Teaching Design of Emerging Embodied Technologies

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ABSTRACT

How does design of emerging embodied technologies enrich the HCI learning processes? We introduce a model for embodied interaction and use it in the development of a painting app for children, based on the motion sensor *Asus Xtion Pro (similar to Kinect)*. The development of the app was part of a HCI course for engineering students. The motion sensor was interesting as a design tool, because it appealed to full body interaction. The development exemplified and unfolded the embodied elements: Multiple modalities, physical, bodily, social, and symbolic interaction in a situated environment.

Subsequently, we introduce a physical-digital toolbox, illustrating the span of parameters within the model for embodied interaction: Robot Technology, Tangibles, Wearables, Interactive Surroundings, and Bigger Objects.

INTRODUCTION

In this article, we explore how having a body affects interaction design (Pfeifer, 2007). Last autumn, my fifth semester engineering students used the motion sensing input device, *Asus Xtion Pro* (similar to *Microsoft's Kinect*), for the design of embodied interaction tools for children. The platform was interesting as a design tool, because it appealed to full body interaction. In addition, it appealed to innovative and creative development projects (Borenstein, 2012).

The design was part of a course in physical-digital interaction design, where the students explored other interactive platforms than PCs and tablets. The students developed a painting application, where at the end, users painted in ten different colours by waving one of their hands.

Basically, we have several categories of physical-digital interactive devices for embodied interaction: Robots and Robot Technology, Touch and Tangibles, Interactive Wearables, Interactive Surroundings, and Bigger Objects. Interactive Surroundings are Sensor Networks, such as camera tracking, hands-free speech recognition and motion sensor devices, such as Microsoft Kinect or Asus Xtion Pro.

For many years, it has been our desire to develop effective and easy to use handsfree user interfaces. Kinect was the first on the market and was launched in November 2010. It sold 8 million units in the first 60 days and entered the Guinness World Records as the fastest selling consumer electronic device in history (Melgar, 2012).

In this study, we want to investigate the relationship between emerging technologies, embodied and natural interaction, and learning activities. Our teaching and learning approaches are based on participatory, exploratory and reflective learning. The students are to participate actively in all the phases of the design: initial field study, prototyping and testing. This contrasts HCI courses focusing on theoretical studies and analyses of other people's designs. This participatory and reflective learning philosophy is supported theoretically by Schön (1983), Papert, (1993) and Bateson (2000). The students basically learn, while they are exploring and designing new prototypes. In the classroom and in project work, the students reflect on their design ideas, concepts, programming, target groups, test results and academic knowledge. Active participation and reflection is the core of learning (Bateson, 2000; Wenger, 1998). The overall question explored in this paper is:

> *How does a design of emerging embodied technologies, such as Asus Xtion Pro, enrich the HCI learning processes in Engineering Education?*

First, we discuss enriched learning processes in an embodied context and relate this to kinaesthetic, auditory and visual modalities. Then we introduce the concept of embodied interaction, as a combination of multiple modalities, physical, symbolic and social interaction, in a situated environment. As an illustration of this, we describe the students' development of the painting prototype and the user test. In order to focus on the Asus Xtion as an educational tool in the HCI course, we discuss how the students' learning unfolded. The HCI learning loops are illustrated, focusing on the interplay between the students and children in real-life situations. The course is evaluated and the learning activities are pinned down. This is followed by a section on the physical-digital toolbox, which supports embodied interaction. The various categories of physical-digital platforms are: Robot technology, Touch and Tangibles, Interactive Wearables, Interactive Surroundings, and Bigger Objects. Finally, we summarize and conclude.

The research method used in this study is based on Design-based Research and Action Research (Majgaard, 2011; van den Akker 2006; Lewin, 1946). Design-based Research is a branch of educational research that uses the iterative design of educational interventions to exemplify and develop theories of learning. Action Research brings a change in the behaviour of the target group into focus and allows emerging goals. Experiments and critical reflections are at the core of this research method, allowing learning from and through practice. The interventions took place in the target group's natural surroundings e.g. in the classroom.

APPROACHES: EMBODIED INTERACTION AND LEARNING

This study focuses on how embodied technologies theoretically may enrich learning processes. But first we need to describe what we mean by embodied interaction.

The Embodied Interaction Model

The rise of embedded computers helps us move around in the world, do household tasks and automates processes in industry. It also affects the way we learn, teach, experience and explore the world. Both the increase of computational power and embedded computing, provide new ways of interacting. Basically our computers become more and more physical-digital interactive and we use our bodies in the interaction. Smartphones and tablets allow interaction with a high level of graphical abstraction combined with diverse physical-digital participation. Research in Human-Computer Interaction (HCI) has begun to explore these new ways of interacting. Dourish defines this new type of interaction below:

> *Embodied interaction is interaction with computer systems that occupy our world, a world of physical and social reality, and that exploit this fact in how they interact with us (Dourish, 2004, p. 3).*

Dourish describes embodied interaction as a mixture of a physical, social and symbolic reality, see the figure below. The interaction takes place in the physical world and perhaps partly in the virtual world, e.g. a child connects tangible interactive blocks, which symbolically represent music instruments. Secondly, the interaction takes place in a social context. Thirdly, the interaction also has certain modalities e.g. auditory, visual and/or kinaesthetic. The modalities can also be broken up into Gardner's multiple intelligences: musical - rhythmic, visual - spatial, verbal - linguistic, logical - mathematical, bodily - kinaesthetic, interpersonal, intrapersonal, and naturalistic (Gardner, 1983). The aspects of embodied interaction are summarised in the figure below.

