Tangible Interactive Ambient Display Prototypes to Support Learning Scenarios

Dirk Börner
Valkenburgerweg 177
6419 AT Heerlen
The Netherlands
dirk.boerner@ou.nl

Sven Happe
MD.H Mediadesign Hochschule
Werdener Straße 4
40227 Düsseldorf, Germany
s.happe@mediadesign-fh.de

Bernardo Tabuenca
Valkenburgerweg 177
6419 AT Heerlen
The Netherlands
bernardo.tabuenca@ou.nl

Marcus Specht
Valkenburgerweg 177
6419 AT Heerlen
The Netherlands
marcus.specht@ou.nl

Jeroen Storm
Valkenburgerweg 177
6419 AT Heerlen
The Netherlands
jeroen.storm@ou.nl

TEI '15, Jan 16-19 2015, Stanford, CA, USA
ACM 978-1-4503-3305-4/15/01.
http://dx.doi.org/10.1145/2677199.2687908

Abstract
This paper describes the research and development of tangible interactive ambient display prototypes to support learning scenarios. Therefore a prototypical system design called the *Feedback Cube* is presented. The prototypes combine motion sensors, visual and auditive actuators, as well as wireless communication capabilities in a cubic layout. An initial formative study underpins the prototypes' potential to facilitate interaction and/or indicate feedback. Based on the presented results possible applications scenarios in a learning context are outlined.

Author Keywords
Tangible interaction; prototyping; design; research; development; feedback; sensors; actuators

ACM Classification Keywords
H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

Introduction
Following similar principles, "*tangible bits*" by Ishii and Ullmer [6] and "*ambient displays*" by Wisneski et al. [10] both paved the way for embodied interaction. Tangible interfaces are considered as more natural and intuitive than traditional types of interfaces [4]. Ambient systems are subtle and non-intrusive means

for interfacing people with peripheral information. With all these characteristics in mind, both concepts offer great potential to support learning scenarios in various ways. Also related research work in this domain supports that. A review on tangibles for learning by O'Malley and Fraser [7] concluded that tangibles bring physical activity and active manipulation to the forefront of learning, i.e. they reduce the learners' cognitive load in order to enable learners to allocate the resources relevant for the task. With similar conclusions Börner et al. [3] reviewed ambient displays for learning and highlighted their potential to support learning implicitly by raising, enhancing, or supporting awareness, changing behavior, giving feedback, providing assistance and guidance, or just by presenting information.

The presented research and development in this paper aims to utilize both embodied interaction principles to support learning scenarios. With the underlying idea to combine both approaches in a flexible and easy-to-use system, the main focus lies on the exploration and formative evaluation of a respective prototypical system design called the *Feedback Cube*.

Prototypical System Design

To study the support of learning scenarios with tangible interfaces and ambient displays, respective prototypes were developed. The design process followed a system design approach, i.e. putting the actual system in the center of the process and arranging a set of components to create the desired design solution [8]. For the envisioned system, the ability to detect motion, provide visual and auditive cues, and communicate wirelessly were considered as most important. Based on these criteria, the components were chosen and assembled. Instead of using another existing system this offered the possibility and flexibility to change and customize the prototypical design at any time.

Hardware Platform

For the prototypical system design a cubic shape was chosen. As solid three-dimensional objects, cubes represent familiar physical structures that can be utilized for tangible manipulation, spatial interaction, or expressive representation as characterized in Hornecker and Buur's framework of tangible interaction [5].

The exterior of the cube prototypes was made from high-density fiberboard and semi-transparent Plexiglas, whereas five sides of the cube are opaque and only the top is semi-transparent. The interior comprises a set of various sensor, actuator, and communication components as well as the necessary hardware to operate them. The cubes have an edge length of 100mm, so that all components fit in, while still ensuring a reasonable size for tangible interaction. The hardware operating the prototypes is based on the open-source electronics platform Arduino[1]. The main components are an Arduino Uno microcontroller board, an Arduino WiFi/Wireless SD shield, and a TinkerKit[2] Sensor shield. The wireless shield enables the microcontroller to connect and communicate wirelessly either via wireless or mesh networks. The integrated micro-SD card slot can be used to read and store files. The sensor shield provides an easy-to-use hub to connect sensor and actuator components directly to the microcontroller. All hardware components can be

1 http://www.arduino.cc
2 http://www.tinkerkit.com

powered either by a built-in rechargeable battery or tethered via the integrated USB interface.

Sensors And Actuators
The hardware platform is enhanced with various sensor and actuator components. The sensors are used to detect changes in the environment, providing input to the prototypical system. The actuators are used to act upon the detected changes, providing a system output.

As sensor components the prototypes include a TinkerKit Accelerometer, Gyroscope, and Hall sensor. The three-axis accelerometer measures acceleration and can be used to detect movement. The two-axis gyroscope measures orientation and can be used to detect movement and rotation. The measured output of the accelerometer and the gyroscope were combined to emulate an inertial measurement unit. This allows more accurate measurement of the prototypes' inclination relative to the ground. Finally the hall sensor measures changes in the surrounding magnetic field, which can be used for instance to calculate the distance to a nearby magnet.

