Tangibles for Toddlers Learning Language

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ABSTRACT
Here we present LinguaBytes, a modular, tangible play-and-learning system developed to stimulate the language and communication skills of toddlers (with a developmental age between 1 and 4 years) with multiple disabilities. The typical characteristics of these children and their common learning environment call for intelligent systems that are quickly and easily adaptable, or, even better, adjust themselves proactively. Over the last two and a half years we have designed and tested such a system within LinguaBytes. In this paper we will outline starting points, indicate the opportunities of Tangible Interaction and finally give an overview of the current LinguaBytes prototype.

Author Keywords
Interactive toys, tangible interaction, bodily skills, speech therapy, scaffolding.

ACM Classification Keywords
H.5.2 User Interfaces; D.2.2 Design Tools and Techniques

INTRODUCTION
Young children learning language
Pre-school children (aged 1 – 4 years) acquire skills (cognitive, perceptual-motor, social and emotional) seemingly effortlessly. By exploring their surroundings they gradually construct a mental model of the world as they experience it [10]. Since this is a continuous and cross-skill process, the mental model is expanded, refined or reconstructed with each new experience. More capable peers or adults play a fundamental role in this, since these can share their experiences and offer assistance with tasks that the developing child is unable to perform independently (the so called Zone of Proximal Development, ZPD). This process is commonly known as ‘scaffolding’ [16]. Language, especially parent-child communication [13, 15] plays an integral role in this, since internal and external language open up opportunities for learning (through social interaction) and regulate and develop the thinking process.

Early intervention
When language development is somehow hampered, e.g. because of a multiple disability (i.e. cognitive and perceptual-motor), early intervention including Augmentative and Alternative Communication (AAC) is essential. Not only to minimize negative impacts on the development of language, emergent literacy and communication [8], but also on the other skills (cognitive, perceptual-motor, social-emotional), since the developments of these are interdependent at this early age.

Opportunities for design
Earlier studies [e.g., 12] have shown that the effectiveness of early intervention can be reinforced by the use of multimedia technologies. We believe however that these new early intervention materials can only really be successful when they can be tailored to each child’s individual mix of skills, needs and preferences, in other words, to each individual ZPD. Only then can these materials serve as a proper ‘scaffold’. Over the past 2½ years we have been developing such a highly flexible learning environment, a play-and-learning system called LinguaBytes. In the following we will give an overview of the development process of LinguaBytes. We will outline our method, highlight three important starting points, illustrate the suitability of Tangible Interaction and give an overview of our latest prototype.
**LINGUABYTES**

**Introduction and method**

In 2006 we started developing LinguaBytes, based on a preliminary study conducted in 2005. As a result of this study the goal of the LinguaBytes project was stated as “designing an interactive play-and-learning system to stimulate the language development of toddlers between 1 and 4 years old (developmental age) with a multiple disability”.

For developing LinguaBytes we use a method known in the design world as Research-through-Design (RtD) [1]. In other TEI-related disciplines this method is often known as Constructive Research. RtD is a process in which scientific knowledge is generated through iterations of designing, building and testing experiential prototypes in real-life settings. When designing interactive products this process typically moves through several cycles of designing-building-testing, each cycle yielding refined guidelines for the content and the design of the product. For evaluating each cycle we use Process or Formative Evaluation [5], which is aimed at collecting data with which the product can be improved.

We will discuss the result of our latest iteration in the second half of this paper, but before we do that it is important to provide a bit more background information with regard to interaction design in the context of LinguaBytes. Therefore we will first highlight three important starting points and indicate the opportunities for Tangible Interaction.

