Activity Pad: Teaching Tool Combining Tangible Interaction and Affordance of Paper

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ABSTRACT

In this paper, we describe the design process and early experiences of the Activity Pad, an interactive digital artifact for active learning environments. The pad combines a 4x6 grid of programmable NFC readers together with printed sheets of A4-sized paper to allow teacher-driven creation of interactive learning applications featuring application-specific tangibles. We describe iterative design process for this teaching tool, including mock-up prototypes, focus group discussions with teachers and the first complete prototype together with two example applications. Teachers were eager to innovate applications for the Activity Pad, and the feedback indicates the potential of this kind of teaching tool in diverse learning environments.

Author Keywords
Active learning environments; tangible user interfaces; paper-based interfaces; design.

ACM Classification Keywords
H.5.2 Information interfaces and presentation (e.g., HCI): User Interfaces.

General Terms
Human Factors; Design.

INTRODUCTION

Learning processes are becoming increasingly digitalized and supported by various Ubicomp technologies. Through this inclusion of a new infrastructure, new design possibilities are opened for novel user interfaces to support the learning process. One interesting direction of design is to build *tangible user interfaces* for learning applications by leveraging the physical objects of the learning environment. New technologies, and specifically tangible user interfaces, facilitate building *active learning environments*.

In this paper, we report our work for developing tangible user interfaces for active learning environments. We describe a design process, including concept development, participatory design with domain experts, and realization of a prototype. Our concept, *Activity Pad*, combines the physicality of tangibles, affordance of paper-based interfaces [18] and interactivity through programmable Near Field Communication (NFC) readers.

The Activity Pad is a flat device containing a grid of twenty-four NFC readers. The Pad is configured by placing a sheet of paper representing the application user interface on top of it. The user gives commands to the application by placing tangibles on the sheet. The Pad reads the NFC tags attached to the tangibles and reacts according to the programmed logic.

In this paper, we focus on learning applications. We call the sheets of paper representing the user interfaces of these applications as *activity sheets.* Each activity sheet presents a problem with text and graphics, common to traditional paper. A child places the activity sheet on top of the Pad and then places tangibles on the paper interface to solve the problem (Figure 1). During this interaction, the Pad gives feedback with an internal speaker and a series of LEDs.

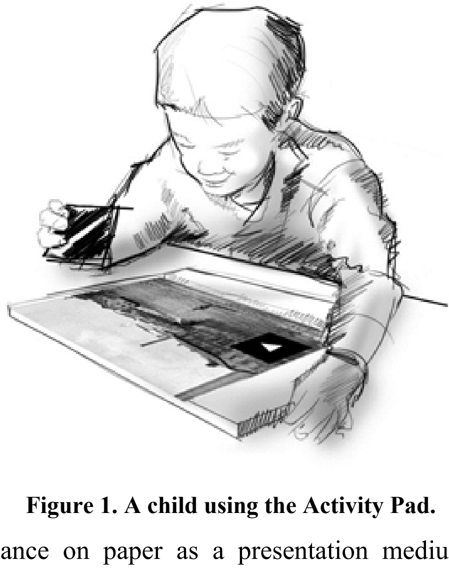

Figure 1. A child using the Activity Pad.

The reliance on paper as a presentation medium allows teachers to create new learning applications for the Pad by printing out a visual design of the application user interface (i.e. the activity sheet) either by using a standard printer or drawing by hand. Programming the Activity Pad does not require a separate desktop-based development environment. Instead, the Pad records sequences of specific constellations of tangibles, placed on the paper interface in correct order

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by the teacher. This is done in a dedicated *programming mode* of the Pad. When the recording process is complete, the Pad can be set to an *interaction mode* together with the corresponding activity sheet. This way, the grid structure of NFC readers establishes natural constraints for placement of tangibles while affording the full expressivity of the activity sheet as a paper interface.

This paper presents the following contributions:

- The concept of the Activity Pad as a tool to create applications based on tangible interaction and paper for active learning.
- The design process, including teachers as both domain experts and co-innovators.
- A prototype device together with two example applications.

The rest of this paper is organized as follows: The next section presents learning environments and the related work. The third section describes investigations on how tangibles and contemporary technologies are used in schools. The fourth section presents the design of the Activity Pad, including the focus group discussions and co-design sessions with teachers. The last two sections present the discussion and conclusions.