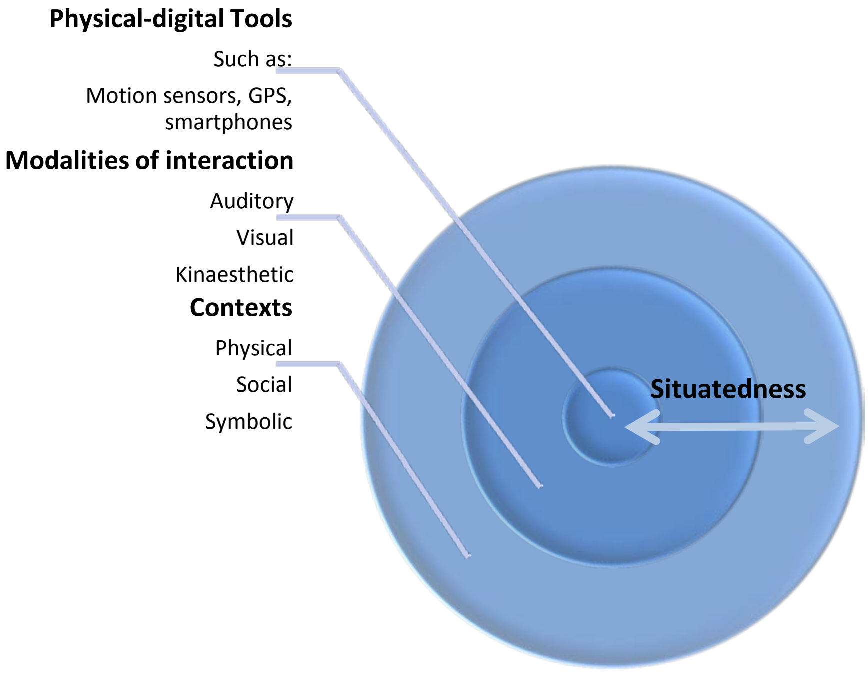

Figure 1: Embodied Interaction Model

Embodied interaction is of a physical nature and unfolds between humans and physical-digital tools. The physical-digital tool, such as the motion sensor, communicates through certain modalities within its context. The modalities relate to all the human senses e.g. visual and kinaesthetic. In the context humans interact physically, socially and symbolically. The interaction is situated in time and space and takes place "here and now".

Modalities and learning processes

Embodied interaction supports multimodal learning processes. As mentioned above, there are basically three major sensory learning modalities: auditory, visual and kinaesthetic. Gardner adds several modalities and characterise them as the multiple intelligences (Gardner, 1983). The multiple intelligences are: musical - rhythmic, visual - spatial, verbal - linguistic, logical - mathematical, bodily - kinaesthetic, interpersonal, intrapersonal, and naturalistic. Each of them represents a relatively independent form of information processing. Among them, bodily-kinaesthetic intelligence, which describes one's ability to control body movements, gestures, and the capacity to handle, objects skilfully. Gardner's philosophy is that each student has one or more strengths in their way of learning – some students are primarily verbal; others are primarily kinaesthetic or visual. Consequently, the teacher has to provide learning materials that support different ways of learning. In other words the learning material should support several intelligences at once. A study shows that children at the age of five learn phonetic rules, while tracing words with an index finger, while pronouncing it and looking at it (Hsu, 2011). This multi-sensory or multi intelligence approach seems to be effective in establishing the connection between visual and auditory representations. The physical-digital motion sensor supports the bodily – kinaesthetic intelligence. Most application will involve the visual and/or auditory modalities as well. This makes motion sensors, such a Kinect and Asus suited as platforms for multimodal educational tools.

Hsu analysed in 2011 the potentials of the motion sensor Kinect as an educational tool (Hsu, 2011). The motion sensor is a physical-digital tool. She recommends the tool as support to kinaesthetic pedagogical practices, to benefit learners with strong bodily kinaesthetic intelligence. The interactivity facilitated by Kinect applications, covers kinaesthetic and visual sensory modalities. Of technical constraints Hsu mentions that calibration takes time.

In summary, multimodal learning processes accommodate the learners’ different ways of learning. Embodied interactive technology supports several learning modalities and several of Gardner’s intelligences.

Situatedness

The interaction is situated and takes place in the “here and now” environment. Situatedness is introduced by Brooks (1991) who addresses a more engineering and robotics related approach to embodied interaction research.

Embodied interaction incorporates a wider range of human skills and abilities. The physical-digital tools are accessible and integrated in our everyday lives, such as smartphones or GPS-systems. They reduce complexity of specific interactions.

Embodiment is very much in focus in the world of artificial intelligence and robotics. Modern robots understand the world though sensors positioned in the right places. And a robot adapts to its surroundings through sensors and effectors. Pfeifer (2007) stresses that intelligence requires a body. He believes that the body enables cognition and thinking. There are two cornerstones in modern robotics: embodiment and situatedness. Embodiment refers to the intelligent and physical-digital body:

> *Embodiment: The robots have bodies and experience the world directly - their actions are part of a dynamic with the world, and the actions have immediate feedback on the robots' own sensations(Brooks, 1991).*