**Starting points**

**Interaction design for toddlers**

A very important thing that should be taken into account first is that LinguaBytes will be developed for toddlers. These, from an HCI perspective, very young children require radically different interfaces than the traditional GUI-based interfaces we are familiar with. In earlier papers [e.g., 6] we have elaborated on this, but in this paper it will suffice to conclude that these interfaces tend to lean heavily on cognitive skills, overshadowing other skills (Figure 1). However, as we have indicated in the introduction, the natural interaction style of toddlers is explorative, playful and involves all skills. Within the LinguaBytes project we want to bridge this incongruity. We believe that the interaction we will need to design should be open and flexible; children should be able to apply their own personal interaction style, which is a result of their personal mix of skills, needs, preferences and behaviours. In short, we believe we should offer the child an interaction platform rather than just an interface. We like to call this Designing for Behavioural Opportunities.

We see opportunities here in Tangible Interaction [7]. We have seen that Tangible Interaction can ‘open up skills through skills’, in this case cognitive, linguistic, social and emotional skills through perceptual-motor skills (Figure 2). We will give an example: the majority of the LinguaBytes target group has a form of Cerebral Palsy (CP), which causes a diminished control over the muscles and therefore a restricted learning environment. By offering children with CP the possibility to overcome some of these limitations by enhancing their perceptual-motor skills, they can experience a richer learning environment (cognitive skill development), have more opportunities for language acquisition (linguistic skills), will become better able to cope for themselves (social skill development) and thus obtain higher self-esteem (emotional skill development).

**Interactive storybook reading**

A second starting point to keep in mind comes from the field of early intervention. Although there are many contexts in which early intervention can take place, one receiving much attention in recent AAC literature is that of interactive storybook reading [e.g., 4]. Story reading plays an important role in the early development of...
language and literacy skills of young children [14]. Stories offer a rich network of words and concepts in a form that appeals to children and triggers their imagination. Also, since story reading in most cases takes place in cooperation with a parent or carer, the child has a communication partner at hand to practice with. Adding interactivity to stories adds richness and thus more triggers for parent-child communication to the story reading process.

Within LinguaBytes, we want to capitalize on this. Since children learn most from parent-child communication, we do not want to design a play-and-learning system that takes over the role of the parent or carer, but in stead serves as a communication mediator, offering more or other triggers for parent-child communication. We will do this via interactive stories and accompanying interactive games and exercises. All communication partners (parent, child and system) should be able to take communicative initiatives.

Adaptivity, adaptability and users that are not programmers
To achieve this, we have to design a system that is highly flexible in use, as we have stated in the first starting point. Ideally the system we will design should both learn from and adapt to any user (we call this adaptivity), and be easily adaptable by any user (we call this adaptability). For practical reasons we will focus first on making the system adaptable before making it adaptive, since the former provides guidelines for the latter.

To get a feeling of the level of adaptability here, we will shortly illustrate the LinguaBytes context of use. We feel this is important because it gives an impression of the need for flexibility and illustrates the appropriateness of Tangible Interaction.

Most often, early language intervention takes place in the form of 30-minute speech therapy sessions. During this half hour a speech therapist has to:

1. Set up the optimal ergonomic conditions for the child;
2. Set the short term goals of that session and retrieve the required learning materials;
3. Exercise with the child and try to keep it motivated during the full session, which is quite long for the younger children;
4. Observe the child, keeping focused on any communicative initiative or reaction of the child, and offer the most appropriate ‘scaffold’ for learning;
5. Log all observations and results with regard to the preset goals at the end of the session before the next child arrives and we return to step 1.

It should be clear from this that 30 minutes is not a lot of time and that there are a number of factors that can be highly disrupting:

- Therapists only have a very short time for setting up their session. During this set up time they will already need to keep the child involved and motivated to be able to start on the right foot;
- Therapists have to be able to change settings within seconds during therapy if they 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 immediate action in order to keep the child’s attention get it motivated. Having to go through menus would be killing.

Finally, one thing to understand is that only very few speech therapists are ‘the programming kind’; all therapists we interviewed expressed no positive feelings towards using the PC or learning “how to operate a program”. Again, we believe that Tangible Interaction can be a powerful platform here, since it opens up opportunities to design a play-and-learning system in which ‘changing settings’ can become part of the therapy sessions without disrupting its flow. We will illustrate this later in this paper.