LEARNING ENVIRONMENTS AND TANGIBLE USER INTERFACES

The concept of *active learning* has been widely used in educational literature and pedagogy. Focusing on children, active learning is defined as "*learning in which the child, by acting on objects and interacting with people, ideas and events, construct new understanding"* [9]. In active learning, the engagement of students in the learning process is emphasized, since only the children themselves can absorb and construct knowledge. The concept *learning environment* has been used broadly in the literature, with multiple meanings. We understand a learning environment as any setting in which learning takes place; for example, a classroom, a museum, home, or a playground. We suggest that a learning environment can be active in three ways: in pedagogical sense [4], in the sense that learning implies physical movement and action, and in the sense that the environment is active (i.e. produces responses). Hence, an active learning environment is a learning environment encouraging active learning and physical movement. In such an environment, learners perform different actions on objects in the environment and the environment produces feedback about these actions. We envision active learning environments as future environments embedded in ubiquitous computing infrastructure providing novel user interfaces. Our vision bears similarities to the concept of Ubi-learning environments proposed by Rogers et al. [16].

Tangible bits [11] were a pioneering work of tangible user interfaces (TUIs) from Hiroshi Ishii's group at MIT Tangible Media Group. The prototypes focused on ambient displaying of information in a non-intrusive way.

Physical objects, also called "manipulatives", have been integrated into learning environments since the beginning of the 20th century [14]. The progress of ubiquitous computing has resulted in emergence of new user interface paradigms that transcend traditional GUIs. Among these, tangible user interfaces have been used in education environments for several years. Although, according to Marshall, it is questionable whether tangibles provide quantitative benefits on knowledge acquisition compared with other computer based methods [13], they have nevertheless been reported to improve the user experience of the learning process and to promote collaboration [20, 21, 22].

Tangible wooden blocks have been used to manipulate abstract structures of a dynamic process (loop, branches) [21] and to program a robot [10]. In the first case, blocks provide visual feedback without any external devices. In the second case, an external computer provides the feedback. Towards Utopia [1] aims to teach students about land planning and sustainable development. It uses a combination of interactive tabletops and tangibles containing RFID tags and fiducial markers.

Reactable [12] is a musical instrument based on a tabletop interface. Objects placed on the surface represent handles to a synthesizer. Physical manipulation of the objects (rotating or moving them) and touching the screen around the object produce variations in the music played by the system. Another system resembling our work is a small table augmented with two RFID readers, a projector, and a speaker [2]. The software presents animated visual and audio feedback on the table when a child places an object (mainly toy letters) on one of the two RFID readers. Moreover, Broll et al. [5] use an approach inverse to the Activity Pad: A game GUI projected on a wall is augmented with a matrix of NFC tags. When a user approaches her/his NFC phone to a point of the surface, the phone reads a position from the closest NFC tag and sends this information to the system, which then updates the projected display accordingly.

All these prototypes share the same constraint: Their programmability is limited. They can be used just for the application that they are designed for. Furthermore, teachers cannot add new content or modify application rules to create new exercises. Moreover, the majority of related work has been tested only in a controlled setting, usually for a limited amount of time, mainly due to complex and expensive custom made setups which include a custom-built sensor system or cameras. Systems based on tabletop surfaces need a lot of space; this usually means that the devices have to be outside the classroom, in another room (usually called the IT room), leading to fragmentation of the learning environment. With the Activity Pad, we aim to a mobile, relatively cheap and more versatile device that can be integrated into a variety of learning environments.

Numerous commercial learning applications are being made digitally available, and new device categories such as tablets have further facilitated this process. However, we focus on paper-based user interfaces and tangibles. Some commercially available devices have tangible user interfaces. The Tag application (www.leapfrog.com) consists of a book and a pen with a loudspeaker. When a letter, a word, or a sentence on the book is touched with the pen, the pen reads it aloud. Compared with the Activity Pad, the Tag has only one tangible, the pen, and the content is created a priori by the publisher. AppMATes (www.appmatestoys.com), in turn, are physical toys for iPad. The AppMATes application can recognize the identities and positions of these toys on an iPad display, allowing the toys to act as physical control handles of the application. This is a single application with emphasis on high-quality digital content and tangibles built by a company, whereas the Activity Pad is a general platform for applications with emphasis on paper and user-created content and tangibles.

Although the progress of computation and computers has constantly declared the death of the paper as an interface, we still use it due to its unique affordances [18], ubiquity and low price. Some authors propose creating interactive systems by empowering papers with digital content instead of completely substituting paper: Wellner's DigitalDesk [19] was one of the first attempts to augment a sheet of paper with computer capabilities while maintaining paper's affordances. DigitalDesk uses a video camera to detect where the user is pointing and to read the paper content. A projector is mounted over the desk, allowing the system to project electronic objects onto the paper. Other authors have used paper-based interfaces to teach geometry [3] and to create musical instruments [7].