When an interactive system integrates sensors, effectors and a control system, it is able to sense changes in the souroundings and react accordingly. The system is embodied, when it reacts dynamically to changes in the world e.g. the Endomondo App senses my running route using its GPS sensor. Endomondo reacts by showing graphics and speaking to me about my speed. Brooks and Pfeifter have a robotic-physiological approach to embodied interaction, focusing on artificial intelligence, grasping physical objects, arrangements of sensors and material properties for the digital agents. The digital agent is another word for robot. They research on the design of the digital agent; how to shape its body, and the embodied interaction with the dynamic envirornment. Embodiement relates to the physical proporties and physical interaction in Pfeifers and Brooks perspective. They don’t describe the surroundings as social, and they don’t link embodiment to something social. In contrast Dourish links embodiment to social aspects, such as incorporating social understandings into the design of interaction (Dourish, 2004:16). An understanding of the social world and incorporation of this understanding into the embodied interaction design processes. First we need to explore the concept of situatedness. Situatedness refers to the“here and now” communication between system and user. Books defines it as:

> *Situatedness refers to how the interactive robot is situated in the world and how it reacts to the “here” and “now” of the environment that directly influences the behavior of the system (Brooks, 1991).*

Brooks focuses here on the dynamics between the robot and the environment, and on how the robot's actions have an impact on its own sensations. Embodied interaction is closely related to both embodiment and situatedness.

Embodied interaction requires a supportive interface. This interface consists of sensors, which are able to sense “here and now” changes in the dynamic surroundings. The interface must in order to communicate meaningfully, be able to process and interpret its sensations and react accordingly. Being situated is a way for the system to understand the surroundings or context. The specific sensors bring attention to specific parts of the context. In the old days before the 1990’s, robots weren’t situated, they just executed their program without regard to the surrounding environment (Brooks, 1991). The old industrial robots couldn’t see or feel their surroundings, and they could harm humans in their near proximity. This meant that humans and robots couldn’t work in the same physical area.

When robots became more situated, robots and humans could begin to interact more directly. Situatedness forms the basis for the research field of Human Robotic Interaction.

EMBODIED INTERACTION IN THE DEVELOPMENT OF A PAINTING APP

Contexts and modalities of embodied interaction are illustrated in the development of the painting application.

The physical-digital tool: The motion sensor in this case is Asus Xtion similar to the Kinect. The motion device is for Windows PCs. Asus Xtion Pro (no RGB camera) and Xtion Pro Live (RGB camera) were released in 2012. The Asus Xtion Pro sees the world in 3D. It is based on an infrared camera that enabled users to control and interact with the computer without touching a game controller. The interaction takes place through a natural interaction, using body and hand gestures.

Figure 2. (a) IR Projected light on a blank surface; (b) 3D image based on IR information

Asus Xtion makes use of an infrared camera for recording the movements of the user, and the recordings are based on variations in depth. The camera has two lenses: one lens projecting an infrared grid, see the figure 2(a) above; the second lens captures and creates a 3D image, see figure 1(b). The closer, the object is to the IR camera, the whiter the image is. The Asus Xtion connects by USB to a PC (Christensen et al, 2013).
The software development kit is called OPEN NI (2013), and it offers methods for skeleton tracking, hand-point tracking, and gesture recognition. The programming was done in the programming environment *Processing* and was based on simple Java-like syntax (Borenstein, 2012; Melgar, 2012). The Asus competes with the Kinect, Wii Remote and Eye Toy. Recently, a new motion sensor called Leap Motion has appeared on the market and it is for hand gestured computer interaction (Leap Motion, 2013). This new device senses hands and fingers and follows their every move. It lets them move in all directions in the space between you and your computer screen (Leap Motion, 2013).
Bob Heddle Director of Kinect for Windows announces that Microsoft will deliver a new generation of Kinect for Windows sensors next year (Kinect for windows blog, 2013). Some of the key capabilities of the new Kinect sensor will most likely include: Higher fidelity, expanded field of view, improved skeletal tracking and new active infrared (IR). Especially, the improved skeletal tracking will promote future innovative physiotherapeutic training applications and other applications.

Related work on using the motion sensor as educational tool: Villaroman et al (2011) present examples of Kinect-assisted teaching, used to achieve some of the learning goals in Human Computer Interaction (HCI) courses. The motion sensor device introduces a natural form of interaction (Melgar, 2012; Villaroman et al, 2011). Exploration of this type of interaction in HCI courses can become very instructive. Kinect or Asus Xtion can provide activities that aid the study of natural user interaction which would otherwise be unavailable. Villaroman et al suggest learning activities such as: (1) "Study how cognitive principles, affordance, and feedback should influence the design of Kinect controlled interfaces in desktop computers;" (2) "Design and implementation for a specific application domain – such as web browsing;" (3) "As an emerging technology, exploring how Kinect or Asus Xtion can help advance the field of gesture-based, natural user interaction;" (4) "Test and analyse whether usability and user-experience requirements can be met with the current capabilities of the Kinect-enabled user interfaces.” Villaroman et al believe that students, who have gone through an undergraduate advanced programming course in C/C++, will find it relatively easy to develop applications directly from the project libraries.

The development process: The students in our case were fifth semester students from the engineering programme, *Learning and Experience Technology*. *Learning and Experience Technology* is a 3 plus 2 years IT Engineering Program. The overall learning goal of the course was to design interactive tools for play and learning. The designs should be based on other media than traditional PCs. Each student did an individual programming assignment and participated in team-oriented project work. As a part of the project work, the students conducted field observations of the target group and they also tested the interactive prototype on the target group. In order to get started on the technological platform, the students read and did exercises from the book, *Arduino and Kinect Projects* by Melgar and Diez (2012).