PROTOTYPE
To date we have gone through four RtD iterations, building and testing as many prototypes. Here we will illustrate the content, design and technical implementation of our latest prototype.

Content
To determine the content of the LinguaBytes play-and-learning system we have analyzed three Dutch word lists that are widely used in early intervention [2, 11, 17] and clustered the most frequently used words (560 in total) into six themes: 1) animals; 2) people, family and parts of the body; 3) food and eating; 4) play, games and activities; 5) in and around the house; and 6) vehicles and traffic. Consequently, we have distributed all words over interactive stories and accompanying games and exercises. A major part of the words are made available as tangible input material. We will illustrate this further in this paper. Some types of words are not suitable for making tangible (e.g. ‘that’ or ‘to want’). We have tried to cover these words as much as possible in stories or as functional communication in exercises or between parent and child.

Design
The current LinguaBytes prototype is a modular play and learning system consisting of five parts: 1) the Central
1. The Central Console
The Central Console (figure 3, left) is the central output module. Containing a 17-inch TFT screen and two stereo speakers, it shows all animated content and plays the accompanying audio. Because the Central Console does not necessarily have to stand upright on a desktop, but can also be laid flat on the ground or even stuck to a wall or other surface, we have made a custom housing design, e.g. by including suction pads on the backside.

2. The Base Module
The interface for the child consists of two parts, of which the Base Module (figure 3, middle) is one half, namely the bottom part. The interface can be made complete and functional by placing one of the interface modules on top. The Base Module contains three RFID readers, two magnets to position the interface modules, and a slot in which thematic sceneries can be slid. These sceneries can be used as tangible programming elements since they filters out the stories and exercises belonging to their themes. The Base Module’s scenery-slot contains four switches that are either pressed (=1) or not (=0), depending on the inserted scenery. Thus, each scenery is represented by a four-digit binary code.

3. Interface Modules
On top of the Base Module four different Interface Modules can be placed:

1. The first one is the BookBooster, which is designed for interactive story reading (figure 3, right). RFID-tagged booklets can be inserted in the BookBooster and moved back and forth by the child, using two handles, one on each side of the interface. Thus, children can read the booklet both ‘outside the system’ as a regular picture book, and as an interactive, augmented story within the system. As such the booklet can serve as a preparation for interactive story reading, and as an assessment tool afterwards.

2. The second interface module, the Phonotron (figure 4, left) is designed specifically for stimulating phonological awareness. It basically consists of a wooden panel with a plastic recess, holding a speaker. When a child places tangible input material in the recess, appropriate audio is played through the internal speaker. We have designed this module so that it can be used...
without the Central Console, with the internal speaker emphasising the focus on phonology. However, if desired the Central Console can of course be connected to add animations to the audio.

3. The third interface module, the PuzzlePointer, is designed for training semantic awareness (figure 4, middle). The interface module consists of a wooden panel in which puzzles can be placed over an array of four force sensors. The force sensors determine which part of the puzzle is being manipulated. For example, one of the exercises we have developed is about learning animal parts. An animal-puzzle can be placed in the PuzzlePointer and then used either explorative or assignment-based. In the former case, the child can push parts of the animal explorative, which are then animated on screen and pronounced in audio. In the latter case, the child is asked to push a specific part of the animal.

4. The fourth interface module (figure 4, right), the Combination Module, is designed to support syntactic exercises. This module consists of a wooden panel with three recesses. As such it either offers the child three choice options or three free input possibilities. Typically, this module can be used for building sentences. Any of the recesses can be closed with a lid, to either build one-word, two-word or three-word sentences, depending on the skill level of the child.