In our earlier work, we have placed NFC tags in a zoological museum to augment animals with audio and images [17], and in a kindergarten, to help early learners (three to five years old) in their first steps towards literacy [15]. In these pilots, NFC tags were embedded in the environment. Children interacted with the tags using a mobile phone providing audio and visual feedback. These pilots confirmed that NFC can be used to build learning environments which encourage children to explore new concepts and promote collaboration and social interaction among children. The main problems faced during this work were the lack of devices with NFC technology that suit small children's hands (due to physical size and the reader ergonomics) and the absence of a framework that helps teachers to create and modify applications. This led us to develop the concept of the Activity Pad.

NEW TECHNOLOGIES AND TANGIBLES IN SCHOOLS

We organized a site survey, an online survey and focus groups sessions with teachers to better understand how new technologies and tangibles are used nowadays in schools. We invited teachers from all around Finland to fill an online survey. We posted the invitation to several professional mailing lists and got 268 responses, from which 213 were complete. 59% of respondents were primary school teachers. Based on this survey, computer learning aids are already common among teachers; 59% use them at least twice a week. The use of tangibles is not that common. Only 45% of teachers use them at least once each week. Teachers use tangibles mainly to demonstrate abstract concepts. The ones used most are cards, 80%, and board games, 75%. Several teachers shared the opinion that some children need more concrete learning aids than others, and for them, tangibles are really useful. Also, teachers felt that concrete objects support social and collaborative work and strengthen motor skills.

After the online survey, we visited a local teacher's classroom during a whole day school session. Her group is a reinforcement group for foreign children from seven to thirteen years old that have recently arrived to the country, sometimes without knowing Finnish or even the Latin alphabet, for that matter. We were able to observe real class sessions and explore the exercise books. These books included lots of manipulatives, such as toy money, clocks, and geometrical cardboard shapes. Moreover, the classroom was filled with physical learning aids (Figure 2). Children had some spare time during the day to freely use any materials available to support their learning tasks. We also visited three other primary schools but only to check the premises.

Figure 2. Tangible teaching materials in a local school.

Finally, we carried out three discussion sessions with a total of 23 teachers in three different schools. The goal of each discussion session was similar to the online survey, but this format gave us an opportunity of having an open and interactive discussion. During these sessions, teachers commented on the main problems of current computer aids for learning. The main concerns were related to the reliability of the systems, the low skills of teachers for using computing technologies, the incompatibility of existing technologies and the lack of time or knowledge to create new content. Teachers commented that manipulatives are better suited for explaining abstract concepts, improving motor skills, and promoting collaboration among children. Manipulatives were seen as a good fit for young children and the disabled. The site survey and discussions with the teachers revealed that manipulatives are used in classrooms more frequently than anticipated by us, and that children view them as commonplace. Despite this, paper is still regarded as the main technology used in teaching. Sometimes, teachers use manipulatives to improvise new games. Although teachers report that they use digital tools during lessons, there is a common belief that the increase in digital tools usage might lead to decreased physicality in learning.

DESIGN PROCESS

Conceptual design

After analyzing the results of the surveys and discussions, we commenced the conceptual design process for the Activity Pad. Our initial premise was that a vast majority of material used in the classroom is based on paper. Traditionally, teachers give questions and propose exercises in sheets of paper, and students write answers on them. We were inspired by Wellner's work [19]; instead of replacing paper-based interfaces familiar to teachers, we decided to augment these interfaces with programmable features. Instead of relying on infrastructural augmentation, our aim from the very beginning was to build an integrated device to maintain the affordances of paper and tangibles, while providing programmable interactivity and immediate feedback to the children. Furthermore, teachers should be able to track the progress with this new device in order to understand the needs of each child.

Most systems resembling this concept are based on optics and rely on static overhead projections. This approach limits the affordances of paper, as these systems tend to be intrusive (i.e. the technology is visible, as reference markers are used) and users can accidentally block a projection or otherwise prevent optical recognition. On the other hand, designing portable devices based on optics is a considerable challenge.

Through the use of tangibles, we wanted to augment the paper user interface with the metaphor of *physical drag & drop*, and to realize this functionality in a compact and integrated form. Once our design goal was articulated in this fashion, it became clear that the device needed to incorporate individually programmable detection sensors with a very short detection range. This led us to investigate the suitability of individual NFC reader units as close proximity detection sensors.

The goal was to identify tangibles placed on a horizontal plane - children perform learning activities by placing tangibles on a sheet of paper (i.e. activity sheet). Hence, the device must inhibit a planar form factor equipped with a matrix of NFC readers. Both the activity sheet and the tangibles are augmented with NFC tags, hidden from the user. Reader units continuously monitor the surface of the device detecting the activity sheet and tangibles placed on it. Augmenting the paper interface from below with integrated sensing removes the need for unobstructed optical projections and allows mobility as children can move around the teaching environment with the device.