The painting application was the result of the project work. The graphical part of the interactive painting prototype was divided into two equal parts, see the figure below. The left side showed the user's painting and the right side showed the representation of the infrared 3D image. An invisible colour pencil was attached to one hand. The pencil was displaced from the centre of the palm to the fingertips. This worked intuitively correct. The registration of the user's hand was done by waving in front of the camera. To control painting functions, an Arduino board with three buttons was used: (1) One switched cyclically between 10 different colours; (2) The second deleted everything that was painted on the screen; (3) The third switched between five different pencils.

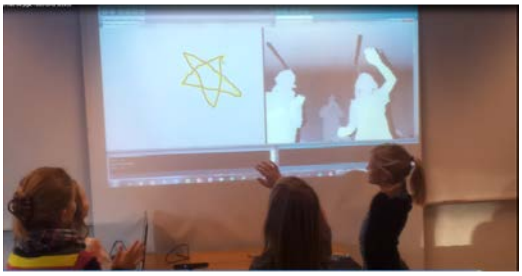

Figure 3. Testing the interactive drawing prototype (the star is subsequently made more colourful)

The test was conducted in the students’ classroom. The testers were four school children from the third grade, who were about 9 years old, see the figure above. The summary of the test is based on quotes from the students’ test log and the oral examination: “the children were excited about the test and the program...”. “They tried to paint Harry Potter, stars, dogs etc., and they learned quickly how to use the programme”, wrote the students. The programme had some bugs, e.g. the hand recognition deadlocked. The students wrote: “When the program went into a deadlock, the children helped each other and restarted the programme.” The students observed that the children took their own playing activity into the testing process: “They took turns to paint and they started to dance and sing, while they were waiting. They could see their own IR image, while they danced and this made it more interesting”. After the test, the students made a short interview. They asked the children what they liked about the programme, and what could be done differently. They got the following suggestions: use the feet as a pencil instead of hands; draw on top of another picture; eraser; undo button; more colour options; insert squares, circles, triangles, etc. The children found it annoying that they had to wave so much to start drawing, and they found the infrared camera was more fun than a normal camera. And they would like the students to develop structured gaming elements, e.g. a competition to draw a human or an animal and receive points.

Finally, the students participated in the student conference (SIDeR, 2013), where they presented the painting application (Christensen et al, 2013) and won an EU funded award of excellence for designing for vulnerable generations - children and elderly (Device, 2013). Another group presented an installation called Chimecloud also based on Kinect technology (Jepsen, 2013; Chimecloud, 2013). Wind chimes are often made by metallic tubes and are to be played by the wind. This Chimecloud installation was to be played, by bodies moving below the chimes. The Kinect sensors detected how fast a person walked by and transformed this into acoustical feedback. Sticks connected to the servo motors pushed the pipes all depended of input from the Kinect sensors. More users could collaborate in playing the chimes. The installation was developed in collaboration between Chalmers University and the municipality of Lundby, and was exhibited in Backaplan Kulturhus. This installation presented the rich potentials in combining aesthetic installations, art and embodied interactivity.

DISCUSSION: EMBODIED INTERACTION AND THE HCI LEARNING LOOP

The discussion focuses on how embodied interaction is implemented in the Painting application. We discuss how the students learn, while they are designing and testing their application. And we call this particular way of learning for the HCI Learning Loop. Finally we evaluate the course and look at upcoming ideas.

The Embodied Interaction Model applied on the Painting App

Does the painting application really support all aspects of embodied interaction? The Painting App viewed in an embodied interaction perspective, see the figure below.