4. The Carer’s Controller
This module is the interface for the carer (parent, therapist, teacher). From an interaction design point of view, it is interesting to realise that a major part of the learning process occurs through the communication between carer and child, as we have mentioned earlier. As a consequence most of the carer-child interaction occurs ‘outside the system’, which makes it really hard for our system to learn from a user. It simply cannot monitor and interpret everything. Therefore, it is necessary to offer the carer control over the system. We have observed in our experiments that carers need to be able to tell the system when to pause or repeat, when to stop and when to go back or ahead. For all these actions we have included a button in the Carer’s Controller. Also, to enable them to quickly react on the performance of the child, carers can easily switch between the explorative and assignment-based versions of an exercise using a toggle switch (figure 5, left).

5. Tangible Input Material
The major part of the LinguaBytes prototype however, is comprised of tangible input materials. For all six themes we have developed story booklets, tangible objects, PCS-symbol cards (globally standardised word pictograms), PuzzlePointer puzzles (all of these can be seen in figures 3 and 4), and a small collection of programmable RFID-labels (figure 5, middle). These labels can be used to make alternative input materials, for example out of a child’s plush toy (figure 5, right). Also, these labels can be used to explain the child spatial concepts like ‘far away’ or ‘nearby’ by hanging them in the child’s environment.

Design rationale
As indicated at the beginning of this paper, one of our most important starting points was to ‘Design for Behavioural Opportunities’; we wanted to develop a learning environment that would support each individual child’s preferred behaviour; to give each child the possibility to play and learn on his or her developmental level, using his or her own preferred interaction style. We have tried to do this by giving the child as many opportunities for taking initiatives as possible, capitalizing on the real-world affordances they understand, keeping the cognitive load low. We have done this by developing a modular tangible interface with a large collection of tangible input material, including possibilities for making personalized input material.
Our second starting point was to stimulate the language development of the child through interactive storytelling and related games and exercises, which we have implemented through the story booklets and wide variety of input material. We have tried to keep the interaction playful, appealing and meaningful for the developing child.

Thirdly, we have emphasized that our design should be highly flexible in use, without disrupting the flow of therapy. We have tried to support this by making the system modular, and by embedding programming actions in separate modules, thus reducing menus. Examples of this are the thematic sceneries, and the Carer’s Controller. Both of these replace the usual menu actions and prevent disrupting the therapy session.

**Technical design**

In our prototype we make use of Phidgets sensors, MAX/MSP and Adobe Flash, along with regular micro-switches and push buttons. The Phidgets sensors (RFID readers, motor controllers, mini joysticks, force sensors) are connected to a Phidgets Interface Kit, which is connected to an Apple MacBook Pro via USB. MAX/MSP is used as a back-end application for both reading and storing sensor values. Flash is used as a front-end application for reading stories and playing games and exercises. MAX/MSP and Flash transfer data via XML (figure 6).

**EVALUATION & CONCLUSIONS**

We have tested the LinguaBytes prototype to date at two centres for rehabilitation medicine in the Netherlands, in weekly sessions with 15 children (figure 7). Each child would use our prototype during its regular weekly 30-minute speech therapy session, with his or her usual speech therapist. Occasionally, other people were present, e.g. one of the parents, occupational therapists or physiotherapists. At the end of a 6-week testing period we have interviewed each speech therapist and asked them to fill out a questionnaire.

Some important conclusions from our observations and questionnaires are:

- By offering tangible input materials and an interaction that is closer to their usual style of exploration, these children were offered more access to their environment, thus acquiring a richer base for language literacy.
within these studies we wish to measure the following:

* Consequently, the children generally showed a longer attention span than usual and more initiative. These observations were confirmed in the therapists’ questionnaires;

* Additionally, it was clear that using tangible input material slowed down the interaction, subsequently giving both children and carers more control over the timing of the interaction. For example, during the three-word sentence exercise children seem to communicate more than in other comparable situations, using the physical input material as an alternative communication means, making up their own stories;

* As a result of this, there were more opportunities for facial, gestural and verbal expressions of the children, letting them evoke more communicative reactions of their surroundings;

* The only situation in which these observations were harder to make was when a carer used the system with two children at the same time. We are trying to redesign our prototype slightly to overcome this. The positive conclusion however was that, due to the tangibility, our system was very suitable for collaborative use.