Our natural choice for the physical dimensions of the activity sheet was the European A4 standard. The operational range of a single NFC reader together with the requirement that adjacent reader units must not cause interference to each other dictated the spatial requirements of a single reader unit. Taking into account the physical size of an A4 sheet of paper and the range of a single NFC reader, the main design of the Activity Pad converged into a four times six, two-dimensional Cartesian grid of reader units, spaced evenly under the paper sheet (Figure 3). This gives a total of twenty-four individually programmable interaction points within an A4 sheet, which we see as a sufficient amount for realizing interactive learning applications.

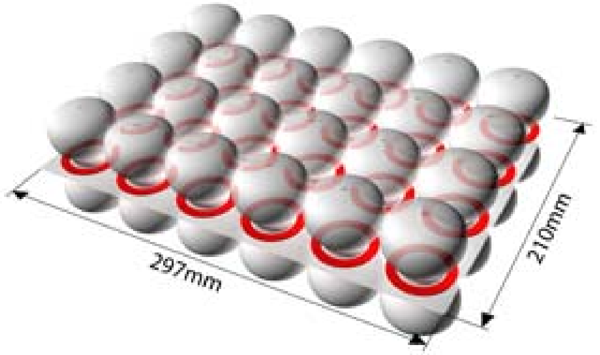

Figure 3. A grid of NFC readers and their wireless operational range, fitted evenly within the A4 standard.

Our aim was to build a device that is cheaper than computers, tablets, and other devices with high-quality displays. We believe that this requirement can be fulfilled with NFC as large amounts of mobile phones are being equipped with this technology already - and hence the cost of NFC readers and tags can be expected to decrease. When applications are built, only NFC tags are needed: activity sheets and tangibles need to be equipped each with an NFC tag. However, the same tangible can be used in several applications, and when an activity sheet or a tangible is no more needed, the NFC tag attached to that item can be removed and used again.

Since our starting point is the paper interface, we can also support the *layering* and *transparency* affordances of paper. Papers with holes cut into them can be placed on top of another paper to give an altered representation, and a transparent paper can be placed on top to augment the paper below.

Focus group and co-design sessions

After finishing the conceptual design, we wanted to chart teachers' opinion of the device. We organized five focus group discussions and co-design sessions with teachers and teachers-to-be, where we discussed the possibilities of integrating the Activity Pad in their learning environments.

Organizing discussions and co-design sessions

We built several mockups to explore different design alternatives and present the idea to the teachers. Mockups were made out of foamed cardboard, quick glue and steel bolts and nuts to give approximately correct weight. Finally, we used a quick filler to give a smooth surface (Figure 4). To add ecological validity, we also created some example applications such as a shopping scenario for teaching children the value of individual coins and correct counting of monetary sums (Figure 5). The activity sheet presents a cash register where children can place individual items with price labels. After placing the item, the application asks children to place a correct sum of toy money on the sheet, i.e. the area next to the register.

Figure 4. An early mockup with an example exercise.

Figure 5. Shopping scenario.

Another scenario created deals with language learning (Figure 6). The activity sheet placed on top of the Activity Pad presents the child with incomplete sentences, and tangibles constitute individual words that can be placed on top of the sheet to correct positions. When a sentence is successfully completed, the Activity Pad will play an associated audio file giving the correct pronunciation of the word. Optionally, a nearby laptop or a public display can show multimedia related to the sentence. With this scenario, we wanted to raise teachers' awareness of how the Activity Pad could be used together with external digital devices.

We advertised focus group sessions among students-to-be teachers through posters and by contacting student guilds. We set up two focus groups in our premises with a total of nine students (four females) aged twenty-one to twenty-nine. Furthermore, we contacted several local primary schools. We arranged three focus group sessions, each one in different school premises. In total, 23 primary school teachers aged 27 to 59 participated in the discussions.

In the first phase of a session, participants filled in a background questionnaire. After that, we started with semi-structured discussions regarding the current practices, drawbacks and future potential of tangibles and computer learning aids. Following this, we introduced the Activity Pad concept by using the mockups and the example scenarios. We discussed the impressions of the participants and the possibilities of using a device like that. Finally, we divided participants in groups and gave them material such as paper, glue, crayons, modeling clay and other stationary material, so that they could design candidate applications for the device.

Figure 6. Language learning scenario.

Discussions with teachers

In order to carry out a formal analysis, we transcribed every comment word-by-word. Based on transcribed comments, we constructed an affinity wall (Figure 7) to cluster the information. From the affinity wall, we learned that the first impressions were positive. Teachers felt that this device could be used for teaching in their classes. They especially liked the idea of using paper and they thought it would be easy to create material for the device. Teachers saw children from six to nine years old and children with disabilities as the best target group for this device. Note that the actual programmability of the device was not yet discussed; instead, the focus was on the overall device concept.

