they embody design rationales. The more detailed the model, the more legible the line of thought. Interactivity is an integral part of this: seeing test subjects interact with your ‘embodied line of thought’ help you identify flaws in your line of thought. It is my belief that, to be able to determine LinguaBytes’ social role as I have described above, LinguaBytes’ functional role should be as realistic as possible.
Chapter 7

Third Research-through-Design Cycle: Click-It

7.1 Determining a design strategy for this Research-through-Design cycle

In the previous chapter I have indicated that, in order for KLEEd to be better adaptable to individual children, the participating therapists needed more stories and exercises, as well as more control over these stories and exercises. In addition, I concluded that this expansion would improve my ability to determine the desired adaptive behaviour of the final LinguaBytes design. Therefore, creating more content was pivotal in this Research-through-Design cycle.

Typically, designing large systems—in this case a system of stories, exercises and interface modules—can be approached from two directions: top-down and bottom-up. In a top-down approach the topology of the system is defined first, after which the individual sub-elements are designed. In a bottom-up approach the sub-elements are designed first and form the basis of the system topology. In this Research-through-Design cycle my fellow researcher Riny Voort and I decided to follow a hybrid approach: she would develop the language content top-down, setting up the structure and dividing the content over stories and exercises, while I would simultaneously approach the interface bottom-up. In this approach the structure of the early language development process (described in Chapter 4) could provide clear learning goals for the interface design, while in turn the quest to design-for-diversity could enrich the language content. In this section I describe the interface design process, but will also highlight the key moments at which the two development processes significantly influenced each other.

7.2 Redesigning KLEEd

As a starting point for our system topology Riny Voort and I decided to focus on a single theme, ‘animals’. Apart from new, to be developed exercises the theme would build on the two-word exercise of the previous Research-through-Design cycle, and keep using the existing Tom And Tes story as the starting point. I therefore began the redesign process with the story module and the combination module. I describe the redesign of these modules here.
Redesign of the story module

In the previous section I have described the main drawbacks of KLEE’s story module: (1) children found moving the handle so pleasant that it disrupted the interaction; (2) the handle did not provide appropriate feedforward or feedback for young children; (3) the physical characters were difficult to place, and their effect difficult to understand, and; (4) the textile sleeves hampered the interaction.

The last drawback did not only apply to the story module but also to the other ones, although to a lesser extent to the combination module. Therefore I decided to replace the material with wood, which has a similar friendliness and warmth and is associated with high quality. In addition, wood can be better equipped against drooling.

Another decision was an obvious one: I decided to remove the handle from the design and to investigate alternative interfaces that would provide better feedforward and feedback, for example information about the length of a story, the current position in a story and how to move through a story. I discuss two designs here.

The first design was inspired by the loupe, an object that allows people an overview over information and access to detailed information in a simultaneous and tangible way. In this design a metaphoric loupe is placed on a slider and can be moved over a physical representation of a story. The design is shown in Figure 7.1. In the leftmost position the slider is directly over the first scene in the story-strip, at the farthest right over the final scene. As such a story can be read by moving the slider-loupe from left to right over the scenes, which corresponds with the Dutch reading direction. The length of the story is clearly visible in the number of scenes on the story-strip, and the position in the story is shown by the relative location of the slider-loupe.

The slider-loupe design however showed a few drawbacks. Firstly, the scenes on the story-strip were very small, due to: (1) the limited reach envelope of the children, as illustrated in Chapter 3, and; (2) the limited length of available sliders. As experts suggest that stories for children this young should be at least six scenes and preferably not exceed nine, this means that the scenes in the shortest story strip could not be wider than 4.3 centimetres, which is far too small, especially for the approximately 50% of these children who experience vision problems;

Secondly, to cover various levels of linguistic development it would be best to offer different story forms: (1) reactive stories, consisting of single visual scenes; (2) linear stories, consisting of multiple scenes in a fixed order, and; (3) branched stories, consisting of multiple scenes that can be read in different orders (Fontijn & Mendels, 2005). Especially the last type of story would be difficult to use in the slider-loupe design, because the slider has a fixed length whereas a branched story has not.

Therefore, I decided to pursue a different approach in a second design that would allow for using stories of different lengths without conceding clarity. In this design the story-strip
was enlarged to the size of a foldable booklet containing single-page scenes. To read the booklets I designed a new interface (see Figure 7.2), inspired by the Fisher Price View-Master. The booklets can be inserted in the right side of the interface, after which the child can use a sliding handle. This switches on an automatic booklet transportation system, which moves the story through the interface until a scene appears behind a viewing window in the centre of the module. At this point the transportation system automatically switches off, and the scene is shown in animated form on the output module. By offering interactive stories in this way, I envisioned a reintroduction of some of the richness of traditional book reading (see also Hengeveld, Hummels, Overbeeke, Voort, Van Balkom & De Moor., 2009):

- More than with the story-strips a child can see the length of the story in the dimension of the booklet;
- When the story booklet moves through the module the story is divided into three segments: one on the left of the module (past pages), the one behind the viewing window (the current page) and one on the right of the module (the remaining pages). This offers clear feedback and feedforward as well as valuable meta-information about story linearity and storyline causality;
- The story booklet can also be used without the module, i.e. as a regular picture book. As such it can be used in preparation for the interactive story or for assessing a

**Figure 7.1** Photoshop rendering of the slider-loupe design. A transparent slider is moved over a physical story strip showing the scenes from a story. Stopping the slider above a scene results in this scene being shown in animated form on the output module.
child’s understanding of the interactive story afterwards;

- Children can use the booklet as an alternative communication means: they can manipulate the booklet similar to a regular picture book and point out details to convey specific words.

To test the feasibility of this design I made 3D study models. Some of these studies are shown in Figure 7.3, left and middle. For example, I made variations of the story booklet and asked speech therapists to determine the most appropriate page size. Also, I tried out booklet transportation systems by making quick-and-dirty Meccano models and off-the-shelf DC motors. As the experimental models did not seem to reveal insurmountable problems I decided to pursue this design for the upcoming prototype.

Redesign of the combination module

KLEEd’s combination module was redesigned in wood similar to the story module. The design is shown in Figure 7.4, along with the modules that I describe on the following pages. The module contained three trays for creating three-word sentences. The rationale behind the trays has been described in Chapter 3, annotation [3]. Using lids, one or two of the trays can be closed to adapt the interface to children in the two- or one-word phase.
Redesign of the output module

The design of the output module was adjusted to the new wooden style as well (see Figure 7.4) and contained a larger, 17-inch screen instead of the previous 15-inch screen. A larger screen offers more space for the same amount of visual information, which should reduce visual clutter. There were no indications that suggested using an even larger screen.

To allow placing the output module in a horizontal position—to support usage on the floor or with two users facing each other—I included rubber knobs at its back side. For placing it in tilted positions, for example for usage on a tabletop, I made the formerly separate foldable stand an integral part of the new output module. For audio I included two integrated speakers in the module.

*Figure 7.4* Photoshop renderings of the redesigned KLEEd modules, which together form the new prototype ‘Click-It’. On the left the back and front view of the output module. On the right, from top to bottom: the earlier described story module, the combination module for three-word exercises and the phonology module, which all can be placed on the base module, shown in top and front view.
Designing additional modules

Parallel to these design activities, new content (i.e. stories and exercises) took shape. As the previous prototype KLEEd did not yet support exercises focused on phonology, these were given priority in this prototype. In total, five phonological exercises were developed: (1) listening to animal songs; (2) listening to animal rhymes; (3) identifying animal sounds; (4) finishing animal rhymes, helped with a visual clue; and (5) finishing animal rhymes without visual clues.

In addition, an alternative semantic exercise was developed—replacing the hide-and-seek exercise—aimed at improving a child’s vocabulary, as well as another syntactic exercise focused on ‘big’ and small’. I come back to these exercises when I describe the designs of the accompanying exercise modules later in this section.

To support these (and future) exercises I made several interface explorations in Photoshop (see Figure 7.5), often on a 1:1 scale, which allows for trying them out quick-and-dirty. The most prominent result of these explorations was the realisation that many modules used the same technology. This made me decide to split the story and exercise modules into separate parts: one part containing all reusable technology, which I called the ‘base module’, and several interface parts that can be attached to the base module (see Figure 7.6). I will describe the base module in detail shortly. I made full-scale cardboard volumetric studies of promising designs, to get more grip on experiential issues such as comfort, usability or mechanical requirements. Some of these volumetric studies were already shown in Figure 7.3, right.

Figure 7.5 Photoshop explorations of alternative functionalities of the loupe-slider module, of new modules or combinations of modules.
Base module. Based on current and expected future exercises, I estimated that the base module would need: (1) three RFID-readers for supporting three-word sentences; (2) a speaker for providing sound with phonological exercises, and; (3) a mechanism for connecting the story and exercise modules. Based on the dimensions of these components I reduced the base module’s size to the bare minimum (see also Chapter 3, annotation [18]) to improve manoeuvrability. I included suction pads in the module’s bottom to prevent it from slipping away. The base module is shown in Figure 7.4, bottom right.

Phonology module. I designed a new module for phonological exercises. This interface (see Figure 7.4) contains a tray like the ones in the redesigned combination interface. The tray contains a cylindrical hole that fits around the base module’s speaker. The interaction with this module is be similar to that with the combination module: children can place input materials in the tray to trigger sounds, rhymes, songs or other audio that stimulates phonological awareness.

The five modules together—story module, output module, base module, combination module and phonology module—form the basis for this Research-through-Design cycle’s final prototype, ‘Click-It’ (Hengeveld, Hummels, Overbeeke, Voort, Van Balkom & De Moor, 2008b). In the next section I describe the prototype in detail.

7.3 The Click-It prototype

Structure of the prototype
The structure of Click-It is comparable to that of KLEEd: there is a module for output and several modules for input. The major difference is in the added base module, which is used across all stories and exercises. This makes that Click-It consists of: (1) two modules that are used across all applications: the output module and the new base module; (2) interface modules that support reading interactive stories and doing exercises; (3) input materials that are used in combination with the interface modules.
To use Click-It, the former two modules always need to be connected to each other, after which any of the interface modules can be placed on top of the base module. Depending on the story or exercise, input materials can be placed on, or inserted in the interface modules. I describe all elements of the prototype here.

Output module
As the output module could not be manufactured in time for the prototype’s evaluation I had to use a regular 17” TFT monitor.

Base module
As described in the previous section, the base module (Figure 7.7) contains the technology that is used across applications. The prototyped version contains three RFID-readers for identifying input materials. Additionally, two magnets are integrated in the far corners of the base module to position and hold interface modules. An earlier version held four magnets, one in each corner, but I came to realise that it would be smarter to use two to prevent interface modules from being placed the wrong way around (with the far side facing you). I use magnets instead of a mechanical connection to prevent parts from breaking off. At the bottom side of the base module are four suction pads, one on each corner, to fix the base module in the most suitable position for each child, and to prevent it from sliding away. The base module is made of ash wood, as are all the other modules that I will describe in this section. The topside is closed with a white plastic cover.

Story module
Although a design often slightly changes during the prototyping process, the prototyped version of the story module is largely similar to the design I have described in the previous section. The story module (Figure 7.8, left) consists of a wooden shell, housing a booklet transport system incorporating a track, a DC motor and a light sensor. I describe these elements in a minute. The bottom side of the story module is closed with a white plastic cover.

Figure 7.7 The base module contains 3 RFID-readers and is made of wood with a plastic cover (left). It has four suction pads at the bottom to fix it to a work surface (right).

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The story module is used in combination with a story booklet. One story was developed, entitled ‘Tom and Tes visit the children’s farm’. In this story Tom and Tes encounter various animals and try to determine which animal eats what. The story booklet is a laminated strip folded like an organ book, and contains pictures from all the story’s scenes. The booklet can be read like a normal picture book as well as in combination with the story module. In the former case a caregiver reads the story to the child, in the latter case the story is shown on the output module accompanied by the audio of a narrator. To access the interactive story the story booklet must be inserted in the module (Figure 7.8, middle), through a slot in the right side. The booklet can be moved through the module by using the handle located in the border of the module’s viewing window. The handle is mounted on two slide resistors. Moving the handle from right to left switches on booklet transportation system, which automatically guides the booklet through a track in the corresponding direction. Two springs connected to the slide resistors move the handle back into its starting position at the rightmost position. When a scene is located behind the viewing window, the light sensor detects a black ‘stop marker’ on the back of the page (Figure 7.8, right) and automatically switches off the transportation system. The scene is then shown in animated form on the output module. Moving the handle again moves the story the next scene, etcetera.

**Combination module**

The combination module (Figure 7.9) consists of a wooden panel containing three trays of white plastic. Two trays can be closed with a lid to support one, two or three input materials simultaneously, e.g., for one-word, two-word or three-word sentences. The module holds no electronics but uses those of the base module.
Input materials

For making sentences in the selected theme ‘animals’ I designed various input materials, resembling those from KLEEd.

Animal figures – Firstly, I designed miniature representations of nine farm animals (Figure 7.10, left). We decided to only use farm animals and to add zoo animals at a later moment. Contrary to the figures used in KLEEd, the animals were placed in a vertical position to make them easier to grab. The animal figures are made of 4-millimeter painted MDF and mounted on a circular white stand. All figures are tagged with RFID. The pieces have a drawn animal on their front side and a rear view of the animal on their reverse side. I included smaller versions of the cow, horse, sheep, pig and dog for a ‘big-small’ exercise. The largest animal figure in the set was 10 centimetres high, and the smallest 4 centimetres. These measurements were fit to correspond with regulations set by Dutch law (e.g., NEN-EN 71, which is aimed at preventing children from choking).

Word cards – Secondly, I designed word cards, depicting 30 core words. The cards (Figure 7.10, middle), measuring 70 x 70 millimetres, include the written core word and a drawing of the word in the same graphic style as the animations. All cards are RFID-tagged.

To build a sentence a child can place an animal figure in the left tray of the combination module and combine it with a verb card in the middle tray. For example, a cow and the verb ‘eating’ results in an animated walking cow on the output module, accompanied by audio saying ‘the cow eats’. In the right tray a third word can be placed, for example the card representing grass. This makes the sentence ‘the cow eats grass’. Only the figures of the cow, the duck and the sheep could be used in this exercise. It would have been highly time consuming to program the exercise so that all animals would be supported. We considered it too much work for this stage in the development of LinguaBytes. For the same reason the exercise only used two verbs: eating and walking.

Phonology module

In addition to the two redesigned interface modules—the story module and the combination module—a new interface module was developed to support phonological
exercises. This ‘phonology module’ (see Figure 7.11, left) was based on the design shown earlier in Figure 7.4, with the difference that it itself included a small speaker (Figure 7.11, middle) instead of the speaker being incorporated in the base module, as in the original design. Moving the speaker into the phonology module could make the child more aware of the importance of sound in phonology.

To do phonological exercises a child uses the nine animal figures described earlier. For example, a child can listen to animal songs. Placing an animal, e.g., a cow, starts a song about a cow; removing the cow immediately stops the song. The song is shown in animation on the output module. The caregiver can choose to play a song over the phonology module’s integrated speaker, or over the speakers of the output module.

Puzzle module
Finally, as a replacement for KLEE’s hide-and-seek module, I designed a fourth interface module to stimulate the child’s vocabulary: the ‘puzzle module’. The exercise stimulates children’s vocabulary by showing them four different animals (a cow, horse, sheep and goat) and highlighting four parts of these animals: their head, body, tail and legs.

To do this exercise I designed four animal puzzles (Figure 7.12, left) and a puzzle module. The puzzles can be placed in a placeholder containing four pressure sensors (Figure 7.11).
7.12, right) positioned below the four animal parts. The puzzles are tagged with RFID for identification by the base module. The exercise can be done in two modes: explorative and assignment-based. In the former mode a child can press any of the puzzle pieces, which triggers animations of the corresponding body parts on the output module. For example, if the sheep-puzzle is being used and the child presses the sheep’s head, the corresponding sheep on the output module starts moving its head, says ‘this is my head’ and starts to bleat. In the other, assignment-based mode the same sheep asks the child to identify a specific body part, e.g., the tail, by asking ‘where is my tail?’ The child should then press the puzzle piece of its choice to answer the question. A correct answer results in the animal moving the correct body part, a wrong answer leads to an auditory encouragement to give it another try.

Software
The story and exercises were all made in Macromedia Flash and MAX/MSP. The software ran on a separate Apple MacBook Pro laptop, connected to the prototype via USB.

7.4 Evaluation of Click-It

Setup and participants
The Click-It prototype was evaluated with twelve children at two child rehabilitation centres in the Netherlands, in a similar set-up as the previous Research-through-Design cycles, as described in Chapter 5.3. Ten boys and two girls participated in the evaluation of Click-It, with calendar ages between 2 years 1 month and 3 years 10 months. Their developmental ages ranged between 1 year 2 months and 3 years 6 months. The children had various disabilities. An overview of the participating children is given in Table 7.1.

Ten out of twelve children had disabilities in their fine and/or gross motor skills. Two children had no motor disability. Eleven out of twelve children were able to manipulate small objects. Eleven out of twelve children had delays in their language development. With the exception of one child, all children could point at objects or make eye contact.
Five children used the prototype in two of their 30-minute speech therapy sessions separated by a week, four children in two 25-minute speech therapy sessions separated by a week, and three children in one of their 25-minute speech therapy sessions. The only instruction to the participating therapists was to always start with the story. They were free to try out the exercises in any order as long as we could evaluate all of them. In other words, the therapists could distribute the exercises over the group of participating children. All sessions were recorded on video. At the end of the test period we asked the speech therapists to fill out a questionnaire.

**Findings**

In this section I present the most significant findings. I start by evaluating the individual modules, after which I outline the feedback of the participating therapists.

**Output module** – As the output module was not finished in time for the planned evaluation we used a standard 17” TFT display. The output module will be evaluated in the next Research-through-Design cycle.

**Base module** – The base module worked well. Only the integrated magnets seemed to be slightly too weak, as the children could push off the interface modules.

**Story module** – The story module experienced technical malfunctions. Most prominently, the sliding handle jammed due the connection of the handle to the two slide resistors, which was insufficiently rigid. As a result, the two sliders did not slide perfectly parallel which made the handle skew and jam. Due to these difficulties we were only able to test the story module (Figure 7.13, left) with three children. However, despite the small test group, flaws in the design could be clearly observed. Firstly, inserting booklets in the

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**Table 7.1 Overview of characteristics of the test subjects.**

<table>
<thead>
<tr>
<th>Child</th>
<th>Sex</th>
<th>Location*</th>
<th>CAb</th>
<th>DAc</th>
<th>Diagnosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>M</td>
<td>1</td>
<td>2.03</td>
<td>0:10 - 0:12 at CA 1:07</td>
<td>Psychomotor retardation</td>
</tr>
<tr>
<td>2</td>
<td>M</td>
<td>1</td>
<td>3.05</td>
<td>1:05 at CA 2:03</td>
<td>Cerebral palsy, spastic diplegia</td>
</tr>
<tr>
<td>3</td>
<td>M</td>
<td>1</td>
<td>2.05</td>
<td>0:10 at CA 1:07</td>
<td>Motor retardation</td>
</tr>
<tr>
<td>4</td>
<td>M</td>
<td>1</td>
<td>3.10</td>
<td>2:07 - 3:04 at CA 3:04</td>
<td>Cerebral palsy, spastic tetraplegia</td>
</tr>
<tr>
<td>5</td>
<td>F</td>
<td>1</td>
<td>3.09</td>
<td>2:04 at CA 3:01</td>
<td>Hydrocephalus</td>
</tr>
<tr>
<td>6</td>
<td>M</td>
<td>1</td>
<td>2.06</td>
<td>1:00 at CA 1:09</td>
<td>Spina bifida L1</td>
</tr>
<tr>
<td>7</td>
<td>M</td>
<td>1</td>
<td>2.01</td>
<td>1:03 at CA 1:04</td>
<td>Spina bifida L4</td>
</tr>
<tr>
<td>8</td>
<td>M</td>
<td>2</td>
<td>3.08</td>
<td>Not available</td>
<td>Cerebral palsy, dyskinetic dystonic tetraparesis</td>
</tr>
<tr>
<td>9</td>
<td>M</td>
<td>2</td>
<td>3.06</td>
<td>3:06 at CA 3:06</td>
<td>Eating disorder</td>
</tr>
<tr>
<td>10</td>
<td>M</td>
<td>2</td>
<td>3.01</td>
<td>N.A.</td>
<td>Psychomotor retardation</td>
</tr>
<tr>
<td>11</td>
<td>M</td>
<td>2</td>
<td>2:11</td>
<td>2:09 at CA 2:11</td>
<td>Cerebral palsy, dyskinetic quadriplegia</td>
</tr>
<tr>
<td>12</td>
<td>F</td>
<td>2</td>
<td>2.07</td>
<td>1:00 at CA 1:11</td>
<td>Psychomotor retardation</td>
</tr>
</tbody>
</table>

*Notes. *Location 1: St. Maartenskliniek Nijmegen, Location 2: Rijndam Revalidatiecentrum Rotterdam. †CA: calendar age (years and months). ‡DA: developmental age (years and months) at CA.
The story module was too difficult. The slot in the side of the module was ill-placed and did not communicate its function well enough. Additionally, the booklet transportation system was unreliable: the track was too fragile causing the booklet to jam, and the axle transporting the booklet slipped. This was clearly confusing and demotivating for the participating children. Thirdly, a conceptual flaw emerged: although children could move the booklet from right to left by moving the handle accordingly, they could not go to previous scenes by sliding the handle back to its starting position. Finally, the handle often jammed above the viewing window, which obscured the child’s view on the scene behind it.