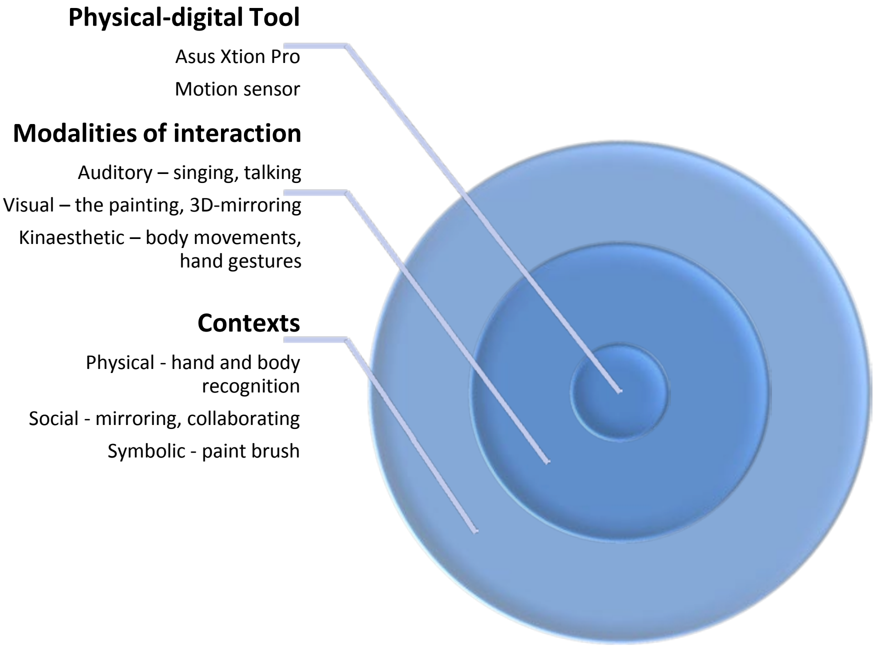

Figure 4. Embodied Interaction using the Painting Application

The children interacted physically, using their hands as paintbrushes. The hand symbolised a paintbrush and worked like one, when the children were interacting with the system. The painting app reacted instantly, when the children waved their hands. This exemplifies that the system is situated and reacts to “here and now” sensations. The painting app supported the children’s social interaction, because more than one could interact with the system e.g. one child could change colours, while another one was painting. The children could also see each other’s 3D reflections on the projector, this also mirrored their social interaction. The physical, symbolic, social and situated aspects of embodied interaction are supported by the designed painting application. The children also used the three major learning modalities. The auditory modality came into play, while the children discussed how to use the painting app and while they sang. There was no audio output from the Painting app – so the audio modality is debatable. The visual sensory modality came into play, when the system mirrored their bodily movements and visualised their hand drawings. The mirroring of their bodies and body movements, also describe a special interaction between the children and the system. The children also communicated with each other, by watching each other in the painting app mirror.

HCI Learning Loop

How did the students learn while developing the system?

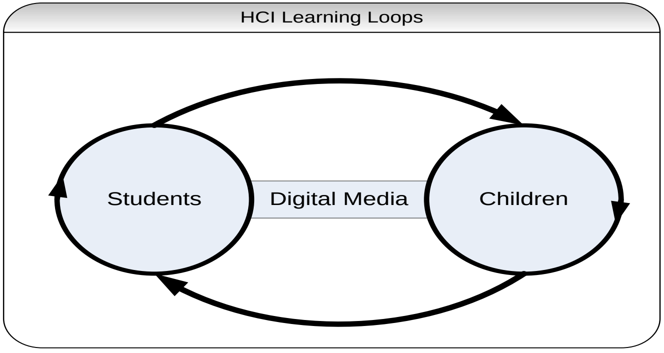

Figure 5. HCI Learning Loops

The above figure illustrates the students' and children's learning loops. First, the students' learning process took place during the iterative design process, illustrated in the left cycle. The cycle on the right side, illustrates the children's playful learning process. The cycles are learning loops of action and reflections (Schön, 1983). The digital media were developed and understood in interplay between students and children. The media constituted a community of practice (Wenger, 1998). Secondly, the students learned, while they watched the media in use. The arrows between the students' and children's learning cycles, illustrate the dialogue, instructions and feedback that took place. Additionally, we reflected on the embodied interaction in the classroom. We discussed the platform potentials in games, rehabilitation, as a hands free web browser etc. We evaluated the design process and the students testing experiences. This type of reflection is retrospective and is a way of optimising design processes. It is also a way to combine theoretical knowledge on embodied interaction and real life experiences.

All the students managed individually programming the device, one of the students made a traditional ping pong game, another combined a music video and the user's body as a skeleton; a third painted circles, and a fourth used the hand as a computer mouse.

The project work resulted in a painting application prototype. The users used their hands for painting and they painted in different colours and used pencils in different sizes. The prototype was tested by four school children from the third grade. The students got a lot of useful feedback from the testers. The feedback fell into three categories: (1) *Usability issues* such as deadlock situations and the hand recognition problem. (2) *Creative ideas* e.g. painting using feet instead of hands. (3) *Unexpected playful use*. The children danced and sang, while they were taking turns. If the painting application was to be developed further, there are promising possibilities for full-body interaction, participatory interaction, and creative interaction.

Altogether, the figure above illustrates learning processes in real-life situations.

Evaluation of the course and future teaching

The students were fifth semester students, and they had been programming since their first semester. The students combined Arduino and Asus technology. They programmed their application from the Arduino programming environment Processing. Processing is a complete and thorough development environment, which makes the development processes smoother for the students. It was relatively easy for the students to develop interactive prototypes, using the additional OpenNI middleware for programming the Asus Xtion. Altogether, it was a very successful experience, to use the Asus in HCI teaching. This is also supported by Villaroman et al (2011). There were some limitations, e.g. it was sometimes difficult, to make the system recognise the hand in the initial phase.

The learning philosophy was based on active participation; experimentation and reflection. The students participated actively in all the phases of design: initial field studies, prototyping, and testing. This contrasts HCI courses, focusing on theoretical studies and analysis of others designs. The learning activities covered: Design using emerging technologies; User testing and experimenting on various conditions that could increase usability; Identification of ways a Kinect sensor could assist

users with certain disabilities; Analysis of usability and affordance. The students learned while they iteratively designed and tested. Furthermore they learned from retrospective analysis of the design process. The learning process can be described as cycles of action and reflections.
Overall, the motion device, Asus Xtion, enriched the HCI learning processes in the classroom.
The students learning activities included:

- Design using emerging technologies.
- User testing and experimenting on various conditions that could increase usability.
- Identification of ways a Kinect sensor can assist users with certain disabilities.
- Analysis of usability and affordance.
- Some of the students explored the sensors advantages and disadvantages, as a web-browsing tool.

A new generation of fifth semester students are now exploring the Asus Xtion Pro. This year, they are developing a mannequin for a fictive clothing store in town. The idea is to mirror bodily movements, from people watching the mannequin. The mannequin is to be built in Plexiglas and the limbs are to be cut out of Plexiglas and connected to the servo motors. The students are currently working on the servo motors and the Kinect separately. The first prototype will be mirroring an arm.