Teachers commented on the differences of learning with a device like this to learning with a computer. One of the teachers said that this device would be a nice tool for language learning since it integrates a written word on a paper, an audio file with the correct pronunciation and a real tangible object as a concrete sample of the word. While learning methods are being digitalized, there has been a loss of physicality in learning practices; handwriting is one example. Teachers considered learning with computers as lonely and lacking of support for motor and haptic skills. Teachers felt that the Activity Pad could support in learning motor skills. Moreover, they felt that a tangible learning aid is more social and encourages children towards face-to-face communication. Finally, teachers were convinced that they could easily transform already existing learning materials to be used with this device. It would be easy for children to create material themselves as well. One of the teachers remarked that the content creation process itself is usually more educative than using the result of this process.

Figure 7. Affinity wall gathered after focus groups.

Co-design sessions with teachers

During the co-design sessions, teachers were very open-minded as for creating a variety of applications. For example, they even invented an application to teach children how to use a map. Other group made up an application to teach different tones and instruments in the music class. Teachers felt that this device could give great help to teach children the association between audible sounds and musical notation printed on paper. One group of teachers built an application to explain different aspects related with weather (Figure 8). Teachers constructed tangibles to embody different physical elements of nature such as the sun, water and clouds. By placing elements over the scene presented in the activity sheet, the Pad could generate feedback about the nature-related phenomena associated with the current constellation of elements.

Figure 8. A weather application created by teachers.

Prototype design

The main physical requirements that we obtained from teachers established that the Activity Pad should give a good support for a sheet of A4 paper. The Pad should be portable and it should be able to be used with differently sized hands. The appearance of the device itself should be neutral not to attract the children´s focus away from the problem being solved. Similarly, to keep the focus on the paper sheet and tangibles, the device was not equipped with internal digital displays. Color LEDs provide the only programmable visual feedback. These decisions resulted in the design sketches presented in Figure 9.

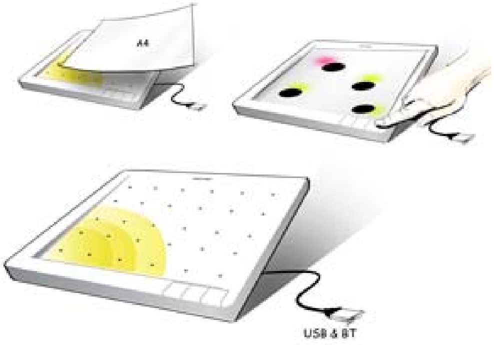

Figure 9. First sketches of the Activity Pad prototype.

After building the mockups for the focus group sessions, we learned that a good shape would be a plate with an elevated L-shaped corner that offers a good grip for a hand and naturally guides the paper to the correct position. An A4-sized flat area is the resting place for activity sheets. Underneath, is the matrix of NFC readers. The L-shaped corner area accommodates LEDs and two capacitive buttons with application dependent behavior. In addition, the device provides audio and haptic feedback through integrated speaker and vibration motor.

Each activity sheet provides instructions on the problem to be solved and graphically indicates possible locations for tangibles. Each sheet also contains an NFC tag at one corner. When an activity sheet is placed on the Pad, an NFC reader reads its id from this tag. A special orientation symbol mark placed on the L-shaped corner and in each activity sheet marks the places of the reader and the tag, respectively, and helps users to orient the sheet correctly. This orientation symbol can be considered as an artificial symbol in the user interface, but its impact on the overall design of the sheet is minimal. Additionally, one of the NFC reader units becomes reserved for reading sheet identifier tags.

Teachers create new learning applications by using the Activity Pad and sheets exclusively. First, a teacher renders the user interface on a sheet of paper, thus creating an activity sheet. The only constraints at this stage are that the orientation symbol is drawn at one corner and that the places for tangibles match the positions of the readers. The UI can be drawn manually or by using a graphics program. Templates can also be provided for different application types.

The second step is to attach NFC tags to the activity sheet and to the tangibles, or alternatively, select existing tagged tangibles. The third step is to program the application. Placing a dedicated “Programming” tangible on the corner of the Pad containing the orientation symbol activates the programming mode. The Programming Mode icon at the left side on the L-shaped corner area (Figure 11) indicates that the device has entered in the programming mode. Next, the teacher places the activity sheet on the Pad, followed by the correct constellation of tangibles. The last step is to press the Programming button placed at the bottom on the L-shaped corner area to store the ids of the activity sheet and the tangibles along with their spatial constellation to the Pad’s internal memory. Turning off the Programming Mode indicator indicates a closure of programming.