On the positive side the children seemed intrigued by the module, booklet and interaction. Also, the dimensions of the module and story booklet seemed appropriate.

**Combination module.** The combination module functioned well: the interaction was immediately clear to all children and the trays seemed to provide clearer feedforward than the input areas of KLEEd’s combination module. Some children did not understand that they were supposed to place subject, verb and object in a specific order. This had to do with the following: when children start using two-word sentences they typically use the order verb-subject—e.g., ‘sleep daddy’, meaning ‘daddy sleeps’—as opposed to
the regular subject-verb order. Consequently, this means that in future versions of this exercise, children should be allowed to place words in the order corresponding with their development (i.e., in the ‘wrong’ order as well). This is a phase children should go through towards the proper word order.

Some flaws could be observed in the design of the input materials used in combination with this module: (1) they were too light and not sturdy enough. Some animals were actually dislodged from their base during interaction. Especially the larger animal pieces needed quick repairs, sometimes during a session; (2) the word cards were confusing. For example, the card representing the verb ‘to eat’ showed the LinguaBytes cow eating grass (see Figure 7.14). Some children found this highly confusing when making sentences; they did not understand why the sentence ‘the cow eats grass’ required them to place a cow, a card of an eating cow and a card showing grass when one single card already displayed the entire sentence. Additionally, having to use the ‘grass-eating cow’ card to make the sentence ‘the duck eats bread’ was also considered confusing. It should be noted that only five out of twelve children used the LinguaBytes word cards. Generally, the speech therapists preferred using the PCSs that the children had already learned and did not feel the need for yet another symbol system.

The combination module was also used for the new big-small exercise, which was a big success with all children. They especially liked seeing animals shrink and grow within seconds. One of the participating girls however was sad that there was no smaller version of her favourite animal: the cat. Therefore I made an additional input figure of a kitten before returning for the girl’s second session.

**Phonology module.** Children found the phonological exercises very appealing. They preferred listening to songs and animal sounds. Children especially liked placing as many animals as possible, as fast as possible. This would result in an, in their opinion, hilarious cacophony of song snippets, barks, bleats and clucks. We considered this a strong indication that children enjoyed the control they had over the interaction, which was confirmed by the therapists.

Generally, the design of the phonology module seemed satisfactory apart from two flaws: (1) occasionally animals were placed with the base outside the tray, as shown in the left image in Figure 7.15. In this situation the animal’s RFID-tag could not be read, which, although it could be argued that the animal was placed within the tray, did not trigger a system reaction. This occurred most often with children with more severe motor disabilities. The low weight of the input figures seemed to be the problem, causing them to easily fall over. Ironically, it was a deliberate design decision to make the input figures as lightweight as possible to reduce the physical strain for the more severely motor disabled children; (2) some of the children placed animal figures on top of the speaker, rather than in the tray. It appeared that this was due to the form resemblance of the figures’ circular bases and the
cylindrical speaker (Figure 7.15, right). Placing a figure on top of the speaker often did not trigger a system response, or resulted in muted audio.

**Puzzle module.** Generally, children liked using the puzzle module and watching the animated animals. Most children could use the puzzle module well, although some flaws surfaced: (1) the puzzles easily slid out of the placeholder. Children often used their whole arm to add weight to their pressing finger. This would result pressing direction away from the body, rather than in a vertical direction towards the puzzle. This problem can be easily solved, for example by re-designing the placeholder or by fastening the puzzle to the module using any of the techniques that surfaced at the brainstorm described in the previous chapter; (2) the puzzle's RFID-tags were not well positioned. As a result the puzzles were often not identified by the RFID-readers, and; (3) the puzzles were fragile, parts could easily break off.

**Additional comments from the participating speech therapists**

**General impression.** All four speech therapists were positive about the Click-It prototype. Moreover, all had the impression that Click-It stimulated the child's communication: children were challenged to imitate, take initiatives, indicate and point, make eye contact, use or practice sign language or verbal utterances. All therapists had the impression that the content and interaction appealed to all twelve children. Using physical materials to control digital content was considered to be highly beneficial over using traditional PC controls. The most prominent reason for this was that Click-It’s input figures offer a less abstract form of interaction with a computer, and provide children with opportunities for active manipulation.

**Design.** Two out of four speech therapists indicated that the input figures should be sturdier, bigger, heavier and suitable for multiple usages. The use of colour, animations, visual style and audio were unanimously considered good. One remark was that the narrator should speak slightly slower. None of the speech therapists were interested in using the new word cards. All preferred to use the well-established PCSs and did not want to
invest in another symbol system first. Some speech therapists asked if it would be possible to have the system respond to wrongly placed materials as well (see Figure 7.15), for example by making the trays slightly larger. This is however not possible: the dimensions of the current trays are based on the sensing range of the RFID-readers. Making the trays larger would not result in a larger sensing range.

There are two possible solutions: (1) using larger, stronger tags; (2) making it easier to place the input materials in an upright position.

*Interaction.* All four speech therapists were enthusiastic about the physical interaction, with the remark that the input materials should be sturdier and heavier. With regard to the story module one therapist proposed using the concept of page turning in the interface design, as an introduction to actual book reading. All therapists were very positive about the adjustable sensitivity of the puzzle module. Some therapists suggested making the combination module extendable to four-word or even five-word sentences. They did not indicate if this included articles (in Dutch there are three articles: ‘de’, ‘het’ and ‘een’). However, as two-word and three-word sentences have already shown to be successful, we decided to focus on optimising other exercises first and investigate multiple-word exercises later.

A final remark was that Click-It could take initiatives once in a while to keep a child’s attention, for example when a child has not responded in a while. Click-It could say encouraging things like ‘why don’t you try another animal’ or ‘shall we do something else’ or simply repeat the last sound.

*Control.* The speech therapists were looking forward to having more control over the content and settings of Click-It. We discussed including a ‘control module’ in the system, to which the speech therapists responded unanimously enthusiastic. As design guidelines they indicated that this module should offer only a limited set of options so that no time is wasted during therapy. They indicated the following functions: (1) choosing a theme; (2) choosing the order of stories and exercises within a theme; (3) controlling the timing and volume of auditory feedback; (4) making custom input materials, and; (5) reviewing results per child afterwards.

In addition to a control module the speech therapists indicated that they would need an overview of all available core words, and of the stories and exercises in which these are used. Finally we discussed the possibility of Click-It becoming adaptive and growing along with the child, which was highly appreciated. The only condition was that the therapists wanted to be able to overrule the system at all times.

### 7.5 Conclusions for the next prototype

Here I briefly summarise the conclusions of this Research-through-Design cycle.

*Interaction* – Click-It could take initiatives once in a while to keep a child’s attention.
Output module – The output module will be evaluated in the next prototype.
Base module – The connection of the interface modules to the base module should be made stronger.
Story module – The story module needs thorough re-designing to solve the mechanical malfunctions of the booklet transportation system and handle. Inserting a booklet should be made easier, and the children should be allowed to move the booklets backwards, too. The dimensions of the module and story booklet seemed appropriate. We could investigate using the concept of page turning in the interface design.
Combination module – The three-word exercise should support ‘wrong’ word orders, as a preparation for correct orders. We could investigate extending the module to supporting four-word or even five-word sentences.
Input materials – The input figures should be sturdier, bigger, heavier and suitable for multiple usages. There is no interest in using the new word cards.
Phonology module – The false affordance of the speaker should be solved.
Puzzle module – The puzzle placeholder should be re-designed to avoid the puzzles being pushed out. Also, the puzzles themselves should be made stronger. The RFID-tags need to be moved to a position where they can be easily detected by the base module’s RFID-readers.
Control – A ‘control module’ should allow speech therapists more control over the content and settings of Click-It, by supporting:
• Choosing a theme;
• Choosing the order of stories and exercises within a theme;
• Controlling the timing and volume of auditory feedback;
• Making custom input materials;
• Reviewing results per child afterwards.

7.6 Reflection on this cycle

In this third Research-through-Design cycle numerous design decisions were made with a recognisable influence on the final LinguaBytes design. Although these encompass many aesthetic changes, other decisions have a far more fundamental impact. In this section I discuss the following topics: (1) exploring colour coding in the Click-It design; (2) opportunities for adaptivity in Click-It, and; (3) using affordances as a tool for research.

Exploring colour coding in the Click-It design
The first topic I wish to discuss here is the use of colour in Click-It. While I was designing Click-It I elaborately investigated using colour coding, an idea that originated from KLEEEd’s combination module: there, the wooden subject figures were to be placed on the wooden input area and the green verb cards on the corresponding green area. This seemed
to work well for the two-word sentences consisting only of a subject and a verb.

However, in the Click-It prototype we supported three-word sentences and although it might seem straightforward to simply add another input location to the module, it is not as easy. Three-word sentences come in many forms, for example ones that would not include a verb but an article and an adjective, e.g., ‘a blue sweater’. This would already make it impossible to use KLEEd’s colour coding where a verb was green and was to be placed in the middle on the green area.

Additionally, while Riny Voort’s study of the necessary exercises took form, it became apparent that this prototype would support many more games and exercises than the previous one. Where KLEEd supported only two exercises, Click-It would support eight different exercises, within a framework that predicted a possible 20-25 types. A quick design exploration showed that using colour coding in one exercise would lead to ambiguity in other exercises. This again ruled against using colours in the interface layers. At that point I started considering trays that could change colour using strong LEDs. However, experimental tests showed that the fluorescent lighting that is often used in speech therapy rooms severely diminishes the discernability of the tray’s colour. Considering that many children with cerebral palsy have vision problem and need high visual contrasts, this design direction was dropped.

Another issue that made colour coding more complex was that it was anticipated that the number of input figures was going to be profound: possibly a few hundred pieces altogether, categorised in semantic themes such as Click-It’s ‘animal’ theme. To keep such a large quantity of input materials usable—finding a single piece among hundreds of similar ones—I decided to give each theme its own colour. That would make it easier to collect available materials, not to mention quicker, which would benefit the flow of the interaction. Of course, this colour coding would be thematic, and have nothing to do with syntax.

All these arguments made me decide to abandon the colour coding system of KLEEd’s combination exercise. The future input materials themselves would provide sufficient colour to appeal to children, which would allow me to keep the interface modules neutral without becoming boring. Moreover, keeping the modules more neutral would allow me to give each group of prototype elements (i.e. input and output modules, input materials, possible future additions) their own binding form quality. This would certainly benefit the overall aesthetics. Therefore I decided to make all modules of wood, with white plastic accents. The wood represented the warmth of the physical world whereas the plastic accents represented links to the technological, virtual world. In Click-It I use plastic wherever modules connect or interaction possibilities are. That is why the top of the base module and the bottom of the interface modules are made of white plastic; the same goes for the trays and the bases of the input materials.
Opportunities for adaptivity in Click-It

In the previous chapter I argued that I would try to determine opportunities for adaptivity in LinguaBytes via the route of adaptability, which has steered many design decisions in this Research-through-Design cycle. For example, the number of exercises has been increased, as has the number of input materials and modules. The concept of modular resolution that I have introduced in this section is a direct consequence of this. The increased adaptability of Click-It has already shown several opportunities for adaptivity, which I describe in the remainder of this section.

Firstly, while designing Click-It’s base module I made an inventory of the reusable technologies it should contain. Knowing that in the future LinguaBytes should be able to adapt to individual users, it seemed likely that these users should somehow be identifiable. With an eye on the future I therefore included two detection systems in the base module, which could adapt Click-It’s setup to the needs and preferences of individual children. One system would detect which interface module was placed on the base module; the other one would identify the child who was using the prototype. Together they could make Click-It automatically load the stories and exercises that are best tuned to the child’s developmental level. Also, they could make it possible to keep track of a child’s development and feed this back to the therapist. These systems were not functional at the time of the evaluation, but I included a slot in the base module in which an identification tag of the child could be inserted (see Figure 7.16). This tag could be kept in the log book speech therapists keep of all children.

Secondly, I have mentioned in 7.3 that the puzzle module uses pressure sensors. The reason why this module uses pressure sensors instead of switches stems from my observations from the first Research-through-Design cycle, most prominently those of the child with motor disabilities. It could be seen that when he pointed at something, for

![Figure 7.16](image)

Figure 7.16 The base module included a (non-functioning) user identification system, consisting of identification tags that could be inserted in a slot in the side of the module. This identification system could help Click-It automatically adjust its settings to the needs, skills and preferences of individual children.
example at one of the PCSs in 3D sketch variant 2, he would put down his entire hand for support. This would mean that, if he would be asked to press the sheep’s head he would probably place his hand on the sheep’s legs and body too, pressing the wrong body parts by accident. Had I used switches, this would have resulted in ‘a detected wrong answer’. Pressure sensors however, allowed me to create lenient ‘pressure profiles’ that take the type of child and the requested body part into account. For example, if the animal asks ‘where is my head?’ the sensitivity of the four sensors are set in the ‘head profile’ (see Figure 7.17, top left), in which the ‘head sensor’ is the most sensitive, the ‘body’ and ‘tail’ sensors are less sensitive, and the ‘legs sensor’ are almost switched off. This will allow children with motor disabilities to place their hand on the puzzle and press the head without accidentally giving a wrong answer.

In this prototype I programmed two default profiles: one for children with motor disabilities, and one for children with normal motor skills. In this profile each pressure sensor is equally sensitive, independent of the requested animal body part, as opposed to the ‘children-with-motor-disabilities-profile’ in which the sensitivity changes with each assignment.

The pressure sensors proved to be a good design decision. One child in particular
pressed almost all of the puzzle pieces at once during his journey to the intended animal part. The two default pressure profiles however needed tweaking with each individual child. During the user tests I could do this by hand: I would observe the children’s behaviour and monitor incoming sensor values in MAX/MSP, especially the peak values. When I would observe the threshold value of the ‘correct’ sensor to be too high for a child’s maximum force, I manually lowered it.

In the future this could also be done automatically: Click-It could learn the personal sensor profile for each child by monitoring the peak values per sensor, and adjust its threshold values accordingly. This could even be done during different types of therapy, for example during occupational therapy where a child’s fine motor skills are trained. In the context of occupational therapy children could do exactly the same exercise, but with a different goal: pressing the proper animal part only, without leaning on other parts. In this situation all sensors should be equally sensitive.

This brings me to the third opportunity for adaptive behaviour: adding context-awareness to Click-It. In future designs Click-It could be made aware of the context in which it is being used—for example, the context of speech therapy, occupational therapy, or simply the home environment—and adjust its settings to these contexts. For example, in the home environment Click-It could be set to offer only explorative, playful exercises. In this situation Click-It could keep track of the most-exercised applications, which might be an indication of a child’s interests. This information could then be used in, for example, the speech therapy context, by automatically pre-selecting these exercises as suggestions for a therapy session.

These examples are not the only ones, but already show that the opportunities to make Click-It adaptive are rich, but also complex. In the next Research-through-Design cycle I therefore abstain from implementing them but will instead invest more time in investigating the optimal modular resolution of Click-It.

Using affordances as a tool for research
As illustrated in Figure 7.15, it appeared that the design of the phonology module triggered an unforeseen behaviour in the children: they were inclined to place animals on top of the speaker, due to their relation in form. This brings me to a property of affordances useful for design researchers.

I have described the concept of affordances in Chapter 2, including how Donald Norman introduced them into the world of design. A few years after Norman Bill Gaver proposed to divide affordances into three categories: perceptible, hidden, and false (Gaver, 1991). Perceptible affordances are action possibilities that are perceived and acted upon conform the designer’s intentions, hidden affordances are action possibilities that are designed but not perceived (and thus not acted upon), and false affordances are apparent
action possibilities that do something else. Gaver also introduces sequential and nested affordances, which respectively are affordances that open up new affordances, or affordances that are perceived as part of other affordances. According to Gaver, the role of a good interface—and thereby the role of the interaction designer—is to ‘guide attention via well-designed groups of sequential and nested affordances’ (Gaver, 1991). The phonology module’s speaker problem described above is a clear example of a false affordance.

Of course, designers do not sit down and decide to design three types of affordances. Moreover, as stated in section 2.3 of this thesis it is arguable that, since affordances are not part of the environment—they are the result of the relation between man and environment—and products are, affordances in Gibsonian terms cannot be designed (Frens, 2006). However, it is my experience that Gaver’s three types of affordances can help explain why some aspects of a design ‘work’ and some don’t. Generally, hidden and false affordances are the ones a designer wants to avoid but always turn out to be there—these affordances are the result of the designer’s wrongly anticipated relation between the designed action possibilities and the properties of the user. These are the affordances that can help designers identify guidelines for improvements. Hidden and false affordances can be easily recognised during a user test:

- Hidden affordances are action possibilities that were deliberately designed and have your full attention while testing. Typically you can easily observe users not recognising these affordances: they simply don’t act upon them;
- False affordances are usually identifiable through a shared confusion with the participant: he or she doesn’t understand why their action doesn’t trigger anything and you as a designer do not understand what the user is trying to achieve by doing something that you know doesn’t trigger anything.

In short, Gaver’s three types of affordances can help identify flaws in your design rationale and are as such very valuable designerly tools for research.
Chapter 8

Fourth Research-through-Design Cycle: Click-It 2.0

8.1 Design refinements

Contrary to the three previous Research-through-Design cycles, which were marked by big design changes, this cycle is one of refinement. In this section I describe the changes that were made to the Click-It prototype, which have led to its successor: Click-It 2.0.

Content: stories and exercises

The first Click-It prototype supported one interactive story and eight exercises, some more explorative, others assignment-based. In this Research-through-Design cycle we aimed at offering all possible stories and exercises within the theme ‘animals’. This would require an additional story and a set of fourteen exercises, of which some should be offered both in explorative and assignment-based forms. In addition to the existing farm animals, zoo animals were added to the theme. Consequently, because it was considered best to keep these two groups of animals semantically separated, many of the fourteen exercises would be offered ‘double’. An overview of all exercises is given in Tables 8.1, 8.2 and 8.3 on the next pages.

A new story was written for the sub-theme ‘zoo-animals’, called ‘Tom and Tes visit the Zoo’. In this story Tom and Tes encounter various, for Dutch standards exotic, animals. As opposed to the existing linear story this story was developed as a branched story: it has a fixed opening and end scene and, between these scenes, several three-scene sequences. These can be read in any order, contrary to the farm animals story, which has a fixed scene order. The branched story booklet looks exactly like the ones in the final prototype (see Figure 1.2 and 1.14). Based on our findings with the earlier linear story we anticipate that branched stories can benefit caregiver-child communication in several ways: (1) because children can determine the sequence of the story a branched story creates more choice moments. Consequently, this creates pauses in the interaction and thus more opportunities for caregiver-child communication; (2) children have more control over the story and are therefore more involved and more concentrated; (3) using branched stories opens up the possibility of stimulating an additional linguistic skill: the order of causally related scenes.
### Table 8.1 Phonological exercises in Click-It

<table>
<thead>
<tr>
<th>Level</th>
<th>Exercise name</th>
<th>Theme</th>
<th>Mode</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Animal songs</td>
<td>F + Z</td>
<td>E</td>
<td>Placing an animal in the phonology module’s tray triggers a corresponding animal song and accompanying animation.</td>
</tr>
<tr>
<td></td>
<td>Animal rhymes</td>
<td>F + Z</td>
<td>E</td>
<td>Placing an animal in the phonology module’s tray triggers a corresponding animal rhyme and accompanying animation.</td>
</tr>
<tr>
<td>2</td>
<td>Animal sounds</td>
<td>F</td>
<td>E + A</td>
<td>In explorative mode, placing an animal in the phonology module’s tray triggers a corresponding animal sound and accompanying animation; in assignment-based mode the child hears an animal sound and has to place the corresponding animal to reveal the animation.</td>
</tr>
<tr>
<td>3</td>
<td>Finishing animal rhymes with visual help</td>
<td>F + Z</td>
<td>E + A</td>
<td>In explorative mode, placing an animal in the phonology module’s tray triggers a corresponding animal rhyme and accompanying animation; in assignment-based mode the child hears an animal rhyme and has to place the animal that makes up the last rhyming word, for example: Ow, ow, ow, in the grass walks a [cow]. To help the child the contour of the animal is shown on-screen. Placing the correct animal reveal it on-screen.</td>
</tr>
<tr>
<td>4</td>
<td>Finishing animal rhymes without visual help</td>
<td>F + Z</td>
<td>E + A</td>
<td>Same as previous, but without the visual help in assignment-based mode.</td>
</tr>
<tr>
<td></td>
<td>Coupling sounds with letters</td>
<td>F</td>
<td>E + A</td>
<td>In explorative mode, placing a letter in the phonology module’s tray triggers the animation of an animal beginning with that letter, plus audio emphasising the sound of the letter; in assignment-based mode the child hears the audio and sees the animal and has to place the correct letter. This triggers the animation.</td>
</tr>
<tr>
<td></td>
<td>Auditory discrimination</td>
<td>F</td>
<td>E + A</td>
<td>In explorative mode, placing an animal triggers an animation of that animal, along with Tom and Tes pronouncing the animal’s name. One of the two says the name correct, the other incorrect; in assignment-based mode an animal is shown, along with Tom and Tes pronouncing its name. The child has to place the figure of the person who said it correctly.</td>
</tr>
</tbody>
</table>

**Notes.**  
1. Level of difficulty: level 1 is for children with a developmental age between 1 and 1.5 years old, level 2 for children between 1.5 and 2, level 3 for children between 2 and 2.5, and level 4 for children between 2.5 and 4.  
2. The theme in which an exercise is available. F: farm animals theme; Z: zoo animals theme.  
### Table 8.2 Semantic exercises in Click-It