As visual actuator the prototypes include an Adafruit[3] NeoPixel ring mounted below the semi-transparent side of the cube. The ring consists of 16 RGB LEDs that can be individually addressed via their built-in microcontroller. Using the available Arduino library the color and brightness of each LED can be controlled. Furthermore the prototypes include a 12-Watt mini speaker that can be used as auditive actuator.

3 http://www.adafruit.com

System Characteristics
The specified form factor, used hardware platform, and chosen sensor and actuator components enable different possibilities to use the *Feedback Cubes*. In general the prototypes can either facilitate some kind of interaction with users or objects (interaction facilitator), indicate feedback information to users or the immediate surrounding (feedback indicator), or do both at the same time.

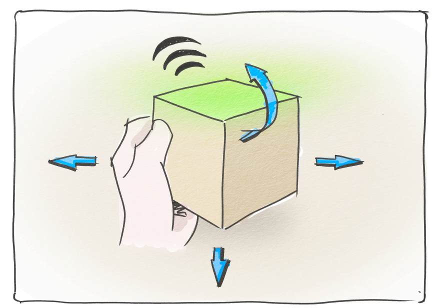

Figure 1. Interaction facilitator concept.

Interaction Facilitator
The interaction facilitator concept as illustrated in Figure 1 is characterized by the prototypes' sensor components. The used accelerometer and gyroscope are able to detect movement on the x-, y-, and z-axis and rotation on the x-, and y-axis (five degrees of freedom). More specifically moving the prototype along the axes, i.e. forward, backward, left, right, up, and down, as well as rotating the prototype along the axes, i.e. rolling and tilting, can be detected. The used hall sensor is able to detect changes in the surrounding magnetic field and thus the presence of magnetic objects, e.g. other prototypes can be detected. Other

means of facilitating interaction are the communication components. The prototypes have built-in serial communication facilities that can be used, e.g. via the available USB-to-serial converter. Furthermore the used WiFi shield enables the prototypes to take client and/or server roles for communication within wireless networks. Alternatively the used wireless shield enables the prototypes to support point-to-point, point-to-multipoint, and peer-to-peer mesh network topologies with other prototypes.

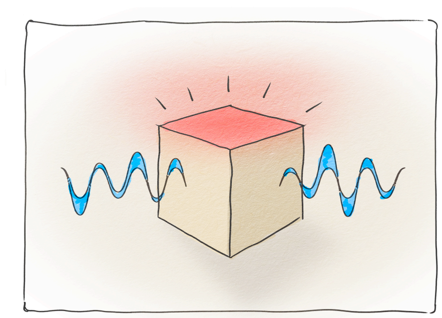

Figure 2. Feedback indicator concept.

Feedback Indicator

The feedback indicator concept as illustrated in Figure 2 is characterized by the prototypes' actuator components. The used LEDs are capable of displaying the full RGB color space with 16777216 colors at 256 brightness levels. All 16 RGB LEDs on the ring can be controlled individually, which allows programming various visual patterns and effects, such as fading, blinking, or color transitions. The used mini speaker can produce sounds in response to the electrical signal input delivered by the microcontroller. Programmatically manipulating the signal input allows creating various audio patterns and effects, such as playing single tones, complex melodies, or even encoded audio files. When using the integrated storage capabilities, it is also possible to create an accessible music and sound effect library.

Formative Study

To explore usability issues of the *Feedback Cubes* a formative study was conducted with a group of 8 participants. All participants were experts in the field of learning sciences with either a technical or educational background. In a first round, after introducing the general idea and the basic functionality of the prototypes, the characteristics of the interaction facilitator concept were highlighted and each participant had the chance to examine the prototypes and test the respective functionality. The participants were then asked to fill in an all-positive version of the System Usability Scale (SUS) [9], focusing their ratings solely on the interaction facilitator concept. In a second round the procedure was repeated once again for the feedback indicator concept.

The interaction facilitator concept received a mean score of 71.9 (SD = 10.3). The feedback indicator concept received a mean score of 69.1 (SD = 15.8). When comparing both scores to other hardware systems [1], the interaction facilitator concept scored higher than 52.3% of the other systems with a "C" grade at an acceptable level, which can be described as "Good". The feedback indicator concept scored higher than 41.6% of the other systems with a "D" grade at a marginal level, which can be described as "Ok". The results show above average ratings for both concepts with room for further improvements. The interaction facilitator concept scored higher than the feedback indicator concept. The participants stated that the tangible interaction is much more intuitive, while the ambient display principle requires an additional mapping to make sense of the provided information. It can be assumed that this changes once the mapping is clearly defined.