Children use the Activity Pad by first placing an activity sheet on the Pad and then placing the correct tangibles to the correct positions. When tangibles are placed on the Pad, the Pad gives feedback: when a tangible is placed on the right position, the LEDs on the corner area blink in green, whereas a wrong position produces red. The Pad gives also audio feedback; one beep for a correct position and two beeps for a wrong position. When the correct answer has been given, i.e. the constellation of tangibles is correct, the Pad starts blinking all the green LEDs in alternating fashion. These visual and auditory feedback patterns will be later subjected to field trials and modified based on the feedback.

The physical casing of the Activity Pad was first divided into an upper and lower cover so that the circuit board, battery and speaker would fit inside these two pieces. The dimensions of these assemblies determined the space needed inside the case. A 3D Model was made with Autodesk Alias designing software.

For our first prototype, we built the covers using 3D printing technology. We found several problems on using this technology. Convex surfaces were left quite rough; an effect caused by the additive layers created by the printer. Lights from the LEDs did not pass through the material (ABS plastic) well enough. Moreover, we found the hardware buttons were too sensitive (although this problem was not related to 3D printing). Finally, 3D printing turned out to be quite expensive through outsourcing.

In our second version, we built the upper cover using clear acryl (PMMA). This material is more transparent and hence more light passes through it. The upper part was built from one rectangular plate and one L-shaped plate. These laser-cut acrylic plates were significantly cheaper to manufacture. We placed the hardware buttons inside small holes to prevent unintentional presses. For the bottom part, we maintained the 3D print and manually removed all convex surfaces. The different manufacturing processes of the upper and lower covers caused these two parts to slightly differ in size although parts of the same size were ordered; hence, we needed to grind some material from the edges of the acrylic upper cover. Moreover, as the acryl cover passes light well through but does not scatter it, we made the light more visible by placing white paper between the LEDs and the L-shaped acryl plate. Figure 10 shows the 3D model of the second prototype (lower cover, circuit board, and the two parts of the upper cover) and Figure 11 depicts the second prototype fully assembled. The white circuit board can be seen through the upper part.

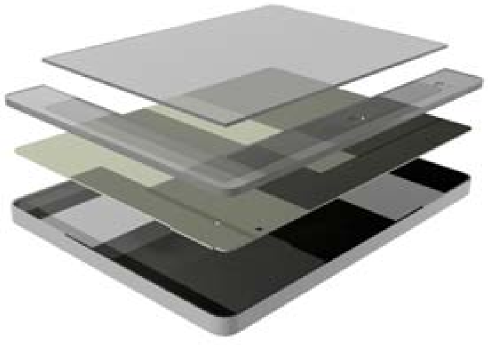

Figure 10. A 3D model of the second prototype.

The main components of the hardware are twenty-four NFC chips with matching networks and PCB strip antennas, and a microcontroller. Due to the fact that the antennas were placed quite close to each other, the mutual coupling interference between individual antennas needs to be considered. In the current version, reading a tag is timed so that adjacent NFC readers do not operate at the same time. The NFC chips are connected to an ARM microcontroller using an SPI bus. This microcontroller controls all the NFC chips and runs the application logic. The logic is simple in the first version: the ids of the NFC tags placed on the Pad are simply compared with the ids read during the programming phase (for the activity sheet id in question). Further coordination of individual reader units during reading events is considered a future work at this stage.

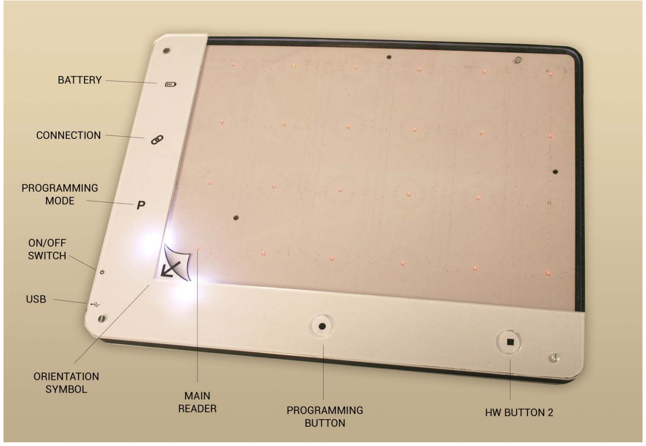

Figure 11. The second prototype.