<table>
<thead>
<tr>
<th>Level</th>
<th>Exercise name</th>
<th>Theme</th>
<th>Mode</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Guessing game</td>
<td>F</td>
<td>E</td>
<td>By pressing an animal-shaped figure in the puzzle module one of a possible four animals is slowly revealed in parts.</td>
</tr>
<tr>
<td></td>
<td>Peek-a-boo</td>
<td>F</td>
<td>E + A</td>
<td>In explorative mode, the child can place an animal figure in the combination module’s middle tray, triggering an animation of that animal being unveiled; in assignment-based mode, the veiled animal is shown on-screen and its sound is played. The child has to place the correct animal to reveal it.</td>
</tr>
<tr>
<td>2</td>
<td>Animals in context</td>
<td>F</td>
<td>E + A</td>
<td>In explorative mode, the child can place three different animal figures in the combination module’s trays, triggering their animated versions on-screen at corresponding locations; in assignment-based mode, the child is asked to place three animals. Placing the correct animal triggers its animation on-screen.</td>
</tr>
<tr>
<td>3</td>
<td>Vocabulary puzzle</td>
<td>F + Z</td>
<td>E + A</td>
<td>In explorative mode a child can press four different parts of an animal on a four-piece puzzle to animate them on-screen; in assignment-based mode the child is asked to press one of these body parts. Pressing the correct one triggers its animation.</td>
</tr>
<tr>
<td>4</td>
<td>Relational classifications</td>
<td>F + Z</td>
<td>A</td>
<td>The child should place three animals in their appropriate context, i.e., zoo animals in the zoo and farm animals on the farm, by placing them in the three trays of the combination module.</td>
</tr>
<tr>
<td></td>
<td>Word associations</td>
<td>F + Z</td>
<td>E + A</td>
<td>In explorative mode a child can place an animal in the combination module’s middle tray. As a result the associated fur of the animal is shown, or its sleeping place. In assignment-based this is the other way around.</td>
</tr>
</tbody>
</table>

### Table 8.3 Syntactic exercises in Click-It

<table>
<thead>
<tr>
<th>Level</th>
<th>Exercise name</th>
<th>Theme</th>
<th>Mode</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Two-word sentence, explorative</td>
<td>F</td>
<td>E</td>
<td>The child can freely combine animals figures with verb cards in two trays of the combination module. The constructed two-word sentence is animated and pronounced on-screen. Word order is not important.</td>
</tr>
<tr>
<td>2</td>
<td>Two-word sentence, assignment-based</td>
<td>F</td>
<td>A</td>
<td>The child is asked to combine a specific animal with a specific verb, in the correct order. The constructed two-word sentence is animated and pronounced on-screen.</td>
</tr>
<tr>
<td>3</td>
<td>Big-small</td>
<td>F + Z</td>
<td>E + A</td>
<td>In explorative mode, the child can place a big or small version of an animal, triggering their growing and shrinking versions on-screen; in assignment-based mode, the child is asked to place a specific animal. Placing the correct animal triggers its animation on-screen.</td>
</tr>
<tr>
<td>4</td>
<td>Three-word sentences</td>
<td>F + Z</td>
<td>E + A</td>
<td>Similar as the level 1 and 2 exercises, but with three-word sentences.</td>
</tr>
</tbody>
</table>

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Output module
As have I described in the previous chapter, the newly designed output module was not prototyped in time for Click-It’s evaluation. In this cycle it was, though (see Figure 8.1). The output module contains a 17-inch TFT monitor and two speakers, one above the screen and one below. Instead of the originally designed rubber knobs for placing the module in a horizontal position, I included four suction pads. For placing it in tilted positions the module contains an integrated stand.

Base module
The most prominent weakness of the base module was that the magnetic connection of the interface modules to the base module was not strong enough to keep them in place. This issue was solved by making all modules’ white plastic covers thinner.

In addition, a more significant change was made to the base module: to reinforce the thematic sub-division of farm and zoo animals I designed two thematic backgrounds, one depicting a zoo environment and one a children’s farm environment. These backgrounds can be inserted in a slot at the far side a slot of the base module (see Figure 8.2). The backgrounds provide the child with an illustrative context, with opportunities for matching and pointing. As such the backgrounds can offer another means of alternative communication.

The slot contains a simple switch-based identification system that can recognise which background is present. Thus, Click-It 2.0 can automatically filter out the stories and exercises available within a particular theme. The edges of the slot are slightly raised to help prevent interface modules from being pushed off. I programmed the identification system so that the thematic backgrounds can be switched at any moment, i.e. also during exercises. The benefit of this is that the flow of the interaction does not have to be disrupted to change to another theme. This can be necessary in several situations, for example: (1) a child appears to have difficulties with zoo animals and starts losing its attention. In this case

Figure 8.1 The output module.
it is wise to try the same exercise with ‘easier’ animals and to switch to farm animals; (2) a child appears to be more in the mood for zoo animals than farm animals; (3) a specific exercise is going well with one type of animal it is worth trying the same exercise with the other type of animal, or; (4) a caregiver wants to assess if a child understands the same exercise in a different theme.

*Story module*

The story module as described in Chapter 7 showed significant design flaws. I describe the major changes here, which have resulted in the new story module shown in Figure 8.3.

*Two handles instead of one* – In the previous design one handle was used to move the story booklet through the module. This created the conceptual inconsistency that when the handle would be moved from left to right—back to its original position—the booklet did not move accordingly, whereas moving the handle from right to left did. To solve this the redesign has two handles: one for moving the booklet to the next scene and one for moving the booklet back.

*Position of the handles* – The two handles are positioned at the left and right side of the module. The handles are located where the story booklet moves into and exits the module, thus drawing attention to these ‘action locations’. Repositioning the handles away from the viewing window solves the problem from the previous design where the single handle would often obscure vision through the viewing window.

*Jam prevention of the handle and booklets* – I prevented handle jamming by mounting them on mini joysticks instead of slide resistors (as used in the previous story module) and booklet jamming by redesigning the transportation system.
Phonology module

The major design flaw of the phonology module—the false affordance of the circular speaker—was solved by redesigning the speaker housing, see Figure 8.4.

Puzzle module

Click-It’s puzzle module had displayed various impracticalities: the puzzles easily slid out of the placeholder, were fragile and were difficult to identify due to ill-placed RFID-tags. To solve these issues I: (1) added a narrow rim to the far side of the placeholder to prevent the puzzle from slipping out; (2) changed the construction of the puzzles, and; (3) made some changes were to the puzzle module's software making the RFID-tags easier to read.

Combination module

The design of the combination module was not changed in this Research-through-Design cycle; only the number of exercises it supported increased. In the previous Research-through-Design cycle the combination module was used for the syntactic exercises only. In this cycle it is also used for semantic exercises (see Table 8.2).

Another change compared to the previous Research-through-Design cycle is that different word orders are now supported in the two-word and three-word sentence exercises, as was explained in the previous chapter, in the evaluation of the combination module. The exercise now also supports making strange word combinations, for example ‘the cow eats the duck’ or ‘the sheep eats the fence’. We support these unusual sentences for three
reasons: (1) to assess whether this would appeal to children; (2) to see if this would lead to more opportunities for caregiver-child communication; (3) to make children aware that, although they can use their preferred subject-verb or verb-subject order, a sentence is not just a combination of words but an ordered combination of words.

**Input figures**

Click-It’s input figures showed two weaknesses: (1) they were not strong enough and broke easily; (2) the input figures were too light, which made them prone to toppling.

For these reasons I made the input figures out of heavier and more sturdy 8-millimetre acrylic. I made input figures of all farm animals from the previous prototype, as well as of newly designed zoo animals and of five letters. All input figures can be seen in Figure 8.5. Contrary to the previous input figures the new input figures only contained an animal picture on the front and not on the rear. This was done for three reasons: (1) in the stories and exercises only the front sides of the animals are shown; (2) children appeared inclined to place animals facing the front side, and; (3) placing an animal facing the backside had no...
result on the accompanying animated animal, although that would have been logical.

In addition to these acrylic input figures a second set of farm animal figures was made, consisting of ten small stuffed animals (see Figure 8.6). This set was intended as a preparatory set for the acrylic animal figures as described above. With these animals we wished to research whether such a preparatory set would be less abstract and thus easier to understand than our drawn animals, and whether such a set was at all viable.

*Contextualised graphic symbols*

None of the participating speech therapists indicated that they wanted to use a new set of graphic communication symbols. Therefore I decided to only use PCS, despite the fact that I consider many symbol systems sub-optimal.

*Programmable RFID-labels*

To meet the therapists’ wish to enable caregivers to create custom input materials (as explained in the previous chapter) I designed RFID-labels, see Figure 8.7, left. These are the exact same labels that have been described in Chapter 1 (see Figure 1.5). Any of LinguaBytes’ core animal words could be assigned to an RFID-label by placing one of the labels in the middle tray of the combination module and selecting the core word from a pre-set list, using the buttons on the control module which I describe in the next section.

*Control module*

In the previous Research-through-Design cycle it was concluded that Click-It should allow caregivers more control over its content and settings. The participating speech therapists

![Figure 8.6 The preparatory set of stuffed animal input figures.](image)
provided a wish list of functionalities, but also stressed that the to-be-developed ‘control module’ should only offer a limited set of options so that no time is wasted during therapy.

To meet these wishes several adjustments and/or additions were made to the Click-It prototype of which I have already described the thematic backgrounds. After inserting a thematic background the stories and exercises are shown in a start-up menu (see Figure 8.7, left). To choose and select a story or exercise from the start-up menu caregivers can use the newly designed control module (see Figure 8.7, right), which contains four buttons and a switch. The buttons can be used to select exercises whereas the switch can be used to set the mode of the exercises to explorative or assignment-based. During stories and exercises the buttons can be used to repeat scenes, sounds or assignments, to go to the next or previous scene or assignment, or to stop an exercise. The switch can be used to switch between the explorative and assignment-based versions of an exercise without having to exit the exercise to the start menu. This benefits the flow of the interaction.

The caregivers’ wish to be able to review results was postponed, as this was not seen as essential for Click-It’s functioning at this stage, but rather as a part of its future adaptive behaviour.

8.2 Evaluation of Click-It 2.0

Setup and participants
The Click-It 2.0 prototype was evaluated with nine children at the same two child rehabilitation centres in the Netherlands as with the previous prototype, in a similar set-up as described in Chapter 5.3: in the children’s familiar speech therapy room with their familiar speech therapist. Occasionally, a parent or other therapist would be present. Six children used the prototype in three 15 to 25-minute speech therapy sessions, two children in two 20-minute speech therapy sessions and one child in only one 10-minute session. All
sessions took place in the children’s customary speech therapy context and were recorded on video. As in the previous Research-through-Design cycle the instruction to the participating therapists was to start with a story, either the existing linear one or the new branched one. After the story the speech therapists could choose any of the exercises related to the story in any order, as long as we could evaluate all of the exercises. So, as in the previous Research-through-Design cycle, the therapists could distribute the exercises over the group of participating children. All sessions were recorded on video. At the end of the test period we asked the speech therapists to fill out a questionnaire.

Seven boys and two girls participated in the evaluation of Click-It 2.0, with calendar ages between 2 years 7 months and 4 years 6 months. Their developmental ages were average or slightly below average. The children had various disabilities. Five out of nine children had a delayed receptive language development, the other four children scored average. Eight out of nine children had a delayed productive language development. Their developmental levels ranged from babbling to making proper sentences. Two children could not speak but used a speech output device. All children were able to manipulate objects. An overview of the participating children is given in Table 8.4.

**Findings**

In general the Click-It 2.0 prototype worked well and was well received. All stories and exercises were evaluated, though not all equally many times. The children especially liked the zoo story and the explorative ‘Animals in context’ exercise (see Table 8.2). According to the speech therapists this was due to respectively the appealing animals, and to the high level of control over a funny situation: making animals appear and disappear at different locations).

**Table 8.4** Overview of characteristics of the test subjects.

<table>
<thead>
<tr>
<th>Child</th>
<th>Sex</th>
<th>Location*</th>
<th>CA*</th>
<th>DA*</th>
<th>Diagnosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>M</td>
<td>1</td>
<td>3:06</td>
<td>Average (IQ=98)</td>
<td>Cerebral palsy</td>
</tr>
<tr>
<td>2</td>
<td>F</td>
<td>1</td>
<td>3:01</td>
<td>Below average</td>
<td>General developmental retardation</td>
</tr>
<tr>
<td>3</td>
<td>M</td>
<td>1</td>
<td>3:10</td>
<td>Below average (IQ=62)</td>
<td>Walcott Rallison syndrome with general developmental retardation</td>
</tr>
<tr>
<td>4</td>
<td>M</td>
<td>2</td>
<td>2:10</td>
<td>1:03 at CA 1:04</td>
<td>Spina bifida L4, hydrocephalus with drain</td>
</tr>
<tr>
<td>5</td>
<td>M</td>
<td>2</td>
<td>4:06</td>
<td>2:07 – 3:04 at CA 3:04</td>
<td>CP, spastic tetraplegia</td>
</tr>
<tr>
<td>6</td>
<td>M</td>
<td>2</td>
<td>3:02</td>
<td>0:10 at CA 1:07</td>
<td>Motor development retardation</td>
</tr>
<tr>
<td>7</td>
<td>M</td>
<td>2</td>
<td>4:05</td>
<td>2:04 at CA 3:01</td>
<td>Hydrocephalus</td>
</tr>
<tr>
<td>8</td>
<td>M</td>
<td>2</td>
<td>3:00</td>
<td>0:10 – 1:00 at CA 1:07</td>
<td>Psychomotor retardation</td>
</tr>
<tr>
<td>9</td>
<td>M</td>
<td>2</td>
<td>2:07</td>
<td>0:10 – 1:00 at CA 2:03</td>
<td>Psychomotor retardation</td>
</tr>
</tbody>
</table>

*Notes: *Location 1: St. Maartenskliniek Nijmegen, Location 2: Rijndam Revalidatiecentrum Rotterdam. *CA*: calendar age (years and months). *DA*: developmental age (years and months) at CA.
In this section I describe the most significant findings per module. After that I illustrate the additional feedback we received from the participating speech therapists.

**Output module** – The output module worked well. It was only used in a desktop setup, not in a horizontal setup. The speech therapists considered this latter setup less suitable for the participating children, although one therapist indicated that she was very interested to try it out with other children in a future stage. The following aspects showed room for improvement:

- The wooden output module was quite heavy compared to plastic computer monitors, making it less motivating to move the module;
- The integrated stand was under-dimensioned. This made the output module instable, especially when children touched the screen to point at details in the animations;
- The lower speaker was located behind the base module’s thematic backgrounds, which consequently muffled the sound. This made the audio more difficult to discern;
- With the change of the seasons the output module suffered from linear thermal contraction and expansion. The resulting material stress eventually caused the module to crack open and the screen cover to bend open and crack at the connections.

These are minor design flaws that will be easy to solve in the next Research-through-Design cycle.

**Control module** – The control module worked very well and was unanimously considered as a positive addition to the former Click-It system. The switch for changing the mode of the exercises was used frequently, not only when choosing an exercise but more often during the exercise itself: often a speech therapist would start an exercise in the assignment-based mode, observing the child’s responses. When a child would show repeated difficulties with one particular word, the therapists would switch to the explorative mode and demonstrate that word repeatedly. Then they would switch back to the assignment-based mode and remind the child of their explorations when the word was asked again. The only negative remarks were that the previous, next and repeat buttons were too much alike, and that more different sounds should be repeatable.

**Base module** – The major change that was made to the base module was the inclusion of the thematic backgrounds. These were regarded as positive additions, although the speech therapists thought that their value would really show when more themes would become available. Now there were only two backgrounds. The children seemed to like the thematic backgrounds. They often grabbed them and repeatedly pointed at Tom and Tes whenever they appeared on the screen as well. A resulting comment was that future backgrounds should include more visual elements that children could point at. However, there were
also two problems with the backgrounds: (1) the laminated scenes started to peel after having inserted the backgrounds in the slot multiple times. This made them increasingly difficult to insert; (2) the cut in the zoo background—included for the background’s identification—was too narrow, causing one of the switches to break off whenever the background was not inserted in a perfectly vertical line. This made switching backgrounds more cumbersome than necessary.

The base module itself seemed satisfactory. The RFID-readers worked perfectly now that they had their own USB-connection, and the module’s additional 3 centimetres in length and 5 millimetres in depth did not appear to be problematic. The problem of the previous base module regarding the connection of interface layers was solved.

**Story module** – The story module performed very well. All children immediately understood the interaction, whereas only one of them had used the one in the previous Research-through-Design cycle. Most children waited patiently for the end of a scene before moving to the next or previous one, although Child 2 and Child 3 were mostly interested in the handles themselves during the first session. Over time, children’s active communication seemed to increase. For example, at his third session Child 1 started using sign language: he particularly made the sign for ‘giraffe’ as he wanted to repeat the giraffe scene. After that he deliberately moved the left handle to move the story booklet back to the appropriate scene. Child 5 repeatedly made eye contact (he cannot speak), pointed at the story booklets and used his speech output device. Child 7 could use the story module independently and often echoed sentences from the story. There were many pauses during which the speech therapist asked the girl questions, which she could answer well.

The repositioning of the handles was an improvement with regard to the visibility of the booklet behind the viewing window. The handles were easy to manipulate and did not jam. The transportation system worked flawlessly. There were three remarks: (1) some children were extremely right or left-handed. For these children the handles were placed too much to the side of the module, forcing them to reach too far; (2) it was difficult to insert the story booklets in the module. The opening in the right side of the module was too much hidden from sight and too narrow (see Figure 8.8); (3) the wires for the story module’s computer and power connections exited the module at the rear side. This caused them to interfere with the thematic backgrounds in the base module: the cables and wires were often crammed between the story module and the thematic backgrounds, making it difficult to place the module on the base module, or to insert a thematic background.

**Phonology module** – The earlier design flaws of the phonology module were fixed. However, a new problem was that the speaker was not loud enough. As a result, the speech therapist preferred using the output module’s speakers. In these situations they would even simply use the combination module (with the two outer trays closed) instead of the phonology module.
All children (even Child 9 who was generally uninterested in anything) enjoyed the phonological exercises. For example, Child 3 very much enjoyed the explorative version of the ‘Animal sounds’ exercise. However, during the assignment-based version of the exercise the boys seemed to recognise only a few of the sounds. His speech therapist suspected that this had to do with the boy’s bilingualism. Child 5 did the most difficult phonological exercises: ‘Coupling sounds with letters’, and; ‘Auditory discrimination’ (Tom and Tes pronouncing animal names). Child 5 performed these exercises flawlessly. After his performance the boy looked proudly around the room.

Puzzle module – The additional placeholder rim worked well. No puzzles were pushed out. The new puzzle construction was much sturdier than the old puzzles. It was unclear if children recognised the ambiguous animal as an animal. This was however not regarded as vital since the exercise was not aimed at recognising abstract animals. Recognising the abstract puzzle figure was considered a bonus. The more important thing was that the white figure contrasted well with its blue surrounding, making it easier for children with vision problems to find it.

There was a persistent problem with the software, though: the recognition of puzzles often malfunctioned and the sensors showed unexplainable peak values. These issues caused the puzzle exercises to restart mid-exercise or identify answers that had not yet been given. Consequently, this dampened the children’s motivation.

Combination module – As the combination module’s design did not change compared to the previous Research-through-Design cycle, I will only describe the most interesting findings in the exercises this module supported.

In general, the new exercises seemed to trigger communicative activity from children. For example, Child 3 made eye contact repeatedly while doing the semantic exercise

Figure 8.8 The slot in which story booklets could be inserted was somewhat hidden from view, which hampered the interaction with the story module.
‘Animals in context’ (i.e the farm or the zoo), looking very pleased with himself. He responded to instructions such as ‘you can take the animal off now’ or ‘do it again’ and started experimenting with the animals’ positions, moving them from tray to tray and seeing them disappear and reappear on the screen. After a few minutes he made the link between the animals’ physical location and their virtual one.

CHILD 8, a younger boy, enjoyed the ‘Peek-a-boo’ exercise in which animals are unveiled. In this exercise animals are partly hidden under a veil. When a child places the correct animal the veil is pulled away with a whooshing sound and the animal is revealed. The boy imitated the animal sounds and kept saying ‘pee-boo’ in anticipation of the voice over. He especially liked the chicken because one of the chickens on the screen kept laying eggs unexpectedly, which rolled all over the field.

Various children did the three-word sentence exercise, which now supported different word orders, as was explained earlier. This was highly valued by the speech therapists and seemed to open these exercises to younger children. CHILD 2, who mostly used two-word sentences, managed to make three-word sentences with some assistance. She seemed to understand what she was doing, too. For example, after having made the sentence ‘the sheep eats bread’, CHILD 2’s speech therapist asked her if the sheep also liked other food. The girl adequately replaced the bread card with a carrot card. CHILD 7 used the three-word sentence exercise to create an original ‘story’ with her therapist: she made the sheep walk to the fence to feed it with bread because all that walking had made the sheep hungry. She enjoyed story telling very much and had excellent attention and concentration. She started to cry when the session was over.

As said in the previous section, we also supported unusual sentences in this exercise, for three reasons: (1) to assess whether this would appeal to children; (2) to see if this would lead to more opportunities for caregiver-child communication; (3) to make children aware that, although they can use their preferred subject-verb or verb-subject order, a sentence is not just a combination of words but an ordered combination of words.