After evaluating the perceived usability of the single concepts, the whole group was asked to capture their general impressions about the prototypes using a modified electronic version of the Product Reaction Cards originally developed by Benedek and Miner [2]. The group was asked to agree on 6 cards with words that described their experience with the prototypes best and comment on their selection. The group agreed on the following selection of words: *engaging*, *straight forward*, *customizable*, *responsive*, *fragile*, and *familiar*. The group commented that the prototypes are *familiar* in a sense that form and function are evident without creating additional obstacles or distraction. However, the prototypes' design was also characterized as *fragile* and several improvements were suggested to make it more robust. Besides that, the prototypes were characterized as *engaging* due to the fact that specific user inter- and reactions are encouraged. The interactive and especially the indicator functions were characterized as *straight forward* and *responsive* with the potential to implement feedback and direct interaction mechanisms. The group also commented that the prototypes are *customizable* in a sense that various individual and collaborative scenarios could be supported.

Discussion And Conclusions

Following the formative study the participants were asked to think about and discuss specific learning scenarios that could be supported. This discussion, the given system characteristics, as well as the formative results, helped to outline the following application scenarios. Based on the introduced interaction facilitator concept the *Feedback Cubes* could for instance support memorization tasks by enabling users to easily relate visual and spatial information. Under the assumption that using the tangible interactive prototypes facilitates retention, the prototypes would augment the task. The users would receive visual instructions for a randomized sequence of moves that they have to repeat with the prototypes. After each correct repetition one more random move could be added to the sequence. In a collaborative group setting the interaction capabilities of the prototypes could also be used to moderate an ongoing discussion session, e.g. if a common agreement is needed at the end of the session. Each opposing party would receive a *Feedback Cube* and could confirm or decline arguments by tilting the prototype left and right. Whenever the parties agree on the same argument the prototypes should be moved closer to each other, reaching the final agreement when both prototypes touch each other.

Other application scenarios based on the feedback indicator concept could support the users' individual or group performance by increasing the awareness on certain indicators. The assumption would be that this increased awareness triggers reflection and eventually provokes users to adapt their behavior accordingly. In this context the ambient display functionality of the prototypes would be used to provide this feedback. In a collaborative setting with several groups, each group could receive one *Feedback Cube* that indicates for instance the (externally measured) general speech volume within the group. Whenever the volume gets too loud (and thus prevents the exchange of arguments in the discussion) the prototype makes the group aware of that through visual or auditive feedback. In a similar manner the prototypes could also be used as personal peripheral displays. For instance in combination with a time/task management application the *Feedback Cube* could indicate the timing or completion of certain tasks. In combination with an activity tracking application the prototype could provide an overview of individual performance parameters or patterns.

In conclusion the presented system design of tangible interactive ambient display prototypes allows utilizing embodied interaction principles to support learning scenarios. A formative study underpinned the prototypes' potential to facilitate interaction and/or indicate feedback. Especially the interactive capabilities were considered as functional and encouraging, while several improvements were suggested. Finally the gathered insights informed application scenarios of the *Feedback Cubes* in a learning context, which will be implemented as proof of concept for further evaluation in a next step.

Acknowledgments

The presented research and development is partly funded by the METALOGUE project. METALOGUE is a Seventh Framework Programme collaborative project funded by the European Commission under grant agreement number: 611073 (http://www.metalogue.eu).

References

[1] Bangor, A., Kortum, P.T. and Miller, J.T. Determining What Individual SUS Scores Mean: Adding an Adjective Rating Scale. *Journal of Usability Studies 4*, 3 (2009), 114-123.

[2] Benedek, J. and Miner T. Measuring Desirability: New methods for evaluating desirability in a usability lab setting. In *Proceedings of Usability Professionals Association 2003*, UXPA (2002), 8-12.

[3] Börner, D., Kalz, M., and Specht, M. Beyond the channel: A literature review on ambient displays for learning. *Computers & Education 60*, 1 (2013), 426–435.

[4] Dourish, P. *Where the action is: the foundations of embodied interaction*. MIT Press, 2001.

[5] Hornecker, E. and Buur, J. Getting a grip on tangible interaction. In *Proceedings of the ACM SIGCHI Conference on Human Factors in Computing Systems (CHI'06)*, ACM Press (2006), 437–446.

[6] Ishii, H. and Ullmer, B. Tangible bits: towards seamless interfaces between people, bits and atoms. In *Proceedings of the ACM SIGCHI Conference on Human Factors in Computing Systems (CHI'97)*, ACM Press (1997), 234-241.

[7] O'Malley, C. and Fraser, D. S. *Literature Review in Learning with Tangible Technologies*. 2004.

[8] Saffer, D. *Designing for Interaction: Creating Innovative Applications and Devices*. New Riders, 2007.

[9] Sauro. J. and Lewis, J. When Designing Usability Questionnaires, Does It Hurt to Be Positive? In *Proceedings of the ACM SIGCHI Conference in Human Factors in Computing Systems (CHI 2011)*, ACM Press (2011), 2215-2224.

[10] Wisneski, C., Ishii, H., Dahley, A., Gorbet, M., Brave, S., Ullmer, B., and Yarin, P. Ambient displays: turning architectural space into an interface between people and digital information. In *Cooperative buildings: Integrating information, organization, and architecture*, Springer (1998), 22–32