PERSPECTIVES: THE PHYSICAL-DIGITAL TOOLBOX FOR EMBODIED INTERACTION

In this section, we put focus on the physical-digital tools. We zoom into the left box: Physical-digital Tools in the embodied interaction model. See the figure below:

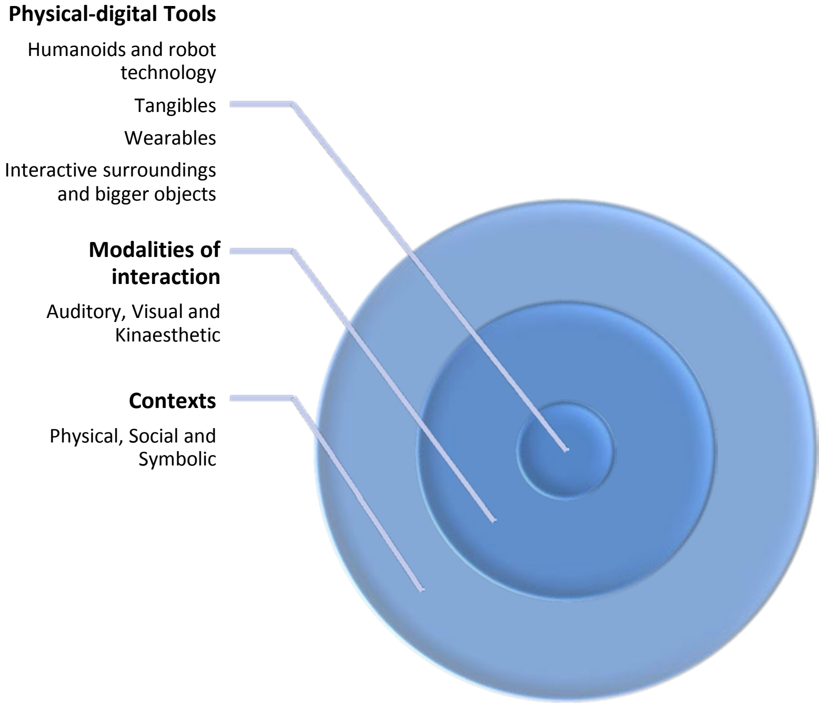

Figure 6: Embodied interaction – focus on Physical-digital tools

There are several categories of interfaces for physical-digital interaction. This paper introduces multiple characteristic types: Humanoids and robot technology; Handheld Interaction so-called Tangibles; Interactive Wearable's; Interactive Surroundings and Bigger Objects. In actual applications, the platforms might be integrated. The painting app is an example of the category

Interactive Surroundings. Below we introduce the toolbox for exploring emerging embodied technologies in HCI teaching.

Robot technology and Humanoids

Humanoids and robot technology are in a broad sense technology, which senses the surroundings and react according to a programmed algorithm. The robot consists of sensors, such as touch or motion sensors. In addition, it consists of effectors such as: light diodes, sound or servomotors. Drivers and software, controls the robot. LEGO Mindstorm is the most well-known robotic kit in Denmark. It is widely use in schools and universities for applied sciences.

At the moment I am part of a research project, where robots are introduced in primary and secondary schools (Fremtek, 2013; Majgaard, 2014). The robots, we are using are the so-called NAO from Aldebaran (Aldebaran-robotic, 2013), see the figure below. The NAO is a programmable, 58 cm tall humanoid robot with the following key components: electric motors, LED lights, cameras, microphones, tactile sensors, and pressure sensors, CPU, battery and much more. The robot is programmable in both drag and drop language for programming novices. More low level programming in python or C++ is available for experienced programmers. In our research, school children are using the robots in the classroom. Below is a picture of the NAO. The educational goals cover programming, potentials of humanoids, mathematics, physics, storytelling and so on.

Figure 7. NAO Robot (Aldebaran-robotic, 2013)

The NAO can be programmed to walk, dance, recognise faces or objects, avoid objects, transform text messages into audio and much more. The programmed NAO robot is situated and reacts immediately, if for example a known face appears in front of it.

The NAO is developed as an educational tool. It is used in schools and universities for programming, understanding of technology, automation, physics, and mathematics (Aldebaran-robotic, 2013).

The embodied interaction covers all the major sensory modalities. The robot provides auditory feedback. If programmed properly, it can recognise your face and e.g. say “Hello Harry”. The robot can visualise a geometric form, by walking by it. The users can in a special mode, program the robot by moving its body parts. This supports the kinaesthetic modality. The humanoid supports the modalities differently, depending on whether it is in programming or executable mode (Majgaard, 2014).

Handheld devices – tangibles

Handheld tangibles are devices such as smartphones or modular cubes. A smartphone supports embodied interaction, e.g. when I touch the camera app icon on my smartphone. The touch sensor detects precisely the position of my touch and opens the camera app. The physical interaction with the display and symbolic interaction with the app, produces the embodied interaction in this example.

As ideal types, it has been customary to distinguish between screen-based interaction on the one hand and the purely physical interaction with interactive tangibles, e.g. cubes, on the other (Majgaard, 2011; Sharp, 2007; Dourish, 2004). Screen-based media is known from PCs, tablets and smartphones. Tablets may e.g. be iPads. Screen-based media’s classic strength is in their use of abstract visual and auditory symbols, and their support in learning processes. Interactive blocks can provide a more tangible physical form of symbolic information and support more intuitive, bodily, and embodied learning processes. However, the tendency is that the two types of media are merging. Traditional screen-based media now contain multiple sensors and become more bodily in their interactions, and interactive blocks or cubes are being equipped with screens.