The children’s responses varied greatly. The younger children often looked puzzled, the older children profoundly amused or totally indifferent. It is therefore difficult to draw conclusions with regard to the first aforementioned reason. However, the weird sentences seemed to trigger more caregiver-child communication, for the simple reason that there was something strange to talk about: independent of their reaction, children often paused to have a closer look at the situation and glanced around to other people. In response the speech therapists asked the child questions about the scene and about how the scene would be better. Consequently, children were forced to think about the role of each input material and about which piece caused the anomaly. This seemed to confirm the second and third reasons listed above.

Input materials – The input figures were more stable due to their increased weight. This
was a major improvement. However, especially the larger animals (elephant, cow, horse) often broke on accidental or intentional\(^1\) impact with the floor. The smaller pieces all survived a drop from table-height. It would be best to make the larger pieces slightly smaller in the future, and to investigate using a less amorphous plastic. Another aspect that needs improvement in the final Research-through-Design iteration is that the paper drawings peeled off the plastic and that the blue spray paint scratched. It should be prevented that children accidentally swallow peeling paper or paint.

The newly developed textile animal figures were rarely used. Only the child that we gave the RFID-tagged fluffy animal used the textile dog figure. The boy appeared to appreciate the sensation and seemed to manipulate the figure more than the plastic variant. However, after a short time he slipped back into his safety zone. It was therefore difficult to evaluate the textile figures. There seemed to be three arguments against using them, though: (1) the textile figures did not match the representation on the screen, which contradicts their purpose—the textile figures were made as less abstract representations, preparing children for graphical representations. It would have been better if the textile animals would appear in the animations in the same form. In our opinion this would only work if everything in the animation would be in the same style; mixing drawings and textile figures would in our view result in an estranging overall image; (2) the textile figures were quite expensive to manufacture compared to the plastic ones. Considering that the final LinguaBytes prototype could possibly hold a few hundred figures, production costs are an important restriction; (3) the function of the textile figures overlapped with that of the RFID-labels, which we considered to have more potential. For these reasons it was decided to discontinue developing textile input figures.

**RFID-labels** — The RFID-labels were used once. One of the participating boys (CHILD 9) did not show any interest in any of Click-It’s materials or applications. This corresponded with his usual behaviour. He was only slightly interested in the ‘Animal songs’ exercise. Whenever his therapist placed an animal, the boy looked up at the screen and seemed to follow what was going on. After the song however he lowered his head and merely waited in silence. He did not grab any animals himself. During the second session one of the boy’s fluffy toys was tagged with one of the RFID labels and used to trigger the dog song in the ‘Animal songs’ exercise. After some hesitation the boy started attempting placing the dog on the interface himself, though hesitantly. The speech therapists found this promising although the boy also seemed uncomfortable with the fluffy animal’s unfamiliar

\(^1\) At one of the sessions two children used LinguaBytes at the same time (see next section). Both children seemed to like the cow the most, resulting in one of them hurling the animal through the room, exercising the adagio ‘If I can not play with the cow alone, no one should play with the cow’.
powers. Despite this single example, all participating speech therapists indicated that they found the RFID-labels very promising and were looking forward to using them more. They especially saw potential in using the labels to explain more linguistic concepts that are related to bodily experiences such as ‘near’, ‘far’, ‘high’, ‘low’, ‘warm’ or ‘cold’.

**Collaboration CHILD 2 and CHILD 3**

CHILD 2 and 3 used LinguaBytes together during one of their sessions. After watching the story of the zoo, the ‘Animals in context’ exercise was selected by the participating speech therapist as most appropriate for collaborative use. At first the collaboration went chaotically—both children wanted to place their animals at the same time at the same place, or preferably even the animal of the other—but after a while they learned to wait their turn. Many social skills were stimulated during the interaction: turn-taking, waiting for the other child, understanding ‘first it is her turn and then yours’ all passed revue. The collaboration seemed to stimulate communication as the children responded to each other as much as they did to the exercise itself. Both children often emphasised their actions by pointing at the screen and saying to the other “Look, CHILD 2”.

The participating speech therapist indicated that she found the collaborative setup both easy and difficult: easy because the children occupied themselves and were communicating extensively, difficult because it was hard to observe both children at the same time and respond to their actions adequately. The speech therapist suggested making it easier to change the spatial layout of LinguaBytes, or to include a mirror to see both children’s faces at the same time.

**Additional feedback from the participating speech therapists**

Two therapists filled out the questionnaire; two others were interviewed. All therapists were positive about the prototype. They were most prominently very happy with the control module, especially the functionality that allowed them to switch between explorative and assignment-based exercises. Additionally, all speech therapists were satisfied with the repeat, next and stop buttons that allowed them to respond quickly to sudden situations, although the similar shapes of the buttons made them less intuitive; the buttons’ text labels were frequently checked, which sometimes hampered the speech therapists’ timing. Finally, they indicated that the structure and number of available exercises within the animal theme were sufficient and could perfectly serve as the basis for the development of the remaining themes.

In one of the interview sessions with two speech therapists from the same rehabilitation centre we came back to the collaboration between CHILD 2 and CHILD 3. The speech therapist had at the time suggested making it easier to change LinguaBytes’ spatial layout. It was investigated how this could best be done. The screen seemed to be the bottleneck,
mostly due to its weight and the instability of the stand. It would be better if the screen would be lighter, more stable and easier to rotate. It was decided to reconsider these aspects of the output module in the final Research-through-Design cycle.

In addition the suggestion to include a mirror in the design was reviewed. It was decided to investigate whether a mirror should be part of the design or a separate piece of equipment. Also, we suggested including a webcam in the output module. This camera could literally offer another perspective on a child’s actions and be used to record these. For this recording functionality another button would be included in the control module. The speech therapists were positive towards this addition as long as it would not force them to spend too much time behind a computer. They were enthusiastic about the possibility to record similar actions over a longer of time, which would enable them to for example monitor progress in a child’s use of sign language. I decided to explore the possibilities in the last Research-through-Design cycle.

Negative comments generally corresponded with the design drawbacks we had observed during the test sessions, and have been described in this section.

8.3 Conclusions for the final prototype

**Output module** – The output module was very heavy, as well as slightly instable due to the dimensioning of the stand. This made it difficult to adjust the module’s orientation. Additionally, the lower speaker should be better placed and the effects of linear thermal contraction and expansion should be reduced. Possibilities for including a mirror or camera should be investigated.

**Control module** – The previous, next and repeat buttons should be less alike.

**Base module and thematic backgrounds.** Future backgrounds should include more visual elements that children can point at, and constructed differently so that they are easier to use without wearing. The cuts included for the background’s identification should be better proportioned to increase rigidity and usability.

**Story module** – Three weaknesses should be solved: the handles should be relocated for right or left-handed children; inserting story booklets in the module should be made easier; the module’s connections should not interfere with the thematic backgrounds in the base module.

**Phonology module** – The speaker volume is currently too low. This should be either improved, or the module will lose its added value over the combination module.

**Puzzle module and puzzles** – The puzzle software is unreliable, which should be solved in the interest of the children’s motivation.

**Combination module** – The combination module is good in its current form.

**Input materials** – The input figures show room for improvement: the larger animals often broke on impact with the floor; the paper animal drawings peeled off the plastic and that
the blue spray paint scratched. The textile input figures will be discontinued.  

**RFID-labels** – The RFID-labels are good in their current form.

### 8.4 Reflection on this Research-through-Design cycle

In this section I reflect briefly on two topics: (1) Click-It 2.0’s system resolution, and; (2) additional opportunities for adaptivity.

*The system resolution of Click-It 2.0*

Looking back at the LinguaBytes development process so far, it can be seen that the system’s vastness has been increasing rapidly. It was the goal of this cycle to fully design one sixth of the complete system—i.e., one of the six themes—which, when extrapolated, could give an indication of the complete system. This would help me in determining the optimal system resolution for the final prototype, i.e., the optimal amount of (modular) system elements in terms of personalisation versus usability. Currently, Click-It 2.0 consists of:

- Three modules that are used across all applications: the output module, base module and control module;
- Four dedicated modules, i.e. modules that were particularly designed to emphasise the nature of applications through their interaction: the story module, the puzzle module, the phonology module and the combination module;
- Two thematic backgrounds for filtering content: one children’s farm background and a zoo background;
- Input materials to interact with content: thirty-six animals, five puzzles, six word cards, two story booklets (one consisting of five individual parts), and a collection of RFID-labels.
- The identification tags described in chapter 7 (see Figure 7.16) for automatically tuning LinguaBytes’ settings to individual children, and for logging their use of LinguaBytes. As said this part of the LinguaBytes system is not yet functional.

Looking at these five groups, I expect that most relative expansion will occur in the thematic backgrounds and the input materials. Looking at the design of LinguaBytes in its current form, the number of modules appears to be sufficient; adding modules could reduce LinguaBytes’ usability without adding real value. The current use of the phonology module illustrates this well: without a properly functioning speaker this module loses its raison d’être. However, adding content and accompanying materials to interact with this content could significantly increase LinguaBytes’ life span and keep its users interested for a longer period of time. After all, LinguaBytes is aimed at children of extreme diversity, with ages from 1 to 4 years old, and should provide the richness and flexibility to keep being adjustable to these children’s needs, skills and interests.

In other words, I expect two design paths for the next Research-through-Design cycle.
The first is aimed at refining the details of the modules, the second at increasing the richness of content and accompanying materials without compromising LinguaBytes’ usability. This could prove to be challenging: based on Riny Voort’s research it can be expected that the final LinguaBytes prototype may hold around 300 input materials. This will demand increased attention to maintain usability and a solid prototyping strategy, especially when we consider our target to test three fully functional prototypes (see section 2.4).

Based on the fact that LinguaBytes is a relatively restricted system it is my strong conviction that creating rich prototypes will be one of the major challenges in systems design research. I will go deeper into this in the final chapter of this thesis.

**Opportunities for adaptivity**

In the previous chapter I have illustrated three opportunities for making the final LinguaBytes prototype adaptive. In this chapter I want to illustrate another one, based on the newly developed thematic backgrounds. These were developed to provide a thematic context that could trigger more communicative actions from a child, while at the same time serving as content filters that can help caregivers set the prototype up in as little time as possible. This diminishes the risk of losing a child’s attention and motivation.

The opportunity for adaptivity lies in combining the thematic backgrounds with the three identification systems described in my reflection on the previous Research-through-Design cycle: the one for identifying the user, the one for identifying the placed interface module, and the one for identifying the context of use. As the thematic backgrounds function as thematic content filters these four systems combined could make it possible for LinguaBytes to keep track of the developments of individual children per theme within different contexts, and tune its settings to the optimal level in a child’s Zone of Proximal Development (see Chapter 4.2). As such, LinguaBytes could assist caregivers as a platform for scaffolding.
Chapter 9

Fifth Research-through-Design Cycle: LinguaBytes

9.1 Introduction

So far I have described four Research-through-Design cycles. The one described in this chapter is the fifth and final one. This means that the prototype I describe in this chapter is the one I have described in Chapter 1.

To avoid repetition I will in this chapter only describe the modifications to the design of Click-It 2.0—which have resulted in the final prototype that I call LinguaBytes in this chapter—and the rationale behind these modifications. Additionally, I give the results of the longitudinal evaluation of the LinguaBytes prototype and my reflection on this final Research-through-Design cycle.

An overview of the prototypes of all five iterations is given in the A3 overview included with this thesis.

9.2 Modifications to the design of Click-It 2.0

Output module

Click-It 2.0’s output module showed three imperfections: (1) the wood casing suffered more from linear thermal contraction than expected, causing it to crack when it became too small for the TFT screen; (2) the integrated stand was badly dimensioned, making the heavy module instable; (3) the thematic background in the base module often muffled the output module’s lower speaker.

To solve the problem of linear thermal contraction I changed the construction of the wooden casing and added a tolerance of up to 5 millimetres of space around the module’s internal components, most prominently the TFT screen. I also completely redesigned the integrated stand (see Figure 9.1, left) to increase overall stability. In addition, the stand’s hinging point was moved to the lower edge of the module (see Figure 9.1, middle) to increase ease of use and manoeuvrability. You can now simply place the module in a horizontal position and ‘open’ it up, holding the screen with one hand and locking the stand with the other hand, with two integrated safety catches (see Figure 9.1, right). Integrated ball transfer units in the stand make it possible to easily roll the screen around or rotate it in the best orientation for both child and caregiver.
The speaker imperfection was easily solved: I simply moved it up (see Figure 9.2, left and middle). The module now held a speaker in both corners thus providing the bonus that we could now use stereo sound effects, for example for objects moving across the screen in the new theme ‘vehicles’.

In addition to these aspects I investigated the possibilities of integrating a mirror and/or webcam in the output module to improve the therapist’s view on a child’s facial expressions. I decided not to include a mirror in the output module since mirrors are usually around already in a home, therapy or special education environment. I did however choose to include a small camera in the output module (see Figure 9.2, right), between the two speakers. With this camera pictures can be taken e.g., from a child’s facial expressions, language signs, eye gaze or manual interactions. These pictures—or even better, video clips—could be archived and reviewed in sequence at a later time, which would provide a good overview of the development of a child’s communication skills.

**Story module**
Click-It 2.0’s story module had three imperfections: (1) it was difficult to insert story booklets; (2) the two handles were too far apart, and; (3) the wires coming out of the module interfered with the thematic backgrounds. To solve these issues the story module was slightly redesigned. I placed the handles closer to each other, left and right of the viewing window (see Figure 9.3, left). A track was cut out of the wood surface (see Figure 9.3, middle), which makes it easier for a child to insert a story booklet independently. The two handles were enlarged, making them easier to move, hit or hold. The exit point of wires and power connector were moved from the rear of the module to the far left corner (see Figure 9.3, right).

**Combination module, phonology module and puzzle module**
The combination module and the phonology module were merged into one ‘exercise module’ (Figure 9.4, left), for two reasons: (1) firstly, as explained in the previous chapter, with most of the syntactic exercises the combination module was used with the two outer trays closed. In this form it highly resembled the phonology module, apart from not having an internal speaker. As a consequence, the combination module was often used for phonological exercises as well. This saved time and did not seem to have any negative effect on the child; (2) secondly, phonological exercises were mostly done in combination with the output module’s speakers during the previous two Research-through-Design cycles. Only rarely did the speech therapists use the phonology module’s internal speaker. The main reason for this was that the internal speaker’s volume level was insufficient. As a consequence, the combination module was often simply left on the base module when phonological exercises were done.
These observations made me realise that, although the two modules may be conceptually different, physically they were not. Therefore I decided to merge the two modules. In the new exercise module the middle tray now holds an integrated speaker for audio (Figure 9.4, middle) while the two outer trays still come with removable lids (Figure 9.4, right). For most exercises only the middle tray is used.

Furthermore it was decided to omit the puzzle module from the final prototype, for the following reasons. First and foremost, although puzzle concept worked well for animals, design explorations revealed that it fit less with other themes. Secondly, for some themes the format of the exercise did not seem to add any elements that could not be offered in the format of the other exercises. Thirdly, although the module’s reliability improved with its final redesign, it remains the weakest link in the LinguaBytes system, both in terms of hardware as in software. We anticipated that the puzzle module would demand too much aftercare.

On the whole, we decided that the minuses of the puzzle module outweighed the pluses, which made us decide to eliminate the module from the final prototype.

Control module
The main point for improving the control module was that the buttons were too much alike which reduced their intuitive usage. I solved this by changing the control module’s button layout and by replacing the previous and next buttons with a mini joystick (see Figure 9.5). The joystick also makes moving through the start menu quicker and more intuitive.

Base module
The base module hardly changed in comparison with the version of the Click-It 2.0 system. Two alterations were made to the design: (1) I added a fourth switch to the thematic background slot, because there turned out to be more than seven backgrounds (the number of backgrounds that could be covered with three switches, see chapter 8.4); (2) I made the thematic backgrounds slot itself larger to compensate material shrinkage and added a chamfer to the slot’s edge to make it easier to insert backgrounds.

Thematic backgrounds
The backgrounds themselves were slightly redesigned as well to make them easier to insert and remove. I filleted all lower corners, and widened the cuts at the lower edge of the backgrounds, which in the previous prototype these were too narrow, causing the switch to break. In total 8 backgrounds were developed (see Figure 9.), belonging to six themes: (1) ‘Animals’; (2) ‘In and around the house’; (3) ‘Traffic and vehicles’; (4) ‘Toys and clothes’; (5) ‘Food and drinks’, and; (6) ‘People and the body’.

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Content

The final LinguaBytes prototype encompasses approximately 500 core words. These are distributed over 16 interactive stories and 220 exercises1. Each theme comes with at least two stories of which one is linear and one branched. Per theme, exercises are clustered into phonological, semantic and syntactic exercises. Stories and exercises can be selected from the LinguaBytes start-up menu (see Figure 9.8), by inserting a thematic background and using the control module’s joystick and selection button.

Input materials

The final prototype holds 16 story booklets, 236 input figures and 31 word cards (Figure 9.7) to interact with the stories and exercises. The designs of the input materials were slightly changed compared to the previous Research-through-Design cycle.

Firstly, since the final LinguaBytes prototype had to be made in threefold and tested for at least a year, I had to think of a new way to manufacture the input materials. Not only because making 54 booklets, 708 input figures and 93 word cards is different than making Click-It 2.0’s 50 input materials, but more importantly because the materials should survive a year of testing. The input figures needed most attention. As a first step I decided to switch from painted acrylic to coloured acrylic: in the previous figures the paint and paper animal pictures would start to peel towards the end of a testing period, which not only made the figures look less aesthetic but could also lead to children eating paint or paper. This is not desirable and in my view justifies using a six times more expensive material. Also, I replaced the paper pictures with versions printed directly on the acrylic. To fix the printed image a layer of transparent glossy paint was sprayed over the acrylic. This type of paint is very tough, making it virtually impossible for children to accidentally scrape off and swallow it; young children have the habit of tasting their toys before playing with them.

Secondly, as I announced in Chapter 7.6, I assigned a colour to each of the six themes to enhance LinguaBytes’ usability. This facilitates the storing and retrieving of input materials. Light blue had been already in use for the ‘Animals’ theme. I assigned dark blue to ‘In and around the house’, red to ‘Traffic and vehicles’, yellow to ‘Toys and clothes’, green to ‘Food and drinks’ and ivory to ‘People and the body’, which also includes cross-theme input figures such as letters and the words ‘round’ and ‘square’.

The colours were chosen to form an aesthetic ensemble, using the bright colours that young children prefer but staying clear of the standard primary colours. The colours were assigned to their themes based on how they contrasted with the pictures within those

1 Exercises that can be done in both the explorative and assignment-based mode are counted double.
**Figure 9.1** The output module’s integrated stand was made wider and thicker to increase stability and rigidity (left). The stand included four ball transfer units, which enabled rolling the output module freely into the optimal orientation between child and caregiver. The stand’s hinging point was moved to the lower end of the module (middle). When opened, the stand could be locked in position with two safety catches (of which one is shown on the right).

**Figure 9.2** The redesigned output module (left) has two speakers (detail: middle) at the top instead of the earlier set-up of one speaker above and one below the screen. Between the two speakers a webcam is included (right) which enables caregivers to take pictures of a child’s interactions, for example of facial expressions or language signs. This functionality is currently not yet functional.

**Figure 9.3** The new story module has a handle on either side of the viewing window (left) and a wide track in which story booklets can be easily placed (middle). The module’s connections were moved from the rear side to the far left corner (right).

**Figure 9.4** The exercise module (left) was an integration of the combination module and the phonology module. The module’s centre tray contained a speaker for exercises aimed at phonological awareness (middle). The RFID-tagged lids covering the outer trays could be removed (right) for exercises where input materials could be combined or clustered.
themes. Because Tom and Tes are recurring figures, used across all themes, they were assigned the most neutral colour. For the sake of uniformity the same ivory colour was assigned to the entire ‘People and the body’ theme, as well as to letters and shapes. The reason to include letters in the ivory group was that, like Tom and Tes, letters are used across all themes. The reason to include shapes (square and round) in the ivory group was twofold: firstly, an exercise in the ‘Clothes and toys’ theme, aimed at recognising colours, already used square input materials in red, green, yellow and blue. It would have been inconsistent to use the representations of colours for the representation of ‘square’, too. Secondly, the reverse line of thought argues that in the ‘square and round’ exercise (also in the ‘Clothes and toys’ theme) the focus should be entirely on shape, not colour. Since in this exercise children were asked to recognise the shape of several toys (which had a colour of their own) using coloured shape representations would have made the exercise confusing for children. They might start matching colours instead of shapes.

I apply the colour coding of the six themes consistently to indicate which materials belonged to the same theme: input figures within a theme are all made of the same plastic; the story booklets, word cards and thematic backgrounds hold the theme colour on the backside (see Figure 9.9 and Figure 9.10). Some word cards are used in two different themes, e.g., the verb ‘eating’. The verb ‘walking’ is even used in three different themes. The backsides of these cards show multiple theme colours (Figure 9.10, right). In this, the use of colour on the back of the word cards is different than how we dealt with the cross-theme input figures: these figures—such as Tom and Tes and letters—were all put in the ivory group. The main reason for the difference in colour use is that the colour coding of the word cards is located on the backside and as such less prominently visible and thus, less distracting than the colour coding of the input figures. Cards belonging to two themes have two diagonally divided colours; the card belonging to three themes three horizontally divided colours. As such the colour pattern adds to the card’s recognisability.

The RFID-labels did not change. However, I designed a theme-dependent menu, which shows all the programmable core words within a chosen theme. For example, when the ‘Vehicles’ thematic background is inserted in the base module, the RFID-programming menu only shows this theme’s core words. How to assign a word to an RFID-label has been explained in Chapters 1 and 8.