Example applications

We built two different prototype applications in order to test the devices and to obtain an understanding of the application development process. Note that these applications were built on the actual working prototype of the Pad, and are thus different from the ones presented to the teachers in the co-design sessions. The first example application encourages children to recycle. The sheet of paper presents a typical trash collection point (Figure 12). Teachers have to collect trash materials and glue them over NFC tags. A teacher programs the Activity Pad through the procedure described earlier.

Children only have to place the paper presentation of trash collection point over the Activity Pad to start the application. Children recognize materials represented by tangibles through visual and tactile inspection, and place them over the correct dustbins of the activity sheet. The Activity Pad gives visual feedback for children as described earlier. The benefit of using the Activity Pad is that children can use multiple senses when exploring the trash materials. As an example, some plastics produce noise while squeezing them, and metallic coatings over paper can be identified through combined visual and tactile inspection.

In the second scenario, the teacher writes descriptions of different stones on the activity sheet. There can be as many sheets as the teacher deems necessary. An associated NFC tag identifies every sheet. The Activity Pad has red LEDs passing light trough the paper, thus giving a hint of the position of the reader units. This makes it easier for the teacher to mark areas on the sheet where stones should be placed. After paper sheets are ready, the teacher programs the Activity Pad in a way similar to that described in the first scenario. Children have to observe the rocks by watching, scraping and comparing them. After that, children have to place the rock samples to correct positions on the sheet (Figure 13). The Activity Pad gives feedback as described above.

Figure 12. The recycling application.

Figure 13. The application for identifying rocks.

DISCUSSION

During the design process and discussions with teachers, we learned that there exists a need for this kind of device. Teachers would like to use such a device and it would be easy to produce learning material for it. Involving teachers within the design process helped us to understand the essential characteristics the device should have. The design process is still ongoing and the next step is to test the second prototype in real classrooms in real learning situations and with real pupils. We do believe that getting the prototype tested with children will reveal valuable information on further development.

The construction of the Activity Pad was quite straightforward. The interference between neighboring NFC antennas had to be considered during the design. Casing required more work than expected. We ordered the casing as 3D printed, but as the result was not satisfactory, the upper part was manufactured from clear acryl to the final version.

Constructing example applications verified that dedicated programming skills or tools are not required – just drawing skills, either by hand or by using a computer application, are sufficient. Otherwise, programming requires only attaching NFC tags and assembling the correct constellation of tangibles on the Pad. Building similar computer applications would require dedicated programming skills. An application with a graphical user interface might be built for teachers for creating this kind of applications. This would decrease the requirements set for the teachers, but content would be digital and the user interface would be graphical instead of a tangible one. A tangible user interface could be created for tablet applications with the technology used in AppMATes, but this proprietary framework is not extendable beyond the commercially available tangibles. As we do not have the detailed specifications of this technology, we cannot perform a more detailed comparison.

The main advantage of the Activity Pad compared with other similar solutions is its versatility. The setup is not application specific, but instead permits teachers to create their own material and program the applications using the Pad. Furthermore, the full affordance of the paper interface is preserved. This can potentially establish more control for teachers over the learning process, which is generally lost in computer learning aids where others generate the content. Other important point to remark is that the Pad is a *complementary* tool for the teacher, not aiming to substitute existing materials. Finally, co-creation of applications with children can be a creative learning exercise in itself for both teachers and children.

Augmenting activity sheets with NFC tags and associated tangibles is significantly more expensive than using a traditional paper interface. On the other hand, NFC enables interactivity and programmability. Moreover, a complete system including the Activity Pad and a set of activity sheets and tangibles can be expected to be quite cheap once the NFC technology becomes more common – specifically when compared to computing devices with high-quality digital touch displays.

The current software of the Activity Pad supports only simple stateless applications. Our goal is to enable sequences of tangible constellations with automated closure of interaction. Our future work includes enabling more complex application logic and investigating the user experience of programing the logic by users. We are also developing a protocol for external devices to communicate with the Pad using USB and Bluetooth, this in its turn will enable more complex application logic and user experiences to be realized. Another possibility for future work is to connect several Pads together to handle larger areas with an increased amount of readers. Finally, a mechanism could be developed for clipping the paper to the device, increasing robustness during mobility and handling by children.

CONCLUSIONS

The work reported in this paper is part of our larger effort to understand and study active learning environments: What they really are and how they should be built. Our constructive goal is to discover new technological enablers for active learning environments. This paper presents the first practical steps towards this very goal. Through the piloting started in this paper, we aim to inform teachers regarding future user interfaces for learning, as well as to raise awareness of the potential of tangible user interface.

Despite the fact that the device is not fully ready yet, we and the teachers view the Activity Pad as a potential complementary learning aid in a classroom environment. The role of the device is somewhere between existing tangible learning aids and digital learning aids that schools already have. Especially, the Pad could support children from six to nine years old and children with learning disabilities.