Our computers are becoming more and more physical. Smartphones and tablets allow for interaction with a high level of abstraction and graphical interactive participation. Furthermore, they offer new forms of interaction in terms of touch and pressure sensitive displays. Additionally, there will often be a compass, GPS and 3D accelerometer, for detecting where and how it is situated in the world. It is for example the 3D accelerometer that senses your tablets/iPads position and causes change in orientation of the display. And it is the same group of sensors in the smartphone, which count the number of steps we take, or record our running route. Thus, it suddenly becomes possible, to integrate body and movement in the interaction. This is done without sacrificing the visual abstract possibilities. For example, we do not just count the number of steps or specific GPS coordinates - we get the route shown on maps and view statistics about how our speed have varied through the run.

Approximately, half of the Danes have smartphones, and one in five of them would rather throw out their television than their smartphone (Media Watch, 2012). Families and Kindergartens in Denmark show a great interest in tablets. They are bigger than the smartphones, this means more than one user can look and collaborate. Currently many experiments are going on involving IPads in Danish kindergartens and schools, in order to support the children in their development and learning processes

The intelligence can also be distributed between several modular tangible devices. A lot of development and research have been done in modular tangibles over the last ten years (Lund, H. et al, 2007; Majgaard, 2011; Majgaard, Misfeldt & Nielsen, 2010; Nielsen, et al, 2008; Piper & Ishii, 2002) The devices are able to interact with each other and the people around them. See the figure below:

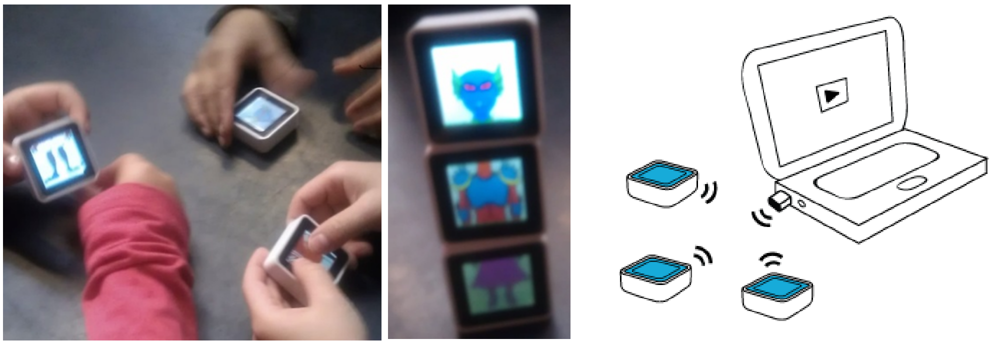

Figure 8: Tangible Sifteo cubes (www.sifteo.com)

The Sifteo cubes are interactive cubes for playing and learning. They are an example of modular tangibles. Sifteo merges interactive blocks and screen-based interfaces, and each block has a small display of 128 x 128 pixels. This is enough to dynamically perform small animations and display pictures, letters, numbers and other symbols. Each Sifteo package consists of 3-6 Sifteo blocks. Each block is clickable, contains a colour display, a number of motion sensors and a rechargeable battery. Each block is just under 4 x 4 cm. The blocks are connected wirelessly to a computer via a USB radio link. Sifteo applications are executed from a special Sifteo-runner program on your computer. It is possible without programming experience, to develop simple variations of Sifteo Creativity Kit. On the above figure are the Sifteo cubes and a sketch of how they are linked wirelessly to the computer. The children interact while connecting, shaking, tossing, and turning the cubes. The children can also collaborate with each other, while interacting with the cubes.

My students have been developing new software for the cubes, in order to explore new ways of interacting (Majgaard, 2012). We wanted the students to try out other, more natural user interfaces such as robotics, interactive blocks and Kinect. We wanted our students to experience embodied interaction, and to develop systems which focused on movement, spaciousness, motor skills and physicalities in general. Our intention is for our students to master both the development of graphical and physical interfaces. The students analyse and explore the applicability of these interfaces, and in a design process assess when to use physical and/or graphic-based interfaces. They can hopefully therefore in practice understand and utilize these media comparative strengths.

Basically the interactive cubes support embodied interaction. This embodied interacting Sifteos are more natural, varied and direct than the indirect manipulation of the graphical user interface (GUI) via a mouse. The users' get physical and bodily experiences, while they operate the system.

Interaction with interactive cubes is physical, and the cubes represent something other than their physical form. The tangibles support both physical-digital and symbolic interaction. This is particularly true for Sifteo cubes, which represent symbols in the terms of graphics, animations, letters or numbers. Even interactive cubes without a graphical interface often refer to something else. In another example a pink cube symbolises a particular musical instrument, but physically it just looks like an overgrown dice (Majgaard, 2012). The symbolic expression adds a meaning into the interaction. Dourish describes the link between physical and symbolic interaction as:

> *Tangible computing is of interest precisely because it is not purely physical. It is a physical realization of a symbolic reality, and the symbolic reality is, often, the world being manipulated (Dourish, 2004, p. 207)*

Tangible computing relies on symbolic interaction instead of eliminating it. From a design perspective, the physical and symbolic expression needs to complement each other. The embodied interaction connects both the physical-digital and the symbolic interaction.

The embodied interaction covers all the major sensory modalities. The cubes can provide auditory feedback. Each cube has an interactive display, and the visualisations can change, when the cubes are touched or connected in new combinations. They are kinaesthetic, because the children can touch and connect the physical artefacts.

Embodiment in Wearables and Body Area Networks

Wearables address the technology you might wear such as Google glasses, smart phones, GPS watches, heart rate monitors, interactive clothes, accelerometers etc.