Storage box
For storing the LinguaBytes prototype I designed a box (see Figure 9.11, left), organised in two layers: the bottom layer holds six compartments for the input materials of the six themes (see Figure 11, middle) and can be closed with a lid, thus creating the second layer. This top layer holds the modules and other non-thematic materials (see Figure 9.11, right). The box can be closed with a lid and two strips of Velcro: many children are familiar with
this material, which allows them to ‘help’ the therapist with opening the box, which thus creates more opportunities for communication. I placed the box on four swivel casters, which enables it to be rolled around—possibly even by the children themselves or with a child sitting on top. The height of the box corresponds with the sitting height of your average caregiver.

*Mac Mini*
Each prototype comes with an Apple Mac Mini on which MAX/MSP Runtime and the Macromedia Flash Player are installed to run the LinguaBytes applications. USB and power cables are included. I designed a LinguaBytes screen wallpaper, showing the order in which the LinguaBytes software should be started (Figure 9.12, left).

*Manual*
Riny Voort has written a comprehensive LinguaBytes manual (see Figure 9.12, right), which provides a thorough overview of all of the themes and their stories and exercises. An overview of the core words per theme is given, as well as available input materials and a description of the stories and exercises. For each application the manual describes which input materials can be used and provides the caregiver with helpful suggestions and strategies for interaction, both with the system and the child. The manual is included (in Dutch only) on the enclosed DVD.

**9.3 Longitudinal user-test of the LinguaBytes prototype: objectives, setup and participants**

*Objectives*
This user-test had the following objectives: (1) to research the usability of LinguaBytes. In ISO 20281 usability is defined as ‘the extent to which a product can be used by specified users to achieve specified goals, with effectiveness, efficiency and satisfaction, in a specified context of use’ (Van Kuijk, 2010). This research includes the effect of LinguaBytes on children’s language development, although this is not per se the focus of thesis; (2) to research whether the measure of adaptability of the LinguaBytes system is sufficient, as well as to identify opportunities for adaptivity.

*Setup*
LinguaBytes was tested at the two rehabilitation centres that participated throughout the earlier project phases: St. Maartenskliniek Nijmegen and Rijndam Revalidatiecentrum Rotterdam. Each centre had one LinguaBytes prototype at their disposal, for the period of ten months. A third prototype was kept standby, as a back-up in case (parts of) the other two would cease functioning.
**Figure 9.5** The control module has a joystick for navigating through the LinguaBytes menu, stories and exercises a repeat button, a stop button and a switch for changing the mode of an exercise (i.e., assignment-based or explorative).

**Figure 9.6** The eight thematic backgrounds can be placed in the base module’s slot (as shown earlier in Figure 8.2). The four switches in the slot detect the pattern of cutaways of the backgrounds and thus determine which theme is selected.

**Figure 9.7** The LinguaBytes play-and-learning materials, from left to right: 16 story booklets, 236 input figures and 31 word cards.
Figure 9.8 The LinguaBytes menu for the theme ‘In and around the house’ (left) and the subtheme ‘Toys’ (right). Note the differences in available content: the left menu contains three stories (in the yellow column), the right menu two; the left menu contains more phonological exercises (in the green column) and semantic exercises (in the pink column) than the right one, which in turn contains an additional syntactic exercise (in the blue column).

Figure 9.9 Theme colours on the backside of the linear stories (left), branched stories (middle) and thematic backgrounds (e.g., the one belonging to the theme ‘Vehicles’, right) make them easier to retrieve.

Figure 9.10 The LinguaBytes word cards contain a colour coding on the backside indicating to which theme the card belongs (left). Cards can belong to more than one theme, which is reflected accordingly in the colour coding (right). The three cards on the right belong to one theme, two themes (diagonal division into two colours) and three themes (horizontal division into three colours: dark blue at the top, green in the middle, light blue at the bottom).
In order to benefit from the wide offer of available in-house expertise, as well as from the variety of available children within the scope of LinguaBytes, any therapist, teacher or caregiver at the two rehabilitation centres was allowed to use LinguaBytes. At each centre one speech therapist served as a liaison between the local staff and myself, for communicating results and repairs. At the beginning of the evaluation period I gave a demonstration of LinguaBytes at both centres, to get the available staff acquainted with its possibilities. LinguaBytes’ goal, structure, content and interaction were addressed.

The instruction to the participating therapists was to use LinguaBytes as if ‘they had just got it from the store’. In other words, they were allowed to use the prototype, move it or modify it in any way they deemed appropriate in the context of their work. The participants were instructed to use all of LinguaBytes’ options and to keep track of malfunctions in software or hardware. Additionally, they were asked to keep an eye on striking results and positive or negative anecdotal evidence.

I was available for prototype repairs throughout the evaluation period. Typically, a round of repairs was combined with interviews during which the participant and I evaluated the most recent test period. At the end of the ten-month user-test the participating therapists were asked to fill out a questionnaire, containing 5-point scale rating questions and open questions. The answers were reviewed in an interview.

Participants
At St. Maartenskliniek Nijmegen 10 therapists participated: three speech therapists of whom two used LinguaBytes intensively on a daily basis; six therapeutic preschool teachers, who used LinguaBytes less frequently, approximately two days a week; one occupational therapist who used LinguaBytes in combination with a speech therapist. LinguaBytes was tested at one location, i.e. the division specialised in preschool child rehabilitation. Within this location LinguaBytes was used in therapy rooms, as well as in group rooms, multiple times a week. Throughout the evaluation period 30 children used LinguaBytes repeatedly, often in individual sessions with a speech therapist, but sometimes also in group sessions.

At Rijndam Revalidatiecentrum Rotterdam nine therapists participated, all in speech therapy. They used LinguaBytes at three different locations. At one location LinguaBytes was only used in a therapy room, at one location in a ‘low stimuli’ room and in a group room, and at the third location in a room that became known as ‘the LinguaBytes room’. The LinguaBytes room also contained a Nintendo Wii. On average LinguaBytes was used on a daily basis, at one location multiple times a day. Throughout the evaluation period 35 children used LinguaBytes repeatedly, mostly in individual sessions with a speech therapist, sometimes in groups up to four children, sometimes of immigrant families. Occasionally more than one therapist was present, or a parent or caregiver. An overview of the specifications of the longitudinal user-test is given in table 9.1.
At both institutions children used LinguaBytes in the normal course of their day programme.

9.4 Longitudinal user-test of the LinguaBytes prototype: results

In this section I present the results of the ten-month test period. I start with describing the general impression of the LinguaBytes prototype before going into the results regarding the two research topics described at the beginning of the previous section.

General impression

The participating therapists generally regard LinguaBytes as a very valuable addition to the available body of speech therapy materials. They value LinguaBytes’ wide range of attractive stories, exercises and materials and the high measure of control children have over the interaction. It is the general impression that LinguaBytes keep’s today’s children’s attention better in comparison with traditional materials such as picture books, and LinguaBytes offers children more control and more opportunities for initiative taking compared with interactive computer programs. LinguaBytes’ design is generally regarded as ‘good’ to ‘very good’, its content as ‘good’ and its flexibility as ‘very good’.

The most prominent critical remark was that LinguaBytes is undeniably a prototype: it is somewhat vulnerable compared with off-the-shelf commercial products, which makes that the participating therapists were sometimes scared of breaking the prototype.

<table>
<thead>
<tr>
<th>Rehabilitation Centre</th>
<th>Test locations</th>
<th>Used spaces</th>
<th>Therapists</th>
<th>Children</th>
<th>Impairment</th>
</tr>
</thead>
<tbody>
<tr>
<td>St. Maartenskliniek</td>
<td>1</td>
<td>Therapy rooms</td>
<td>10</td>
<td>30</td>
<td>Cerebral palsy</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Group rooms</td>
<td></td>
<td></td>
<td>Cognitive impairment</td>
</tr>
<tr>
<td>Rijndam</td>
<td>3</td>
<td>Therapy rooms</td>
<td>9</td>
<td>35</td>
<td>Cerebral palsy</td>
</tr>
<tr>
<td>Revalidatiecentrum</td>
<td></td>
<td>Group rooms</td>
<td></td>
<td></td>
<td>Genetic syndromes</td>
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<tr>
<td></td>
<td></td>
<td>Low stimuli room</td>
<td></td>
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<td>Muscular diseases</td>
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<td></td>
<td></td>
<td>LinguaBytes room</td>
<td></td>
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<td>Cognitive behavioural disorders</td>
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<td>Speech/language impairment</td>
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<td>Hearing impairment</td>
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<td>Autism</td>
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</tbody>
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Notes. *Test location: at Rijndam Revalidatiecentrum LinguaBytes was moved between three different buildings, in three demographically different areas of the city. *Used spaces: within the test locations LinguaBytes was moved between various types of rooms. *Therapists: number of participating therapists. *Children: number of participating children. *Impairment: type of impairment of the participating children.
Additionally, LinguaBytes’ software was more unpredictable than in commercially available suites: sometimes LinguaBytes just did not do what was expected, especially when the software had been running for hours. Most therapists indicated that they did not mind these typical prototype issues, but also that they expected that it had scared some of their colleagues away. This is well illustrated by the following quote from one of the therapists:

“All the cables can be intimidating to some people. The same goes for the inch-thick manual. I think that, if you would have divided it into six mini-manuals - one per theme - more people would have had a crack at LinguaBytes.”

**Usability of LinguaBytes**

LinguaBytes was unanimously regarded as ‘very suitable’ for non- or hardly speaking children between 1 and 4 years old. At both rehabilitation centres LinguaBytes was also used with older children, up to 6 years old (Rotterdam) and 9 years old (Nijmegen). The participating therapists indicated that they found LinguaBytes suitable for any child between 1 and 4 years old, except for children with very severe motor disabilities (GMFCS 5, or MACS 5, see Chapter 3), children who do not understand 2D representations, children who do not understand action-reaction relations, or children with severe vision limitations. One therapist said:

“All I’ve used LinguaBytes with children with a myriad of impairments, and it was never not useful.”

**Evaluation of the content, graphic design, product design, audio and interaction** – The content was generally regarded as ‘good’. The number of stories and exercises were regarded as ‘good’, their quality and their suitability as ‘good’ to ‘very good’. LinguaBytes was considered ‘very useful’ for stimulating the child’s vocabulary, syntax, phonological awareness and communication (especially turn-taking and action-reaction). The stories and exercises are well chosen and designed in congruence with children’s perception of the

![Image of LinguaBytes prototype](image)

**Figure 9.11** Each LinguaBytes prototype can be stored in a custom designed box (left). The box is mounted on four swivel casters and can be closed using a lid and two strips of Velcro. The height of the box corresponds with the average sitting height of benches that are often used in the preschool context. The bottom compartment of the two-story box contains the six thematic groups of input figures (middle), the top compartment holds the modules and other non-thematic materials (right).
world, which makes LinguaBytes highly appealing. The appeal of LinguaBytes was nicely illustrated by one of the therapists, who said:

“Sometimes I tell the children that, if they behave, they can play with LinguaBytes before they go home.”

The graphic design of the animated content as well as of the physical materials was generally regarded as ‘good’, some elements as ‘very good’. The design of the manual was rated as ‘good’ to although there were critical remarks about its thickness and lack of a search structure. The physical design of LinguaBytes was generally rated as ‘good’, except for the design of the box, which was rated ‘neutral’ to ‘good’. One suggestion was to let the box communicate more about its contents in its design. The sturdiness and safety of the prototype were regarded as ‘good’, despite the prototype issues I have described in the ‘general impression’ section. The maneuverability of LinguaBytes was rated as ‘neutral’. The main comments were that the storage box is rather large for most therapy rooms: it would be better if the box was either smaller or turned into a rolling cupboard. The maneuverability of the modules was considered limited due to the cables. The audio was rated as ‘good’. The pace and quality of the spoken audio was good, although could sometimes be better in intonation. The non-spoken audio was regarded as good overall. The interaction with LinguaBytes was considered suitable for non- or hardly speaking children between 1 and 4 years old. The materials are friendly and the interaction is playful and appropriate for the majority of the children (apart from those mentioned on the previous page). The physical nature of the interaction makes that children can look around the room holding input materials for communication, can keep looking at the output module while interacting with the input materials, and can take more initiative. According to the participating therapists, the children appeared to like using LinguaBytes ‘very much’

![LinguaBytes](image)

**Figure 9.12** I designed a desktop wallpaper for the output module (left), showing the subsequent start-up steps to get LinguaBytes up and running. Also, a manual was included (right) to offer instruction and inspiration to caregivers.
(unanimous 5 on a 5-point scale). The following two quotes illustrate this well:

“When the children see me enter the building they shout ‘Computer!’ They know I’m the one in charge of LinguaBytes, you know…”

“Children typically do two things when they have to stop: they get angry or they start crying.”

The therapists found LinguaBytes easy to use, but rated LinguaBytes’ clarity and its learnability as ‘neutral’ to ‘easy’ on a scale between ‘very difficult’ to ‘very easy’. The main dampening factor was that the manual had to be used to look up which materials could be used for each exercise. The satisfaction of using LinguaBytes was rated 4 to 5 on a 5-point scale (‘pleasant’ to ‘very pleasant’). This satisfaction is nicely reflected in the following quotes:

“I’ve only had LinguaBytes for a month now, but I am already dreading the moment that I have to give it to the next team. I secretly hope they forget I have it.”

“Bart, I promise you: when you come to take LinguaBytes away, all 13 of us are gonna throw ourselves on the box to stop you.”

All therapists were very positive about the modular organisation of LinguaBytes, as well as the ability to do exercises in two modes (assignment-based and explorative). LinguaBytes offered more than enough opportunity and room for social interaction and communication with the child, as well as more than enough opportunities for learning (all were rated 5 on a 5-point scale).

*Evaluation of the effect of LinguaBytes on the children’s development.* Although this user-test is not a formal effect study the participating therapists regarded it ‘probable’ to ‘certain’ that LinguaBytes stimulates the linguistic development of non- or hardly speaking children. They regarded it ‘probable’ that LinguaBytes actually contributed to the linguistic developments of the participating children, although they indicated that you can never be 100% certain. However, the child’s motivation, attention, concentration, initiative and engagement while using LinguaBytes were all unanimously rated as ‘better than normal’, which can be considered as indications of learning. The following quotes of the participating speech therapists illustrate the probability of the positive effect of LinguaBytes on the children’s development:

“Children learn better and faster when they are motivated. LinguaBytes evokes plenty of motivation through the appealing design of the stories and exercises. That keeps children’s attention and concentration.”

“LinguaBytes helps children develop some of the linguistic modalities in a fun and playful
The child’s communication while using LinguaBytes was rated as ‘better than normal’ to ‘normal’. The participating therapists indicated that LinguaBytes has a positive effect on children’s cognitive development in terms of the stimulation of pre-lingual conditions such as action-reaction, attention, concentration, listening attitude and the ability to execute assignments. They indicated positive effects on children’s perceptual-motor development, attributed to: (1) the frequent manipulation of materials; (2) the fact that LinguaBytes stimulates careful perception of these materials, and; (3) the fact that LinguaBytes stimulates motor activity.

The effect of LinguaBytes on children’s socio-emotional development was regarded as positive, especially when two children use LinguaBytes together. This stimulates collaboration and turn-taking. The fact that Tom and Tes also do everything together contributes to this. Consider the following quote of one of the speech therapists:

“I believe that LinguaBytes has had a very positive on the emotional development of the children I’ve seen: kids laugh when they see LinguaBytes and know that they may practice. I have even seen a very anxious, introvert little boy relax completely; he actually started talking when he heard songs of the animals.”

The response to the question whether children could express themselves through LinguaBytes was mixed: answers ranged from ‘neutral’ to ‘absolutely’, respectively a 3’s and 5’s out of 5. According to the participating therapists LinguaBytes is not a communication system per se, in the way that sign language or communication symbols are. However, they did observe that during sessions children used LinguaBytes as an addition to language signs and symbol sets. As such LinguaBytes provided children with an extra alternative. The following quote illustrates this well:

“LinguaBytes is not a communication system as the available specialised assistive communication equipment, I think. However, children can make some things clear through LB, especially in a game situation: in LB’s explorative mode a child can decide what it wants and can take initiative and actually express him or herself. In assignment-mode, communication is more directed: targets have to be made.”

Repairs. Over the ten-month test period the following repairs were necessary. All repairs were done on-site: (1) one of the story modules needed repairs after it fell on the ground:
the white bottom cracked and the bearing of one of the axles of the booklet transportation system broke. At both test locations one of the story module’s handles got dislodged; (2) the two base modules showed initial malfunctions in the background identification system. In both cases this could be attributed to bad wiring; (3) in total, 15 input figures needed repairs. This equals 3% of the 472; eight figures had bad RFID-tags, seven needed regluing after a drop on the floor; (4) 16% of the content needed minor reprogramming. One software issue that could not be resolved, was that the RFID-labels could not be programmed due to licence limitations. As a compensation I would program the RFID-labels on demand, which effectively resulted in them being used only sporadically.

Evaluation of the adaptability of the LinguaBytes system and identifying opportunities for adaptivity.

As described in the past pages, LinguaBytes was tested with children between 1 and 4 years old, but incidentally with older children as well, as illustrated by the following e-mail:

Re: LinguaBytes
To: B.J.Hengeveld@tue.nl

Hej Bart,

What might be cool to know is that today we (a physiotherapist and I) have tried LinguaBytes with a 9-year-old boy who is sub-comatose. He is crazy about computer games but now, after an accident, he is so severely impaired that he can barely control his motor system. Additionally, he is in a stage of semi-consciousness. But......the story module he can (!!!) operate. I am extremely happy and so are his parents. The only thing is that his interests are more on the level of the Lords of the Rings than that of Tom and Tes. Nevertheless, for us this step is an important one, he can actually do something by himself!

Best regards,
...

The participating therapists unanimously indicated that LinguaBytes offered more than enough flexibility to be used with diverse children (5 on a 5-point scale) and were of the opinion that LinguaBytes could probably to certainly grow along with and remain interesting for children over several years (4’s and 5’s on a 5-point scale). Reflecting on LinguaBytes in its current form, the speech therapists indicated that the major forte of the system is that children can themselves have control over what happens on-screen, which is highly beneficial for their initiative and imagination. Two functionalities were identified as ‘lacking’: (1) the possibility to log and review results; (2) the possibility to use personal
affects of the child as input materials. This latter lacking functionality was of course due to the aforementioned software licence limitation.

As indicated earlier LinguaBytes’ current interaction was not considered suitable for the children with the most severe motor disabilities, nor could it be made suitable. These can only use LinguaBytes with assistance. This could be expected, as we had decided early in the project to aim LinguaBytes at 95% of the children and to postpone including the final 5%, as stated in Chapter 3 annotation [13]. As part of the post-experiment interviews I discussed opportunities with the participating therapists for making LinguaBytes adaptable to these children, or even adaptive. For this I used examples from the adaptivity brainstorm described in Chapter 6. I will go into the results of our discussions in the final section of this chapter. Generally, therapists were very interested in opportunities for adaptivity, but sometimes also sceptical: many pointed out that there will always be children who are so severely disabled that they may never be able to use LinguaBytes independently. However, they also indicated that for these children LinguaBytes already provides the most important thing: the feeling that they can actively participate.

In conclusion, it is the general opinion that LinguaBytes is currently sufficiently adaptable for the defined target group. Adaptive elements in the design could include the most severely disabled children, while maintaining the forte of allowing children control over the interaction.

9.5 Reflection on this Research-through-Design cycle

The consequences of longitudinal testing on a Research-through-Design process

In this chapter I have described the fifth and final Research-through-Design cycle of this thesis. Looking back at the previous four cycles, the major difference of this one is in the duration of the testing period and the quality of the prototype. To put it bluntly, as the previous prototypes were tested for a few weeks at the most, this was the maximum period that they had to maintain their quality. This is not banality but pragmatism: there is undeniably a trade-off between the necessary quality of a prototype and the consequential time investment. The final prototypes on the other hand were to endure a year of intensive day-to-day testing. As a consequence I had to solve quite a few prototyping issues to guarantee durability and safety. For example, whereas the previous prototypes often needed instant fixes between test sessions, I could not afford driving between Rotterdam and Nijmegen every time some animal lost its head—literally. Also, for the sake of the children’s health I had to solve the input figures’ peeling paint problem, as well as the tearing animal prints, because as I have said before: children like to taste their toys before playing with them. These issues forced me to completely re-think my prototype production method. An impactful issue here is the prototype’s scale: the final prototype saw an explosion in its vastness, compared to the previous prototypes. Moreover, it had to be
manufactured in threefold by myself, which came down to lots and lots of work. Let me give some examples.

Example 1: creating stories and exercises – During this final Research-through-Design cycle, my fellow researcher Riny Voort provided me with clear textual storyboards of all stories and exercises that I could use as the basis for animations and audio. Using these storyboards I typically recorded and edited the audio, after which I numbered the individual audio snippets in sequence and sent them to a professional multimedia designer. He animated the story in Flash, using the audio as a time line. As soon as the animations were returned to me I added ActionScript to each story or exercise to make them fit in the overall software structure. The exercises did not use a preset sequence of audio, which consequently meant that the professional animator merely provided me with animated building blocks that I could use and reuse across different exercises. The audio within these exercises was typically cut up into fragments, which were combined and played dynamically, using ActionScript. Knowing that LinguaBytes holds 16 stories and 220 exercises, and that I recorded a total of 1987 audio fragments, may give an impression of the amount of work².