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REFERENCES

1. Antle, A. N., Wise, A. F. & Nielsen, K. 2011. Towards Utopia: Designing tangibles for learning. In *Proc. 10th International Conference on Interaction Design and Children*, ACM Press (2011), 11-20.
2. Bodén, M., Dekker, A. & Viller, S. 2011. Discovery table exploring the design of tangible and ubiquitous technology for learning in preparatory classrooms. In *Proc. OzCHI'11,* ACM Press (2011), 54-57.
3. Bonnard, Q., Jermann, P., Legge, A., Kaplan, F. & Dillenbourg, P. 2012. Tangible paper interfaces: Interpreting pupils' manipulations. In *Proc. ITS'12*, *ACM* Press (2012), 133-142.
4. Bonwell, C.C. & Eison, J.A. 1991. Active learning: Creating excitement in the classroom. *Washington, DC: School of Education and Human Development, George Washington University*.
5. Broll, G., Graebsch, R., Holleis, P. & Wagner, M. 2010. Touch to play: Mobile gaming with dynamic, NFC-based physical user interfaces. In *Proc. MobileHCI'10,* ACM Press (2010), 459-462.
6. Colardyn, D. & Bjornavold, J. 2004. Validation of formal, non-formal and informal learning: Policy and practices in EU Member States. *European Journal of Education*, 39: 69–89.
7. Costanza, E., Giaccone, M., Kueng, O., Shelley, S. & Huang, J. 2010. Tangible interfaces for download: Initial observations from users' everyday environments. In *Proc. CHI'10 Extended Abstracts*, ACM Press (2010), 2765-2774.
8. Fitzmaurice, G.W., Ishii, H. & Buxton, W.A.S. 1995. Bricks: Laying the foundations for graspable user

interfaces. In *Proc. CHI '95*, ACM Press (1995), 442-449.

9. Hohmann, M., Weikart, D. P. & Epstein, A. S. 1995. *Educating young children: Active learning practices for preschool and child care programs*. Ypsilanti, MI: High/Scope Press.
10. Horn, M.S., Crouser, R.J. & Bers, M.U. 2012. Tangible interaction and learning: The case for a hybrid approach. *Personal and Ubiquitous Computing Journal*, *16*(4), 379-389.
11. Ishii, H. & Ullmer, B. 1997. Tangible bits: Towards seamless interfaces between people, bits and atoms. In *Proc. CHI'97*, *ACM* Press (1997), 234-241.
12. Jordà, S., Geiger, G., Alonso, M. & Kaltenbrunner, M. 2007. The reacTable: Exploring the synergy between live music performance and tabletop tangible interfaces. In *Proc. TEI'07,* ACM Press (2007), 139-146.
13. Marshall, P. 2007. Do tangible interfaces enhance learning? In *Proc. TEI'07*, ACM Press (2007), 163-170.
14. Montessori, M. 1964. *Montessori method*. Random House Digital, Inc.
15. Riekki, J., Cortés, M., Hytönen, M., Sánchez, I. & Korkeamäki, R.L. 2013. Touching nametags with NFC phones: A Playful approach to learning to read. In *Transactions on Edutainment X*, Springer Berlin Heidelberg, 228-242.
16. Rogers, Y., Price, S., Randell, C., Fraser, D. S., Weal, M. & Fitzpatrick, G. 2005. Ubi-learning integrates indoor and outdoor experiences. *Communications of the ACM*, *48*(1), 55-59.
17. Sánchez, I., Cortés, M., Riekki, J. & Oja, M. 2011. NFC-based interactive learning environments for children. In *Proc 10th international conference on interaction design and children*, ACM Press (2011), 205-208.
18. Sellen, A.J. & Harper, R. 2003. *The myth of the paperless office*. MIT Press, 2003.
19. Wellner, P. 1993. Interacting with paper on the DigitalDesk. *Communications of the ACM*, *36*(7), 87-96.
20. Xie, L., Antle, A. N. & Motamedi, N. 2008. Are tangibles more fun?: Comparing children's enjoyment and engagement using physical, graphical and tangible user interfaces. In *Proc. TEI'08*, ACM Press (2008), 191-198.
21. Zuckerman, O., Arida, S. & Resnick, M. 2005. Extending tangible interfaces for education: digital Montessori-inspired manipulatives. In *Proc. CHI'05*, ACM Press (2005), 859-868.
22. Zuckerman, O. & Gal-Oz, A. 2013. To TUI or not to TUI:. Evaluating Performance and preference in tangible vs. graphical user interfaces. In *International Journal of Human-Computer Studies, 71(7-8)*, 803-820.