These and other conclusions strengthen us in our belief that we are on the right track and that Tangible Interaction is a suitable platform for interaction design for toddlers.

**FUTURE WORK**

We are currently building three full prototypes, i.e. prototypes in which all six themes are covered. We plan to have these finished in March 2009, after which we will conduct longitudinal studies at three different locations. Within these studies we wish to measure the following:

1. Does the *LinguaBytes* prototype really stimulate language development? Data from our earlier evaluations strongly suggest this, but a longitudinal study will certainly enable us to make a stronger case of this. We wish to measure this by having our collaborating speech therapists evaluate the children’s progress in a period using the *LinguaBytes* prototype, compared to a period without using the prototype. We understand that this may not be reliably possible, due to the fact that we depend fully on the therapists’ interpretation, but we also acknowledge that within this specific context we have to rely on their professional judgements. We will use questionnaires and video analyses in this.

2. How do factors like the child’s attention span, communicative initiative taking, et cetera change over time? Our past evaluation periods were never longer than 6 weeks, in which we submitted the toddlers to many ‘first impressions’. We can imagine that once the children start familiarising with the prototype, some of the enthusiasm might diminish or change. We want to examine if this happens, and in what way. This will give us information about the proper way for the prototype to ‘grow along’ with the developing child. We can use video analysis for this, e.g. by comparing similar actions over time. We want to do this by cutting up all video footage and pasting similar (inter)actions in a sequence. In this way we can observe changes in behaviour better.

3. Related to the previous point of attention, we want to determine whether the child’s other skills improve as well. There are different techniques available for doing this, for example we can use the sensors in our prototype to monitor the ‘aim’ and strength of the child and visualise how these develop over time. Additionally, we can use questionnaires to determine the development of the child’s social skills.

We will use the results of these tests to implement adaptive behaviour in the prototypes.

**DISCUSSION**

In this paper we have outlined the development of the current *LinguaBytes* prototype. We have given our starting points, an indication of what we see as opportunities for design in general and Tangible Interaction in particular. We have extensively illustrated our current prototype and highlighted our most important findings with regard to language learning, in relation to Tangible Interaction. Finally, we have described three topics we want to research more.

Although we have written this paper with the focus specifically on the design, architecture and implementation, we see that there is a wealth of information in our user studies that is worth sharing with the TEI community. We feel that we should devote another paper to this, so here we will discuss only one aspect, related to the design of complex, adaptive tangible interfaces.

As we have mentioned in the introduction, our ultimate goal is to make a system that is adaptive to individual users. In order to achieve this goal, we have focused the systems adaptability first, since this would give us insights in the desired adaptive behaviour. However true, the longer we are in the process, the more we have to acknowledge that designing behaviour is a complex business. One reason is that it is quite complex to map out the guidelines, requirements and criteria for (developing) a complex product or system. A table or other static
representation often does not suffice, due to the interdependencies of many guidelines: change one, and all related others change along, and those related with those, etcetera. We are still investigating ways to tackle this problem, which we feel most developers of complex products or systems have encountered.

ACKNOWLEDGMENTS
We thank the Dr. W.M. Phelps-Stichting voor Spastici and the consortium of additional sponsors for funding the LinguaBytes project. We also thank the therapists of the two centers for rehabilitation medicine, Marjolijn Priest and Dominique de Backere at the Rijndam Revalidatiecentrum in Rotterdam, and Saskia Peek and Huguette de Roover at the St. Maartenskliniek in Nijmegen for their valuable feedback and for enabling us to test our prototypes. Finally, we thank the people of the /d. search lab for helping us build the LinguaBytes prototypes.

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