Example 2: making input figures – The final prototype encompassed 236 input figures, which were made using the following procedure:

1. *Create drawings of core words.* I imported the Flash drawings of all core words to Illustrator, where I adjusted their colours for print;

2. *Create laser cutter paths.* Then all drawings were outlined and offset to serve as a cutting path for a laser cutter. As the plastic pieces would be connected to bases using a mortise and tenon joint, I added a tenon to each cutting path at the bottom of each piece (see Figure 9.13, left). In this I took each piece’s centre of gravity into account to prevent them from toppling;

3. *Prepare figures for printing and cutting.* As a third step I added cutting paths of the required number of bases. I used circular bases for smaller input figures and rounded rectangles for larger ones (see Figure 9.13, left). Then I duplicated all pictures, laser cutter paths and bases, and organised them as tightly as possible so that two complete sets of input figures would fit on a single 400 x 700 millimetre acrylic plate. I added registration marks to the layout, to be able to align the laser cutter to the print;

4. *Print drawings.* Per theme two acrylic plates were printed, giving me four complete sets of input figures: three sets for the three prototypes and one set for spare parts;

5. *Cut and fix drawings.* The printed figures were then cut using a laser cutter, after

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² Using synthetic speech would probably have saved a lot of production time here, but most experts in AAC highly recommend using natural speech.
which I sprayed painted the plates holding the cut-out figures with one or two layers of transparent glossy spray paint, to fix the printer inks;

6. Create final input figures. After a day of drying I removed the figures from the 400 x 700 millimetre acrylic plates and glued them to their bases. I then glued a congruent shape of white 4-millimetre acrylic to the bottom of the bases. These contained a circular cut-out in which I glued an RFID-tag (see Figure 9.13, right);

7. Program RFID-tags. As a final step, I created a list of all input materials—input figures, story scenes and word cards—and assigned a number to each for identification. These numbers were accordingly programmed onto RFID-tags;

8. Test input figures. I tested all input figures across a selection of exercises. The reason why I spend a full page describing these two examples is not to boast, but to illustrate that there is a consequence to doing Research-through-Design to the extent of the study described in this thesis. Making three fully functional prototypes simply is a lot of work. The important question then is: was it worth it? In my opinion: yes. First of all, as LinguaBytes is aimed at stimulating children’s language development it is necessary that it can be adjusted to the developmental level of individual children, while taking their personal needs, skills and preferences into account. This requires a broad offer in learning materials.

Secondly, as the only way to draw conclusions about LinguaBytes’ language stimulation properties is to longitudinally test LinguaBytes, more (and more durable) hardware and software are needed than were offered in the fourth Research-through-Design cycle. As illustrated in the previous section, only 3% of the input materials needed repairs and only four repairs to modules were necessary over the entire ten-month period. The weakest link in this respect was the software.

Thirdly, to properly determine LinguaBytes’ required adaptability and adaptivity it is necessary to get insight in the complete system. To get this insight I feel it is necessary as a researcher to leave as little as possible to the imagination, or as it is written in Chapter 2: “[…] contexts are inherently diverse and rich in subtlety and detail, which means that doing research in these complex contexts asks for developing detailed design prototypes that allow for this diversity, subtlety and richness during their confrontation with the world.” As this thesis is centred around designing for diversity, the investment in rich prototypes is top priority.

Finally, as this is a research project and not a design project, it is interesting to take Research-through-Design this far, as it is the only way to get a grip on the price of richness. Which brings me to a reasonable follow-up question: could the work described in this thesis also have been done in three or four cycles, or should there even be a sixth one? In other words, how do you determine when enough is enough? In my opinion each of the five Research-through-Design cycles described in this thesis made their individual
contribution: the first three cycles were necessary for finding focus, the fourth and fifth cycles were necessary for developing the final prototypes. I do not think that any of these cycles could have been skipped. As for the second part of the question: yes, I do think that a sixth iteration would make the research described in this thesis more complete. I would be very interested in implementing adaptivity in LinguaBytes and assessing whether this adds the value I believe it will. In my opinion this sixth iteration would be a very compelling one for various research communities.

Recommendations for adaptivity in LinguaBytes

This brings me to my second topic of reflection in this chapter. Throughout my research I have increasingly established that the key element of LinguaBytes is its flexibility to support the learning/teaching/communicating strategies of a myriad of diverse users. Additionally, it has become more and more apparent that part of this flexibility could lie in adaptive behaviour of the LinguaBytes system itself, as I have discussed in the previous section. Adaptive behaviour could for example support children with motor disabilities in their interaction with LinguaBytes, or caregivers in setting up the LinguaBytes system as efficient and intuitive as possible. Throughout Part III of this thesis I have reflected on promising opportunities for adaptivity. In this section I do this one final time.

Adaptivity aimed at supporting children using LinguaBytes. In its current form LinguaBytes can already be used by the majority of non- or hardly speaking children. Therefore one of the most valuable opportunities for adaptivity in LinguaBytes lies in including the most severely disabled children, not in a way that emphasises their limitations but in a way that enhances their feeling of independence. One way of doing this is to make

Figure 9.13 All input figures were created using a mortise and tenon connection. The vertical figures were glued on horizontal bases, after which a white layer was glued to the bottom. Finally, an RFID-tag was glued within the white layer's circular cut.
the interaction with LinguaBytes’ stories and exercises easier for these children, without making it fundamentally different. Let me illustrate this.

To make the interaction with the story module suitable for children with severe motor disabilities I would apply two changes to the module’s design: (1) I would make inserting booklets easier by borrowing a technique from copy machines: these often have a suction system that pulls paper into the machine. I would integrate such a suction system in the wooden track of the module, to help the child position the booklet at the proper location. The suction system should not be too powerful—I do not want it to vacuum the room in the meanwhile—but just powerful enough to unobtrusively help the more severely motor disabled child finish its action; (2) I would apply sensitivity profiles to the two handles, just as I had to the pressure sensors of Click-It 2.0’s puzzle module. In this case I would integrate touch sensors in the two handles and mount the handles on servomotors. Children with severe motor disabilities would merely have to grab a handle to trigger the booklet transporting system. Simultaneously, the servo would flip the handle, thus helping the child make the movement. Children with less severe motor disabilities can keep using the story module in its current form.

Especially the second design alteration was received with enthusiasm by the therapists whom I interviewed, as one can imagine reading the e-mail several pages ago. Giving children the feeling that they can actually do something—no matter how insignificant—individually not only boosts their morale but also that of the people around them.

To make the interaction with the exercise module suitable for children with severe motor disabilities I would apply small changes to the designs of the base module and the input materials, using magnets: (1) I would change the current, white plastic ring on the base of each input figure with a metal one and add a film of metal to each word card; (2) in addition I would place magnets under the exercise module’s trays, in the base module. As electromagnets need a lot of space I would preferably use normal magnets placed on cantilevers connected to servomotors (see Figure 9.14). Whenever one of the RFID-readers detects an input figure its accompanying magnet can be cantilevered up, closer to the tray, and not so much attract the input figure, but keeping it fixed to the tray to help children finish their action. In explorative mode the magnet system should respond to any detected input figure; in assignment-based mode it should only respond to correct figures.

Other adaptive behaviour can lie in more intangible aspects, such as the automatic adjustment of the audio volume (for children with hearing problems), the pace the spoken narrative, the speed of animated features, the delay between a child’s action and the on-screen response (for children who need a bit more time to move their eyes from the input location to the output location), the evocation of initiatives when a child appears inactive (for example through spoken prompts or morale-boosts), and more.

Of course these changes only make sense if I include some way of identifying the child
that is using LinguaBytes. I would use the identification system that I have described in Chapter 7.6. This system, using a personal identification tag, can become an integral, playful part of setting up the system just as the thematic backgrounds are. Moreover, inserting their tag can enhance children’s sense of control.

Adaptivity aimed at supporting caregivers using LinguaBytes. As I have hinted at the end of the previous section, the participating therapists were interested in LinguaBytes becoming highly adaptive, especially when this would mean that children with very severe motor disability could be included. They therefore greeted the proposed design alterations as described in the previous section with enthusiasm. Some were however slightly sceptical about LinguaBytes’ ability to keeping track of a child’s “results”. In their expert opinion the development of children can move in such mysterious ways, and depend on such trivialities, that they doubt whether a machine could ever get the sensitivity required to behave truly intelligently. This makes that the therapists saw the added value of a logging system, but were not sure whether LinguaBytes should adjust itself based on correct or incorrect answers alone, for example by offering ‘difficult’ word more frequently than ‘easy’ words. A child’s responses do not necessarily depend on his or her understanding of a word, they can also be determined by other factors such as children’s interests, mood of the day or on the TV-series they saw yesterday.

Based on my discussions with some of the participating therapists I propose the following additions to the LinguaBytes design.

Firstly, LinguaBytes should not only contain a child identification system, but also a communication partner identification system; different communication partners (speech therapists, preschool teachers, parents) can simply have different goals and thus, roles. This means that an additional identification tag should be insertable in the base module, similar to the one described in Chapter 7.6.
Additionally, LinguaBytes should take into account who is interested in which type of information, log everything it can, filter out the relevant information per communication partner and present this information to communication partners in a form that is matters at the moment it matters, without disturbing the flow of the interaction with the child.

This excludes using the output module. A better option would be to include a small screen in the control module on which information can be presented (and reviewed) out of reach of the child. LinguaBytes could for example show a child’s route through the stories and exercises over time and thus give an impression of its development, for example in monthly or half-yearly overviews;

Part of this information can be generated by the webcam that is included in the output module. This camera can record parts of a session with LinguaBytes, for example clips of a child using sign language. The recordings could be made ‘on-demand’, i.e. by the therapist using a record button on the control module, or automatically. For this LinguaBytes should include software that can (learn to) recognise facial expressions and gestures. Some of this software already appears on the market, for example in digital cameras (face recognition and smile recognition) or in Microsoft’s Kinect (Microsoft, 2010). Arendsen (2009) worked on gesture recognition software in the context of sign language for his doctoral dissertation.

LinguaBytes can automatically organise these recordings per sign as it knows which exercise the child is doing and which question it is being asked, and store the recordings per child. As such LinguaBytes can offer speech therapists an overview of how a child develops its mastering of specific signs over time, by showing a chronology of sign-specific movie clips on the control module. This could help therapists determine strategies for teaching children more sign language. Naturally, the webcam can also be used to record other information such as a child’s facial expressions or distribution of attention. LinguaBytes should keep track of the type of recordings per user so it can be more proactive in the future.

Finally, LinguaBytes could use all the information it logs to suggest exercises in follow-up sessions. As I illustrated earlier, some of the participating therapists were sceptical of LinguaBytes’ determining the content of exercises on correct or wrong answers alone, but they were open to a so-called ‘autopilot’: a setting in which they allow the system to learn from the child. In the autopilot setting LinguaBytes is allowed to ‘play the therapist’, under the condition that the human therapist present can always overrule the system. As such the autopilot mode functions as a calibration setting.

Of course, implementing all this is an awful lot of work and falls outside the scope of this thesis. I hope nonetheless that LinguaBytes will get the chance to evolve even further in the future, as the evidence of its potential is overwhelming.
PART IV
Reflections
Chapter 10

Reflections

10.1 Introduction

As I have explained at the beginning of this thesis this research has roughly two interwoven tracks: on the one hand there is the one aimed at developing the LinguaBytes system; on the other hand there is the one aimed at researching how to design a system such as LinguaBytes, or in more general terms 'how to design for diversity'. I have described how this research was done using a Research-through-Design approach, a process in which scientific knowledge is generated through, and fed back in consequent cycles of designing, building, and experimentally testing experiential prototypes in real-life settings.

Therefore, now that I am approaching the end of my 'thesis by design' or proefontwerp it is time for one final reflection on action and consider the contributions of this research. I address three topics. First in 10.2 I reflect on the method that I followed in this thesis: Research-through-Design. I discuss the method in general, as well as my specific use of it in this research. Additionally, I take a look at the future of Research-through-Design. In section 10.3 I reflect on tangible interaction by discussing the paradigm’s apparent strengths based on my research. In 10.4, the final section of this chapter (and thesis) I reflect on ‘how to design for diversity’, the question I raised in the preface of this thesis.

10.2 Research-through-Design

In this section I address the following aspects of Research-through-Design: (1) The changing nature of Research-through-Design prototypes; (2) The changing nature of the Research-through-Design process; (3) The role of the researcher-designer in the Research-through-Design process; (4) Doing Research-through-Design with very young non- or hardly speaking children, and; (5) The changing nature of Research-through-Design tools and skills.

The changing nature of Research-through-Design prototypes

In this thesis I have described how I developed LinguaBytes in a process spanning three years, in which I have designed, built and tested five generations of prototypes. The final result is a prototype that to date has withstood ten months of intensive testing. This prototype is however far from production-ready, which to some people comes as a surprise. Apparently the quality of the final prototype suggests LinguaBytes to be a production
prototype, obscuring the fact that it is a research prototype, a tool for getting grip on ‘how to design for diversity’.

As written in Chapter 2, Research-through-Design “relies on the generation of wealthy, experienceable prototypes.” The resulting end-prototype is, as Frens (2006) puts it, a “physical hypothesis that has sufficient product qualities to draw valid and relevant conclusions from”. In my opinion reaching this ‘sufficient product quality’ has never been self-evident—it simply takes a lot of time—but based on my research it is my conclusion that as we are moving into designing interactive, networked systems, reaching ‘sufficient system quality’ will be one the biggest challenges in future Research-through-Design projects.

The crux in this challenge lies in the word ‘sufficient’. What the work in this thesis shows is that ‘sufficient’ is far from absolute. In the first Research-through-Design cycle cardboard 3D sketch models were sufficient to get grip on the LinguaBytes positioning; in the fifth cycle it was essential to develop a fully functioning prototype. The reason for this was that the sought-for knowledge in the fifth Research-through-Design cycle was of a higher level of detail and consequently required a more realistic physical hypothesis for validation. Considering that products and systems are becoming more and more complex it is inevitable future Research-through-Design processes will require prototypes that go beyond physical hypotheses. Moreover, some systems may even consist of more ‘un-physical’ elements than physical. In my view future prototypes will become ‘embodied hypotheses’, products or systems that are networked, distributed, context-aware and adaptive, rather than merely physical hypotheses. Creating these embodied hypotheses will put a lot of strain on the already delicate trade-off between research goals, resources and effort.

Reflection 1

Considering that we are moving into the design of increasingly complex products and systems, one of the major challenges for Research-through-Design will be the generation of ‘embodied hypotheses’ that have sufficient system qualities to draw valid and relevant conclusions from.

The changing nature of the Research-through-Design process

In LinguaBytes—a relatively small, non-networked system—I have already had a first taste of the aforementioned increasing complexity, from the very first Research-through-Design cycle on. I have illustrated this as early as my reflection in Chapter 5. My conclusion back then was that, to be able to design a prototype with the required amount of adaptive behaviour—which would rely highly on factors like empathy and leniency—I needed: (1) more insight in the factors to which LinguaBytes should become adaptive, and; (2) strategies that will help me design and implement this adaptive behaviour. As I have
described in Chapter 6, I have tried to deal with this by approaching adaptivity through adaptability. In my opinion this approach allowed me to pinpoint realistic opportunities for adaptivity without having to invest in unrealistic ones. By making LinguaBytes highly adaptable first I could get more grip on the role of LinguaBytes, which appeared to encompass not only practical or functional aspects, but also high proportion of social and emotional aspects. I strongly believe that, had I made LinguaBytes highly adaptive from the beginning, I would not have had these insights. The prototyping effort would have been out of proportion. That is, given my current set of skills. I will come back to this at the end of this section.

**Reflection 2**

Making prototypes highly adaptable can help identify realistic opportunities for adaptive behaviour in consequent prototypes, without having to invest in unrealistic ones. Highly adaptable prototypes have the flexibility to support different people’s different behaviours, which helps determine the role of the prototype, both functional and social, in a specific context of use.

Inspecting my process itself, as described in Part III of this thesis, roughly two process phases can be identified: (1) an explorative phase in which the boundaries of LinguaBytes were established, and; (2) a refining phase in which I determined and designed the details of LinguaBytes. The change between these phases took place somewhere in the third cycle. Looking at the two phases shows clear differences.

A first difference is an obvious one: the used design techniques, or rather the balance between design techniques. As the first phase was focused on establishing boundaries, these boundaries were vividly explored and often crossed, using a variety of techniques that have in common that they allow for creating vast numbers of hypothetical realities in a quick and relatively effortless way. As an ensemble, the techniques I used—e.g., brainstorming, sketching, building mock-ups, creating personas, using Wizard of Oz simulations—are highly complementary, triggering different streams of thoughts, supporting different kinds of experience, thus allowing designer-researchers to view (and question) the world from different angles. The second phase however, was focused on refining, which requires additional techniques such as rendering and prototyping, or a different use of the same techniques.

The second, and more interesting difference between the two phases is the shifting balance between my idealism and pragmatism: during the first phase my ideals often overruled the practical consequences for the Research-through-Design process, whereas in the second phase this was the other way around. For example, one of the reasons to make KLEEd out of textile was the purely ideological one that I do not like children playing
with plastic toys only. In the fifth Research-through-Design cycle however, building three prototypes of sufficient quality consumed so much time and effort (see my reflections in Chapter 9) that pragmatism often prevailed.

**Reflection 3**

Building on Reflection 1 and my experiences it is my conclusion that, in future Research-through-Design projects, designer-researchers should fully focus on the idealistic aspects in the earlier, explorative phases of the process, as the practical impact of prototyping increasingly complex systems will become highly demanding in later phases.

As I have illustrated in Chapter 7, my fellow researcher Riny Voort and I tried to deal with the vastness of the LinguaBytes system by following a hybrid top-down/bottom-up approach: she would develop the language content top-down, setting up the structure and dividing the content over stories and exercises, while I would simultaneously design the play-and-learning system’s interface bottom-up. This appears to have been a good decision, since the approach has allowed both of us to balance our own ideals, pragmatisms and priorities and weigh them against the other’s.

One of the clearest examples of where the top-down and bottom-up approaches met is in the establishment of the number of thematic backgrounds. Originally, it was the idea to have one background per theme, for reasons of consistency and clarity. However, there are two themes that come with two backgrounds each: ‘Animals’ and ‘Toys and Clothes’. The theme ‘Animals’ comes with two backgrounds, one for farm animals and one for zoo animals, for the following reasons: (1) farm animals and zoo animals belong in different contexts and should not be mixed, not even in exercises; (2) having too many animals per exercise reduces the number of repetitions per animal, which can negatively affect the learning experience; (3) additionally, offering a child too many choices (= animals) within a single exercise can make the exercise too difficult; (4) not all animals are suitable for all exercises. For example, a fish has nothing to add to the ‘animal sounds’ exercise.

The theme ‘Toys and Clothes’ comes with two backgrounds as well. In earlier stages while my fellow researcher and I were determining the themes, ‘Toys’ and ‘Clothes’ were two separate ones. However, when creating exercises these themes turned out much smaller than the other themes. Additionally, the exercises belonging appeared to be complementary rather than overlapping. As we wanted to keep the LinguaBytes themes in balance in terms of content and materials, we decided to combine the two themes. We decided to use two separate backgrounds, for the following reasons. Firstly, adding a background could create another opportunity for caregiver-child communication. Secondly, to reinforce the thematic context of the interactive stories and exercises: the ‘Toys’ story and exercises were all situated indoors whereas those belonging to the ‘Clothes’ context were mostly connected to the weather outside. This argued for an indoor and an outdoor thematic background.
The role of the researcher-designer in the Research-through-Design process

Let me consider the KLEEd prototype again, for it nicely illustrates the role of the designer-researcher in a Research-through-Design process.

KLEEd was highly impractical: it was too big, slipped across the table, was not ideal for children who tend to drool and was sometimes difficult to interact with. However, most of these impracticalities were expected. I did not design KLEEd as a perfect production prototype. The goal of KLEEd was to get grip on why most of the commercially available products for these children are plastic boxes with buttons. In other words, through KLEEd I wanted to understand the line of thought of the designers of these commercially available solutions. In my view, building and testing experienceable prototypes is essential in this. Moreover, it is my strong conviction that the designer and the researcher should be the same person, although some people believe this to jeopardise the researcher’s objectivity. Let me explain myself.

As said earlier in this chapter, within Research-through-Design a prototype can be seen as a physical hypothesis. As such, it is not the physicalisation of a design; it is the physicalisation of the rationale behind the design. The prototype embodies the choices a designer-researcher makes based on the knowledge he has at a specific moment. This means that when a test subject interacts with a prototype he or she interacts with the designer-researcher’s line of thought. Therefore, the great advantage of the designer and researcher being the same person is that it becomes possible to relate findings to aspects of the design, or to factors in the design rationale, which is always partly based on the designer’s ideals.

Reflection 5

A Research-through-Design prototype is the physicalisation of a design rationale. This means that, when a test subject interacts with a prototype, he or she interacts with the designer-researcher’s line of thought. Therefore it is my conclusion that researcher and designer should be one and the same person.

Doing Research-through-Design with very young non- or hardly speaking children

Here I briefly describe the major issues when doing Research-through-Design with very young non- or hardly speaking children.

Firstly, as these children are young, preliterate and non- or hardly speaking, verbal feedback will have to come from people who can make reliable estimations about the child’s
performance within the research context. In the case of LinguaBytes these were the child’s speech therapists and parents, who know the children best. Throughout the LinguaBytes project their expert opinions have had a profound influence on the development of the design, in the form of questionnaires and interviews of various levels of formality. Not only at the end of each test period but also frequently during the design process, via face-to-face contact, telephone or e-mail.

Secondly, if the preference of the children themselves is to be established, it is wise to offer them physical alternatives that they can point, grab or glance at. Often the clearest sign of dislike is the child pushing your design away, the clearest opposite sign is the child not letting go.

Thirdly, it is important to invest ample time into learning to understand the target group. As I have described in Chapter 5, the success of LinguaBytes depends on its ability to be lenient towards its interaction partner. And as leniency depends on interpretation, which in turn depends on understanding, it is vital that the designer of leniency himself understands the user. There is a wealth of design knowledge in human behaviour. Training your sense of empathy is one of the best investments a designer-researcher can make.

The changing nature of Research-through-Design tools and skills
As I have illustrated in the first section of this section, I believe that the future of Research-through-Design lies in the creation of context-aware and adaptive ‘embodied hypotheses’. Based on my experience with LinguaBytes I strongly believe that the development of these embodied hypotheses, using a Research-through-Design method, will require different tools to keep issues such as the aforementioned out of proportion prototyping effort under control. For example, I myself would have liked low-threshold, easily embeddable, plug-and-play materials for making my prototypes networked and context-aware. Moreover, these materials should offer me the instant prototyping flexibility that is required for Wizard of Ozzing.

There is however a second reason why Research-through-Design requires new tools, apart from solving trivialities such as prototyping effort: new tools evoke new questions. Leonardo da Vinci, arguably the first designer-researcher, created his physical hypotheses based on what he had available. So, what if he had had, for example, electricity? This would have completely changed his scientific perspective. Research-through-Design is simply a method in which design and research are fully interdependent. Therefore, in order to remain relevant and alive, research and design will need to keep pushing each other forward.

Reflection 6
Although this view is not new, I find it necessary to emphasise that Research-through-Design
Which brings me to the following topic. I am a, so to say, traditionally trained industrial designer, which has had a fundamental influence on my approach to the work described in this thesis. For example, due to the simple reason that programming adaptive behaviour is not a part of my current skill set, I have approached adaptivity through adaptability. Making LinguaBytes highly adaptable first enabled me to gain insight in possible adaptive behaviour by investigating the role of LinguaBytes, which as I said encompassed not only practical or functional aspects, but also high proportion of social and emotional aspects. This has resulted in the recommendations for adaptivity in LinguaBytes I have described at the end of Chapter 9.

However, would I have used the same approach if I had more state-of-the-art designer-researcher skills? Probably not, knowing my designerly character trait of selective opportunism. Would I be discussing the same topics here? Probably not, given the reciprocal influence between design and research. Is this a problem? Probably not, given the apparent success of LinguaBytes in the field. However, looking back at my process I do feel somewhat limited by my traditional education. Do not get me wrong, I am very happy with the skills that I have, but I would like to have some more. Not because I want to be able to do everything myself, but because I want to gain a better understanding of the implications of my design decisions.

**Reflection 7**

Designers of intelligent systems need new skills to understand the implications of their decisions.

There is however one thing that will always remain the same in Research-through-Design: it will always be about people giving meaning to their world, in which ever form the world presents itself. We, designers, partially create this form, which gives us the moral duty to do this responsibly. Part of Research-through-Design should therefore always be focused inward, towards the ethics of design itself. On the whole the future of Research-through-Design will equal Process-through-Practice: designer-researchers will have to try out different approaches in order to establish a new set of skills, tools and methods. Through this thesis I hope to have shown my approach to an increasingly complex task, and I hope that my work can inspire my colleagues in theirs.
10.2 Tangible Interaction

As explained in Chapter 2, one of the foundations on which LinguaBytes was built, is tangible interaction. Tangible interaction approaches interaction design from our familiarity with the physical world and is based on a direct coupling between physical representation and digital representation. In Chapter 2 I have pointed out that many researchers believe that tangible interfaces could be highly suitable for learning, but that empirical evidence for this often lacks (Marshall, 2007). This is perhaps even more so in the case of the children at whom LinguaBytes is aimed: children that are very young and can have very limited motor control. I do not see this scarcity of related research as a handicap. On the contrary, it is here that I see the value of LinguaBytes within the tangible interaction research community.

In my experience, the children at whom LinguaBytes is aimed have qualities that by contrast can highlight the added value of tangible interfaces. Firstly, none of the children can read, which severely reduces the suitability of the symbolic indicators we, interaction designers, have been nurtured to rely on—think of arrows, exclamation marks, warning lights, text labels, etcetera—and urges us towards more direct ones. Secondly, many of the LinguaBytes children have reduced motor coordination, which forces us to be critical towards the trade-off between the value of tangibility and a child's effort to access this value.

In other words, by force-fitting tangible interaction with an at first glance unlikely user group, we can investigate which benefits of tangible interfaces persist and which not. In Chapter 2.3, annotations [9] through [13] I have already commented on the six benefits of tangibles for learning as stated by Marshall (2007). Here I take a broader perspective, based on the strengths of tangible interfaces as identified by Shaer and Hornecker (2009). These strengths are: (1) ‘Collaboration’; (2) ‘Situatedness’; (3) ‘Tangible thinking’; (4) ‘Space-multiplexing and directness of interaction’, and (5) Strong-specificness enables iconicity and affordances.

Collaboration – A first strength identified by Shaer and Hornecker is the quality of tangible interfaces to facilitate collaboration through factors including:
  • Familiarity and affordances known from everyday interaction with the real world lower the threshold for engaging with a system and thus increase the likelihood of users to actively contribute;
  • Multiple access points allow for simultaneous interaction and easing participation;
  • Manual interaction with objects is observable and has enhanced legibility due to the visibility of the physical objects;
  • Tangible objects can be handed over and shared more easily than graphics, thus tangible objects foster shared discussion.

Based on my research I tend to stand behind this apparent strength. By offering an interface that connects to the world of children—a generally playful world—they are invited to join in the interaction. The last of the four factors mentioned above is pivotal in this. The
fact that tangible objects can be handed over and shared more easily than graphics makes that LinguaBytes can be used in communication, and thus as a means of participation. Knowing that LinguaBytes builds on social constructivism this quality is fundamental to its contribution to a child’s learning process.

**Reflection 8**

The LinguaBytes research seems to support the advantage tangible interfaces hold over traditional computer interfaces with regard to supporting collaboration. Tangible materials can be used more easily for communication and thus participation than graphical, on-screen materials.

_Situatedness –_ A second strength identified by Shaer and Hornecker is situatedness, which implies that the meaning of tangible interaction devices can change depending on the context in which they are placed, and reversely, they can alter the meaning of the location. According to Farnaeus Tholander & Jonsson (2008) the consequence of this is that interaction designers should also be “thinking about the interactions around the system, and how people interact with each other even when this activity is not directly directed at the interface. Physical interaction will often result in many manipulations of interface elements being performed ‘offline’, directed at the social and physical setting.” I fully agree with this. Moreover, LinguaBytes is aimed at ‘offline’ interactions: those between a child and its caregivers or peers. LinguaBytes creates opportunities for social behaviour, either directed through its digital component or outside it. The behaviour of LinguaBytes itself could be made context dependent, as described in section 7.6 of this thesis.

**Reflection 9**

The LinguaBytes research seems to support that ‘situatedness’ is a strength of tangible interfaces. The meaning of LinguaBytes clearly changes depending on the (social) context in which it is placed, and evidently alters the meaning of the location.

_Tangible thinking_ – Shaer and Hornecker identify a third strength of tangible interfaces compared to traditional user interfaces: “they leverage the connection of body and cognition by facilitating tangible thinking—thinking through bodily actions, physical manipulation, and tangible representations.” Based on my research I agree with this apparent strength. In LinguaBytes tangible thinking manifests itself most notably in the sentence-building exercises. In these exercises children can physically construct sentences and identify in a hands-on way the impact of grammatical elements on the meaning of their combination.
Space-multiplexing and directness of interaction – Space-multiplexing means that an interface uses multiple interaction objects that can represent different functions or different data entities. This supports parallel actions, which can make the interaction more direct than traditional graphical interfaces (which are called ‘time-multiplexed’). In my opinion this apparent strength is not per se unique to tangible interfaces: looking at current advances in multi-touch graphical interfaces it can be observed that these also allow for manipulating multiple data controllers simultaneously. In this, we can even look ahead towards ‘minority report’ interfaces (Twentieth Century Fox Film Corporation, 2002), which are fully virtual, but highly gestural and possibly expressive—I say possibly here because the gestures mostly appear quite aggressive; I would have liked to see some nuance. In my opinion, the major advantages of so-called ‘tangible space-multiplexing’ are not so much that multiple interaction objects can represent different functions or data entities. For me the strength of tangibility lies in how they appeal to the richness of our everyday world. As such tangible interfaces can trigger our imagination.

Looking at LinguaBytes I see the following strengths of tangibility:

• Interaction objects are not bound to the 2D virtual world. This means that they can be used for other purposes outside the interface. For example, LinguaBytes’ story booklets can be used as regular booklets, the input figures are frequently used as alternative communication and the RFID-labels allow for creating even interaction objects that are even richer and more personal. Also, children can use the interaction objects as they would use their toys: they can make a selection, carry them around, have them interact with each other, etcetera;

• Interaction objects allow for eyes-free interaction, which could be clearly seen in the example described in section 6.4, in the evaluation of KLEEd’s combination module. The boy shouting “Tom, wake up!” at the screen kept watching the animated result of his actions without looking at his hands;

• Interaction objects can be used as an appealing alternative for dedicated menu functions, at any time during the interaction. In LinguaBytes the thematic backgrounds (which functioned as menu filters) formed an integral part of the social interaction between caregiver and child, thus turning an otherwise flow-disturbing functionality into an opportunity for learning;

• This makes that the interaction through tangible interaction objects is not only more direct, but also better balanced between the strengths of the virtual world and those of the physical world.

Reflection 10
The LinguaBytes research seems to support that tangible interfaces can support tangible thinking, i.e., thinking through bodily actions.
**Strong-specificness enables iconicity and affordances** – Space-multiplexing means that interaction objects do not need to be abstract and generic but can be strong-specific (Fitzmaurice, 1996; in Shaer and Hornecker, 2009), dedicated in form and appearance to a particular function or digital data. I have illustrated this above through the example of the thematic backgrounds.

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**Reflection 11**  
The apparent strength ‘Space-multiplexing’ ignores the phenomenological aspect of tangible interaction. Tangible interaction is not interesting for what happens computationally, but for the behaviour it can trigger.

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**The contribution of LinguaBytes to tangible interaction**  
Apart from the aforementioned insights in tangible interaction as represented by Reflections 9, 10 and 11, I think there are several contributions LinguaBytes has made to the field that I should highlight.

Firstly, I think LinguaBytes is—for the time in which it started at least—a rare example of how tangible interaction can actually be implemented in a real-world situation and bring real value to real people: (1) tangible interaction grants very young children with often-limited motor skills more room for initiative taking, as the interaction with LinguaBytes is not only limited to accessing digital content. Children can interact with all of LinguaBytes’ tangible materials at any given time. They can use the materials standing in front of them for immediate action, point at or grab other materials to indicate a change of theme or application, or even access the storage box for drastic initiative taking; (2) As a consequence, tangible interaction allows children more control over timing. This typically results in a slower interaction pace, which creates more moments for caregiver-child communication and thus opportunities for learning; (3) Additionally, tangible interaction can involve children in activities typically reserved for their caregivers, such as setting up the system. As such these activities become part of the communication process: children can help choose a thematic background, they can help place the story module or exercise module, even programming their cuddly toy’s RFID-label makes them part of the setup process since it becomes a communication topic; (4) Many existing materials are aimed at making interaction as easy as possible, resulting in interfaces that often emphasise children’s limitations. LinguaBytes’ tangible interaction on the other hand offers an interaction based on low-threshold physical manipulation, allowing children with motor disabilities to prove to themselves that they are capable of the same things as ‘normal’ children. This helps raise their self-esteem and confidence.
As a general consequence children show more engagement in the interaction, which can consequently lead to more opportunities for learning. As such tangible interaction could, as Marshall states, lead to more effective learning. This is not simply my opinion, but one that has been articulated by all participating caregivers in the fifth Research-through-Design cycle.

Secondly I believe this research has contributed to the awareness of the role of design aspects such as form and materiality within the tangible interaction community. These are elements that have a fundamental impact on not only the appeal of tangible interfaces, but also the interaction with tangible interfaces. Consider the impact of making a paper coffee cup out of sponge. Not only would this change the appeal of the cup, but also the interaction with the cup; the way you would drink your coffee. Throughout this research I have spent much attention to design details in order for LinguaBytes to be rootable in reality. Sometimes I had to concede some of my ideals to pragmatism—for example, I did not succeed in offering children the myriad of tactile stimuli I would have liked, or ‘go as embodied’ as would have liked—but on the whole I believe that the attention to the design details and the seriousness with which content material has been created and tested show that this application is not a toy example, created just for supporting a publication, but a serious attempt to advance the state of the art in the field from the perspective of design. There is more to prototyping than rapid prototyping.

Thirdly and finally, as stated at the end of section 2.3 in Chapter 2, at the time this research started there had been a scarcity of examples of tangible interaction in its or similar contexts. I hope that through this research the potential of tangible interaction has become apparent, as well as its viability.
10.3 Designing for diversity

In the Preface of this thesis I have expressed how the world of jazz music—which exists by the grace of personal input from the musician, channelled through the structured openness of a composition—has inspired my view on the role or rather, responsibility of design. I stated that we as designers should be focusing more on creating ‘platforms for personalisation’, platforms that have the flexibility to become the expressive extensions of the people using them. Of course I do not envision a world in which every artefact should be designed as a tool for expression—my vacuum cleaner does not have to be designed to tempt me to tango—but I do believe that designer-researchers should invest in determining how we could design for diversity, now that enabling technologies are within reach.

I have tried to do this through LinguaBytes: (1) LinguaBytes’ goal was to stimulate caregiver-child communication (just as a jazz composition is designed for communication between musicians), which required children to be able to express themselves; (2) the targeted children, as illustrated throughout this thesis, are very diverse in skills, limitations, backgrounds, needs, interests, backgrounds, etcetera (just as individual band members can be). This requires LinguaBytes to be highly flexible, a tool that fits individual children and helps them in their development, from their optimal starting point, via their optimal route.

How to design for diversity?

In the preface of this thesis I identified four guidelines based on my musical history, that I supposed would help me in developing LinguaBytes as a platform for personalisation:

1. LinguaBytes should be adjustable to a child’s personal style of expression in order to support its style of learning;
2. LinguaBytes should grow along with the child, opening up next steps in its development;
3. LinguaBytes should offer structure—its directive is to improve children’s language skills—but also openness to freely move around within this structure; this should keep LinguaBytes alive and interesting;
4. In order for LinguaBytes to be fully flexible it should be context-dependent: it should be able to take into account who is/are using LinguaBytes and under what circumstances and be either adaptable or adaptive to these.

I reconsider these guidelines in the remainder of this section, by reflecting on the final LinguaBytes design and decisions leading up to it. The goal of this reflection is to identify elements that could help designing for diversity.

*LinguaBytes should be adjustable to a child’s personal style of expression in order to support its style of learning* – This is the most difficult guideline of the four, as there is always a reciprocal influence between someone’s expressivity and the platform for expressivity. In
other words, this guideline could imply that whatever you design will do. This, however, is not how this guideline should be interpreted. What this guideline argues for is to take personalisability as a starting point for design, rather than to leave personalisability to chance. I elaborate on this when I reconsider the third of the guidelines mentioned above.

Another difficulty with this guideline is that the expressivity of children with motor disabilities can be very different from the expressivity we are familiar with, as I explained in Chapter 4. This can be compared to how in some cultures smiling is an expression of joy and in others an expression of embarrassment, or even anger. In LinguaBytes this has raised the fundamental question who’s language the system should be developing: that of the child or that of the caregiver? I decided to do a bit of both. LinguaBytes is a platform for creating what I call ‘negotiable languages’. By this I mean that children and their caregivers can use LinguaBytes to learn each other’s language and establish an agreed one. As such, it could be argued that LinguaBytes supports creating intersubjective understanding (see Chapter 2, section on phenomenology).

**Reflection 15**
When designing for diversity it is necessary to provide (inter)actors with a platform with which they can establish shared meaning.

LinguaBytes provides two elements necessary for creating language: it provides vocabulary and grammar. LinguaBytes’ vocabulary is largely physical, represented by the input figures, story booklets, word cards, thematic backgrounds and modules. These are elements that are inherently representational, for example: the story module represents reading interactive stories.

LinguaBytes’ grammar is two-fold. The first part is based on predicable effects of combinations of the physical vocabulary, for example: placing an input figure on the exercise module always results in an animated representation on the output module; moving the story module’s right handle always ‘pushes’ the story booklet to the left. A second part of LinguaBytes’ grammar is based on the system’s affordances. In other words, it is grammar created through behaviour. For example, a child can point at, look at or grab the story module to indicate that it wants to read a story. Or the child can push the module away if it wants to do something else. Or the child can grab the toilet figure to express the need to use the real-life one next door.

**Reflection 16**
LinguaBytes is adjustable to a child’s personal style of expression because it provides a structure of inherently representational elements that is predictable enough to be meaningful.
LinguaBytes should grow along with the child, opening up next steps in its development

Most of LinguaBytes’ ability to grow along with the child is based on cognitive development: the system provides 16 interactive stories and 220 exercises on four different difficulty levels, ranging from fully action-reaction based explorative exercises for the 1-year-olds to more difficult and regulated assignment-based exercises for 4-year-olds. Many exercises are offered in explorative and assignment-based modes, which means that individual exercises can be offered in easier and harder forms, depending on a child’s development. Using the control module it is even possible to switch between these modes during exercises, which makes it possible to finetune them on the level of individual words. This flexibility of, and vastness in content makes that LinguaBytes can support the linguistic development of a wide range of children, over a longer period of time.

In terms of motor development LinguaBytes’ ability to grow along with the child is more limited: the approximately 300 input materials were simply not designed for developing motor skills. Their design was based on providing children with sometimes very limited motor skills with an interface that would enable them to interact with digital materials in a way that would emphasise their physical abilities instead of their limitations. The way in which LinguaBytes’ input materials grow along with the child is through gradual expansion: where 1-year-olds will typically only use a handful of materials, 4-year-olds will be able to use the whole box. This introduces the motor skill of manual selection. As such, the interaction with individual materials will not change, but the interaction with groups of materials will, which could support a child’s motor development, as well as its cognitive development.

Another way in which LinguaBytes takes children’s motor development into account is through the creation of custom input materials, using the RFID-labels. These allow for providing the child with a wide range of tactile stimuli, apart from those provided by the standard LinguaBytes materials. In addition I have described in earlier chapters how the puzzle module’s pressure profiles can be used to develop a child’s motor skills (see Chapter 7, section 3) and how the story module’s handles could be made touch sensitive (see Chapter 9, section 4). However, these functionalities have not been implemented in the final LinguaBytes prototype.
This brings me to the second part of the guideline: opening up next steps in its development. This could suggest autonomous system behaviour. I go into this further in the last section of this section. Here I will merely say that, due to its vastness, it is not necessary that a child follows a prescribed route through LinguaBytes’ content. This makes that, wherever a child may be have started, next steps can present themselves in the form of (1) similar exercises in different themes, or; (2) different exercises in the same theme.

In conclusion, LinguaBytes grows along with the child by providing a very wide range of stories and exercises on different developmental levels, that can be mastered in a non-prescribed route. In addition, LinguaBytes grows along with the child’s motor development by increasing the number of manipulable materials.

**Reflection 17**

LinguaBytes grows along with the child by providing a very wide range of stories and exercises on different developmental levels, that can be mastered in a non-prescribed route. In addition, LinguaBytes grows along with the child’s motor development by increasing the number of manipulable materials.

**How to design for diversity: recommendation 2**

Systems designed for diversity are able to grow along with the user by: (1) providing a wide offer in stimuli for all skills, i.e. cognitive, perceptual-motor, social, emotional; (2) allowing the user the freedom to tap into combination of stimuli; (3) move through the system along any route.

LinguaBytes should offer structure—its directive is to improve children’s language skills—but also openness to freely move around within this structure; this should keep LinguaBytes alive and interesting – I have reflected on this guideline to a large extent in the previous two sections. LinguaBytes provides stories and exercises on different developmental levels. These stories and exercises are grounded in a well-researched structure, thus providing clear developmental checkpoints, which can help establish insight in a child’s linguistic developmental stage. The route to move through the structure is open, i.e. not prescribed. This means that a child may be at a 4-year-old’s phonological level while still at a 1-year-old’s syntactic level, or that a child may have mastered the ‘animals’ theme while being oblivious of the ‘food’ theme.

I think the most important contribution of this guideline lies in the last part: ‘this should keep LinguaBytes alive and interesting’. Throughout the LinguaBytes project there has been a tension between keeping LinguaBytes alive and interesting—which I mostly tried to do by expanding the number of content and materials—and keeping it usable, which is done best by reducing the number of content and materials. In my opinion it is
this tension that will be a major challenge in designing for systems. Let me explain this through an example.

I, like many people, drink my coffee with sugar. Several systems are available that support me in this. For example, I can add a lump of sugar to my coffee, which may seem straightforward enough but sadly, is not: depending on the size of the coffee cup, this amount of sugar is often too much for me. What I therefore often do is break the lump into two pieces, of which I select the one that will most likely meet my desires. By breaking the lump, I have increased the resolution of the sugar system from ‘lumps’ to ‘demi-lumps’, allowing myself more freedom in dulcification. This breaking-of-lumps is often sufficient, but also a bit rough. Luckily for me there are at the university sachets of table sugar, which offer an even higher sugar system resolution: one on the level of individual crystals. Of course I do not go as far as adding a precise number of crystals to my coffee, but at least I have more freedom to adjust the amount of sugar to the size and fullness of my cup. Currently I estimate that my most common sugar consumption is approximately 40% of a sachet per cup. There is probably an optimal sugar system resolution for each every coffee drinker. Where my sugar box will contain quarter and third lumps—which I can freely combine to slightly-more-than-half-lumps for larger cups—somebody else's sugar box may contain half lumps and full lumps.

The important point of this, admittedly rather silly, example is that determining the ‘optimal system resolution’ for static systems for single users is relatively easy but gets increasingly difficult once you start designing dynamic, multi-user systems; systems that are adaptive, growing, open. How can you determine as a designer that enough is enough? How do you design openness without it resulting in arbitrariness? The evaluation of the final LinguaBytes prototype suggests that it holds enough materials to keep it alive and interesting for ten months, but I do not know whether it will be enough to grow along with a child for three years. Therefore, adding to the previous reflections it is my conclusion that LinguaBytes should stay alive and interesting through its vastness. However, it is difficult to establish a rule of thumb for the optimal resolution of a system such as LinguaBytes.

**Reflection 18**

There is no rule of thumb to establish a system’s optimal resolution.

**How to design for diversity: recommendation 3**

Less is not more, more is more.

*LinguaBytes to should be context-dependent: it should be able to take into account who is/are using LinguaBytes and under what circumstances and be either adaptable or adaptive to these – This guideline contains several of LinguaBytes’ most crucial ingredients:*

- A single LinguaBytes prototype can be used by very different children as I have
described at the beginning of this section;

• These children can use LinguaBytes with different partners, e.g., therapists, parents or other children;

• LinguaBytes can be used in different settings, e.g., in speech therapy, occupational therapy, or the home environment;

• LinguaBytes should take any combination of child/partner/environment into account, as these all have an influence on the role of language, and thus on its own role;

• LinguaBytes should be adaptable or adaptive in order to play this role aptly.

I think I have already described enough how LinguaBytes is adaptable in the previous sections. Additionally, I have addressed viable opportunities for adaptivity in LinguaBytes in the final section of Chapter 9.

The most important aspect to reflect on here is ‘context-dependent’. As the description above shows, ‘context’ is a combination of human factors and environmental factors. This suggests that systems that support diversity should ideally be aware of all these factors. I do not believe this is possible, certainly not in the near future. However, as I have shown in Chapter 9, it is also not strictly necessary. I think the essence of context-awareness is not that the system understands everything that goes on, but can identify those elements of the context that can help the system understand its own role. In my research I have done this by making LinguaBytes highly adaptable first. Perhaps future intelligent systems can do the same.

Reflection 19
Context-awareness does not mean that a system understands everything that goes on, but can identify those elements that can help it understand its own role within that context.

How to design for diversity: recommendation 4
Combine and use Reflections 1 and 5.

Designing adaptivity will be one of the fundamental challenges in our move towards designing intelligent products and systems, or more broadly, towards designing Ambient Intelligence, a vision on the future in which technology is integrated in everyday, personal life (Aarts and Marzano, 2003). As I have experienced illustrated throughout this thesis, designing adaptive behaviour is not trivial. It requires synthesising intricate qualities such as empathy or leniency, qualities that depend to a large extent on understanding people's intentions, drives and desires. Moreover, if technology should become an integral part of our everyday lives, it should not only understand the subtleties of our behaviour, but also show that it understands in its own behaviour. This will require a new form of aesthetics.
Reflection 20
Since our everyday world is rich and subtle, the design of adaptive behaviour in intelligent products and systems should be rich and subtle.

How to design for diversity: recommendation 5
When designing adaptive behaviour, begin quantitatively low but qualitatively high: personally I’d rather have something that understands part of me completely, than the complete me only partly.

Diversity, phenomenology, embodiment
The five recommendations above indicate that the key to designing for diversity is in the creation of wealthy and subtle platforms for behavioural opportunities; systems that through our individual input become meaningful, and thus valuable, to us. To illustrate this: throughout this research a trend could be observed that the richer the system became, the more the participating children seemed to act through the system, rather than on it. As such I could argue that to design for diversity is highly phenomenological.

Reflection 21/How to design for diversity: recommendation 6
To design for diversity is to design for behavioural opportunities.

What I should emphasise in this perspective is that the transition from acting on to acting through seemed to be synchronous with the transition from learning language to applying language, i.e., communication. This automatically introduces a partner in interaction and thus, embodied interaction. As stated in Chapter 2 designing for embodied interaction is aimed at creating interactive artifacts that allow for this creation, manipulation, and sharing of meaning. Consequently, I see embodied interaction as a fertile paradigm for designing for diversity.

However, as I have learned from this research, creating such interactive artefacts requires a lot of investing in establishing the role of the artefact within the interaction. By that I mean not only its functional role, but also its social role. In this research it took me five iterations to get a grip on LinguaBytes’ role, and consequently on its required behaviour.

Reflection 22/How to design for diversity: recommendation 7
In order to design for diversity it is necessary to establish the role a system should play in interaction. The system’s required behaviour ultimately will determine its form.
Coming full circle

At the very beginning of this thesis I have described how the designer in me has been inspired by the musician in me. The fair question now is: has the musician in me been inspired by the designer in me, now that both are almost five years further?

My answer is ‘I believe it has’ and I will try to explain why.

Through my research I have found a new appreciation for authenticity and originality, not just of the individual but more that which originates where individuals meet. In the liner notes to Miles Davis’ legendary album ‘Kind of Blue’ pianist Bill Evans writes:

“This conviction that direct deed is the most meaningful reflections, I believe, has prompted the evolution of the extremely severe and unique disciplines of the jazz or improvising musician. Group improvisation is a further challenge. Aside from the weighty technical problem of collective coherent thinking, there is the very human, even social need for sympathy from all members to bend for the common result. (Bill Evans, 1959)”

As a result I believe I listen to music differently, not in the last place my own. Based on what I play and an analysis of how I played, I decided it was time for new ideas; I had the feeling I was playing the same stuff over and over again. Therefore, I have enrolled in the conservatory again, taking lessons from people with strong ideas both about being a musician and about being an instrumentalist.

Time and again am I amazed by the rewarding beauty of the system called ‘jazz’: the more rules I soak up, the more freedom they grant me.
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Summary

Designing LinguaBytes: A Tangible Language Learning System for Non- or Hardly Speaking Toddlers

Technological advances are moving the field of industrial design towards intelligent products, systems and services. Today we, designers, have the possibility to create environments that are aware of, and responsive to our actions, needs and wishes. As such we are getting closer to what is commonly known as Ambient Intelligence—a world of intelligent products and systems that are embedded, adaptive, context-aware and anticipatory. Such a world could considerably enrich our daily lives, under the condition that it fully understands our actions, needs and wishes.

This is where the promise of Ambient Intelligence (AmI) gets difficult. Our actions, needs and wishes are not always straightforward; what we do is not necessarily based on logic—the condition-based perspective of machines—but on what we find meaningful. Consequently, if intelligent products and systems are to blend into our daily environments they should not only be able to understand what we find meaningful, but also respond in a way we recognise as meaningful. Here lies the role of the industrial designer of the future.

This design dissertation is based on the conviction that meaning emanates from how we interact with the world, an idea inspired by Gibson’s theory of perception and the philosophical school of phenomenology. As meaning emanates from how we interact with the world, it is fully dependent on how we are in the world and therefore by definition subjective. Consequently, the only way to design Ambient Intelligence is to be respectful to human diversity. But how can we do this? How can we design for diversity? How can we, designers, deal with the complexity of heterogeneous user groups? These are the central questions in this dissertation.

These questions are addressed in this dissertation using a single, three-year case study, aimed at designing LinguaBytes: a tangible, language learning system for non- or hardly speaking toddlers. Given the fact that these children (with ages between one and four years old) show great diversity in their being-in-the-world, it is crucial that this, to-be-developed, LinguaBytes system perfectly fits the way in which these young children perceive and experience the world, understand the world and give meaning to the world. Consequently, LinguaBytes should be highly flexible to be able to support this diversity.

In this research the question ‘how to design for diversity’ was explored through five Research-through-Design cycles.
The first cycle (Chapter 5) was aimed at defining theoretical foundations for this research and at getting grip on the research context. The theoretical foundations are presented in Chapter 2, which also includes a description of the research method. Chapter 3 and Chapter 4 include additional theoretical foundations and starting points with regard to the users and context of use, and learning (most prominently Social Constructivism) and early language development, respectively. As this research was done using a Research-through-Design method, the information presented in Chapters 3 and 4 was not a given at the start of the project, but accumulated and refined throughout the project in a continuous transaction between scientific knowledge and design action.

The second goal of this cycle—getting grip on the research context—involved gaining empathy for the LinguaBytes users and context of use, in order to determine design strategies as well as a global positioning for LinguaBytes in relation to existing products and systems aimed at stimulating early language development. For this, several actions were undertaken, which resulted in a global definition of the LinguaBytes design space. This space was defined by two characteristics: (1) the system’s presence in the physical and/or virtual domain; and (2) the prominence of language, sub-divided into foreground or background language. It was concluded that LinguaBytes’ design should allow for adjusting the balance between its physical and virtual characteristics, as well as the prominence of language in order to make it suitable for children of different ages and developments.

As an exploration of this design space a set of four experienceable 3D-sketches were developed and tested in a Wizard of Oz setup, with two children from the target group and their caregivers. This exploration resulted in the conclusion that the success of intelligent systems such as LinguaBytes, pivots on the ability of these systems to interpret the user, on the accuracy of this interpretation, and on the ability to accurately interpret the interpretation itself. In short, the success of intelligent systems depends on their adaptive competence. It was concluded that, in order to be able to design a sufficient amount of adaptivity in LinguaBytes: (1) more insight was required in the situated factors to which LinguaBytes should become adaptive. It was decided to focus on children with Cerebral Palsy and on the context of speech therapy; (2) strategies were needed that would help design and implement this adaptive behaviour in future LinguaBytes designs.

These issues were addressed in the second cycle (Chapter 6), through an extensive brainstorm on adaptivity, which resulted in two important conclusions. The first conclusion was that adaptation can be sub-divided using two criteria: (1) Are the adaptations made to the user or to what he or she is using? In other words, is the user being made suitable for what he or she is using or the other way around? (2) Who does the adapting, the user or what he or she is using? In other words, does someone do the adjusting or are the adjustments automated? In this research these two situations are called system adaptability...
and system adaptivity, respectively. The second conclusion was a strategic one: system adaptivity can be approached via the less complex route of system adaptability. Based on this strategic conclusion, it was decided that LinguaBytes would be developed as a highly adaptable system first, which could help determine guidelines for making it highly adaptive later.

The resulting, first fully functional prototype—the adaptable starting point for future, more adaptive designs—was KLEEd, a modular system consisting of four modules and five tangible input materials that supported reading an interactive story and doing a syntactic and a semantic exercise. The KLEEd design was experimentally tested at two locations, a child rehabilitation centre and a school for special education, with a total of seven individual children, accompanied by his or her usual speech therapist or educationalist. KLEEd was tested in two 25 to 30-minute sessions per child, separated by a week.

Three conclusions with regard to ‘how to design for diversity’ were drawn from this study. The first was that, in order to support for meaning creation through action, LinguaBytes should hold opportunities for improvisation; it should allow children to create their own rules within a provided structure. Secondly, it was concluded that a powerful form to support improvisation is through physical manipulation. Thirdly, it was concluded that adaptive behaviour requires two rule sets: one on which LinguaBytes can base its behaviour, and one on which LinguaBytes can decide to change its behaviour. It was concluded that, to establish these rule sets in future Research-through-Design cycles, it was essential to determine LinguaBytes’ role in the language learning process; not only its functional role of providing stories and exercises, but more importantly its social role in the interactive triangle child-caregiver-LinguaBytes. To determine these roles it was concluded that, when doing Research-through-Design, the quality of the conclusions are fully dependent on the quality of the prototype. Rich, full-scale prototypes not only embody designs, they embody design rationales. Experienceability is an integral part of this: seeing test subjects interact with the ‘embodied line of thought’ helps the designer identify flaws in this line of thought.

The third cycle (Chapter 7) was aimed at increasing reality further. The KLEEd system was redesigned in order to support more language aspects and increase its adaptability. This resulted in an expansion of the system. As it was anticipated that the system would increase in vastness further in the future a ‘hybrid’ approach to systems design was devised: LinguaBytes’ content component would be developed using a ‘top-down’ approach, and its physical interface component using a ‘bottom-up’ approach. It was anticipated that this would provide both structure as well as space for inspiration.

The resulting KLEEd redesign was a system called Click-It that, like its predecessor, was a modular system that supported interactive story reading and doing story related,
linguistic exercises. Click-It supported eight exercises, divided over three linguistic categories: phonology, semantics and syntax. Compared with KLEEd, Click-It’s input and output functions were divided over more modules and more, reusable, input materials. In total, Click-It consisted of two modules that were used across applications, four application dependent interface modules and around 25 RFID tagged input materials. Click-It was experimentally tested with a total of twelve children at two child rehabilitation centres. The children used the prototype individually, accompanied by their usual speech therapist, in two speech therapy sessions separated by a week.

Although this design was far from perfect, its higher level of realism allowed for identifying a first set of guidelines for adaptivity. Firstly, it was determined that the final LinguaBytes system should include at least two detection systems to be able to adapt its setup to the needs and preferences of individual children: one to detect the modular setup, and one for the identification of the child using the system. Secondly, LinguaBytes should keep track of a child’s motor behaviour and adjust its own actuation behaviour accordingly. Thirdly, LinguaBytes should behave differently in different contexts of use (for example, the home environment, the context of speech therapy) and exchange information between these contexts of use.

Despite these apparent opportunities for adaptivity, this experiment also revealed scepticism towards adaptivity: no matter how intelligent LinguaBytes would ever become, the participating therapists did not believe it could ever obtain the required social intelligence to equal a human’s. They indicated that they wanted to be able to overrule LinguaBytes when necessary, which could help LinguaBytes learn. In addition, it was concluded that the system should allow for even more flexibility, for example through the possibility of creating personalised input materials.

The fourth cycle (Chapter 8) therefore showed strategic system changes: (1) to increase speech therapists’ control over (the timing of) Click-It’s content the desired ‘control module’ was added; (2) programmable RFID labels were included, with which a child’s own, familiar materials could be turned into system input; (3) two tangible thematic backgrounds were included to increase instant adaptability. In general though, the fourth cycle was one of refinement as the Click-It prototype functioned predominantly well. Click-It was redesigned to solve functional and constructive issues, but most effort was invested in expanding the system to increase adaptability. This resulted in a prototype that supported a full set of stories and exercises within one semantic theme. The prototype, called Click-It 2.0, consisted of two cross-application modules, four application-dependent interface modules and almost 50 RFID tagged input materials. It contained two interactive stories and 39 exercises.

Click-It 2.0 was experimentally tested at the same two child rehabilitation centres
as in the third cycle, with a total of nine children, accompanied by their regular speech therapists. The children used the prototype in up to three speech therapy sessions separated by a week. In addition to individual sessions with Click-It 2.0, some children also used it collaboratively.

From this experiment it was concluded that Click-It 2.0 approached a level of adaptivity required for supporting the diverse language developments of most children from the user group, but also that two actions were needed to thoroughly ascertain this: (1) a longitudinal study with multiple prototypes; (2) a exponential expansion of content and input materials.

The fifth cycle (Chapter 9) was aimed at developing the final LinguaBytes design and producing three fully functional prototypes for longitudinal testing. Click-It 2.0 was therefore redesigned with an eye on stability and safety, and its content was expanded. The resulting design (described in detail in Chapter 1 of this dissertation) encompassed a set of approximately 500 core words, distributed over 16 stories and 220 exercises. To interact with these stories and exercises the design contained a wide range of input materials—16 story booklets, 236 input figures and 31 word cards—and five modules for input, output and control.

The final design, called LinguaBytes, was tested at four different locations with a total of 65 children and 19 caregivers. LinguaBytes was used for ten months on a daily basis, up to multiple times a day. Most often LinguaBytes was used in individual sessions with a speech therapist, but also in group-sessions with up to four children under the supervision of therapeutic preschool teachers.

The longitudinal study showed that LinguaBytes indeed possessed the required amount of content and materials to support the diverse language developments of the targeted user group and resulted in various guidelines for system adaptivity. These are included in this chapter, in the form of design recommendations. In addition, this chapter includes a reflection on the apparent Catch-22 of Research-through-Design: in Chapter 6 it was concluded that, when doing Research-through-Design, the quality of the conclusions are fully dependent on the richness of the prototype. However, this study revealed that there is a price to richness; there is undeniably a trade-off between the necessary quality of a prototype and the consequential time investment.

Chapter 10 presents a reflection on the LinguaBytes case study, focusing on the theoretical foundations of this research, on methodological issues and on the research question. This chapter includes demonstrations of the contributions of this research, as well as a list of guidelines on ‘how to design for diversity’.

Bart Hengeveld, 2011
Acknowledgements

Although I use ‘I’ a lot in this thesis, this research has been a far from solitary endeavour.

I am immensely grateful for all the valuable input, feedback and hospitality of the people at St. Maartenskliniek Nijmegen and Rijndam Revalidatiecentrum Rotterdam, especially Saskia Peek, Huguette de Roover, Dominique de Backere, Marjolijn Priest and Anne Marie van de Zande. Thank you for allowing me to learn from your craftsmanship. Additional thanks go to Judith Stoep and Hans Luijken at De Grummelkes Cadier en Keer and to Reggy Koster at Rijndam Revalidatiecentrum Rotterdam for their involvement in the earliest stages of this research. I would also like to thank Bas Kleverlaan for his marvellous animations and overall professionalism. Naturally, an especially warm ‘thank you’ goes to all the children who so patiently participated, and to their parents.

There are several people I want to thank personally.

Riny Voort
When I got to do this project, I received you as a bonus. Thank you so much for making the past few years such a treat. You have not only been a wonderful colleague but also a warm friend. This work bears your unmistakable imprint.

Kees Overbeeke
Shortly after welcoming me back to your group you said to me: “you’ve matured”. It made me smile. Not so much because of what your remark said about me, but more because of what I recognised in it of you. Thank you for allowing me, or rather inspiring me to be personal in my work.

Jan de Moor
You have made me a much better researcher. Jan, thank you for trusting my intuition while at the same time providing me with a Safety net of Structure. The patience with which you meticulously ploughed your way through my reports has not only improved my writing, it has improved my thinking.

Caroline Hummels
Dear Caroline. Ever since your enthusiasm about that wacky DrPepper bottle I designed in Delft I knew I had to keep you close. Working with you is a joy and inspiration and
you have been a wonderful supervisor: despite your 25 hours of work a day, 8 days a week schedule you were there when I needed you most. Thank you so much for your support and friendship.

Hans van Balkom
Thank you for your energy, enthusiasm and passion. Your expertise has been invaluable and you have been a pleasure to work with! Let’s see what the future holds.

My colleagues
Throughout this research I have had the privilege to have been surrounded by inspiring people who, I am confident to say, have been my primary source of energy. Guys, thank you so much for all your input, insight, inspiration, distraction, patience and support. It is great working with you! Special thanks go to Chet Bangaru and Sjriek Alers for their technical support, creativity and overall problem solving skills, and to Aadjan van der Helm for all his MAX/MSP and Phidgets help, and of course for the fun times in Esbjerg.

My friends
Are priceless.

My family
Dear all, thank you for being the best family I could ask for! Lieve Pappa en Mamma, dank voor alle mogelijkheden, steun en liefde die jullie me altijd hebben gegeven. Katrien, jij bent mijn allerliefste. Samen met Menso.

Of course this research could not have been done without the generous support of the project sponsors: Dr. W.M. Phelps-Stichting voor Spastici (main sponsor), Stichting VSB-Fonds, SKAN Fonds, Nederlandse Stichting voor het Gehandicapte Kind, Nationaal Revalidatie Fonds, Stichting Kinderpostzegels Nederland, Johanna Kinderfonds and Stichting Bio-Kinderrevalidatie. Finally, I thank Eindhoven University of Technology and Delft University of Technology for allowing me this unique opportunity.
Curriculum Vitae

Bart Hengeveld was born in Vlaardingen on the 28th of February, 1977. In 1995 he obtained his gymnasium diploma at the ‘Stedelijk Gymnasium’ in Schiedam, after which he studied Industrial Design Engineering at Delft University of Technology. In 2001 he obtained his master degree on a thesis entitled: 'Relationships, Cyberspace and Rich Communication'. Between 2001 and 2006 he worked as a freelance designer and from 2002 as a multimedia designer while employed at ‘7U Digital Handmade Originals’ in Rotterdam. In 2004 he made two award-winning designs for public art contest ‘KunstXpress’, as co-founder of design consortium ‘NWWRK’. In 2006 he returned to Industrial Design Engineering at Delft University of Technology to start his PhD research. In 2007 he continued his PhD research at the Department of Industrial Design at Eindhoven University of Technology, which has resulted in this thesis.

He is a passionate musician. After having played the drums for nine years, he switched to the bass guitar and double bass in 1994. Between 2007 and 2010 he studied part-time at ‘Codarts Conservatory of Music’ in Rotterdam. In 1995 he started writing jazz music, which was used in movies and commercials, as well as within interaction design education.

Bart Hengeveld lives in Rotterdam with his girlfriend, who is an architect, and their newborn son.
LinguaBytes evolution