Body Area Networks are currently mostly being used as part of rehabilitation and fitness training. For instance, you can monitor your pulse as a part of a spinning class. Or you can put touch sensors in your running shoes, to measure walking or running style. A very popular application is the Endomondo running app. You attach a smartphone on your arm and start Endomondo. The program then tracks you by using GPS, while being linked to Google Maps. During the exercise, you dynamically get feedback on speed and distance. Another growing area is design of interactive clothes, shoes, and accessories. People can place interactive modules on their clothes, such as programmable light diodes (Melgar, 2012).

In research on engineering and rehabilitation a lot of experiments are done based Body Area Network. For instance systems performing real-time analysis of data, collected from sensors placed on the body. This provides guidance and feedback to the user, and can generate warnings based on the user's state, level of activity, and environmental conditions. In addition, all recorded information can be wirelessly send to medical servers and integrated into the user's electronic medical records (Jovanov et al, 2005 and 2009; Choquette, 2008).

I have been involved in a project, where engineers and physiotherapists developed an interactive shoe sole (WTR, 2013). The shoe sole were to be placed in the shoe, and four pressure sensors monitored how the users walk was executed. The system gave dynamically visual feedback on their walking, see the figure below. The prototype was developed using the electronic kit Arduino (Arduino, 2013).

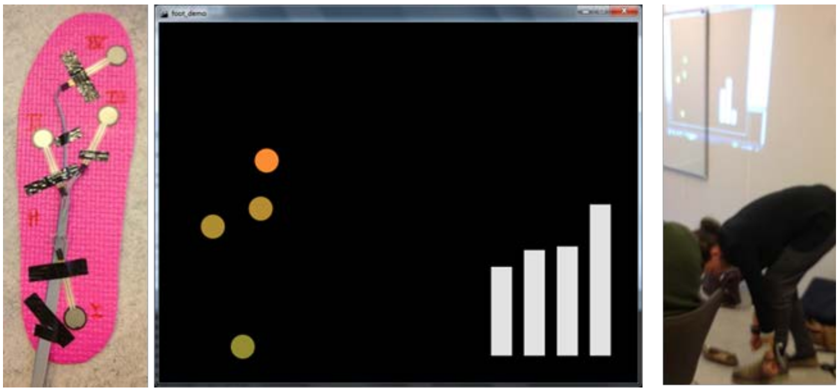

Figure 9. The wearable shoe sole

In our case the interactive shoe sole basically supported visual and kinaesthetic modalities. The users' physical behaviour was interpreted visually. The users interacted symbolically and explored their walking stiles by watching the symbolic interpretation on the screen.

Interactive Surroundings and Bigger Intelligent Objects

Interactive Surroundings are sensor networks, gesture-based interfaces, and bigger intelligent objects in our surroundings. This technology can be integrated in the environment, e.g. as part of the room or furniture. Some of the technologies are not in direct physical contact with the body and requires a more controlled and limited environment. Examples are Microsoft Kinect and Camera tracking and hands-free speech recognition. One of the most popular Kinect applications is Dance Central – combining game play and physical activity. The Asus Xtion Pro case introduced later in this article, is similar to the Kinect.

Some years ago, I was involved in the analysis of an interactive playground called ICON by playground producer KOMPAN A/S (Majgaard, G., & Jessen, C., 2009; Kompan, 2013). The playground is an example of a bigger intelligent object. It was a combination between an outdoor playground and a digital game. This playground combined playing, physical climbing, pushing pressure sensors and physical-digital gaming.

The aim of the digitization of the play equipment in ICON was to initiate physical play among the digital native children, who grow up with digital games as one of their favorite toys. We wanted the children to use their body, to become more physically active. Video game research has shown that children learn new digital games by using tricks and skills, they used in other digital games. They are learning a new kind of literacy (Gee, 2003), and because more and more children are experts in digital games, it seems natural, and even necessary to use this expertise in outdoor games, to promote physical play among children.

The children both used the playground for analogue and digital activities. Analogue activities are traditional play e.g. climbing or hide and seek. Digital activities are e.g. video games or digital games on the climbing rack. See the figure below:

Figure 10. The interactive Playground

The digital playground used various games to challenge the children, to play physically. The playground was divided into three areas, offering different game options.

The first area was a digital top called the Digital Supernova, which was circular and about 6 meter in diameter (above figure to the left). One or more children could participate by making the top turn. In the center was a game console, which invited the children to play different games. A moving arrow was displayed, and the children had to turn the top according to the arrow. The children could also decide to ignore the game console and use the top in the traditional analog manner.

In the middle was a climbing rack the so-called Digital Galaxy. It was about 7 meter in length, 3 meter in breath and 2.5 meter in height and consisted mostly of galvanized steel. In all junctions were programmable light diode buttons. The diodes were e.g. red, green, blue, white, or yellow. In front of the climbing rack was a game console, which could be activated, when a child rocked the seesaw in front of the console. One of the digital games was the Colour-race, and when the game was executed five of the light buttons, became active and lighted up each in different colours. The players would choose a colour each and then chase and touch their colour as fast as possible. When they touched the diode buttons, the light randomly "moved" to another button in the climbing rack. The child, who had touched 10 buttons first, was the winner. The digital games could be played by one or more children. The Digital Galaxy was also used traditionally for climbing, exploring, balancing, training and so on. The digital playground is an example of a bigger intelligent embodied object.

The learning modalities in this case cover auditory, visual and kinesthetic. The playground plays a kind of game-music, when the digital games are activated. The light diodes changes colours, while the children are playing. And the children use their bodies to climb and reach the buttons. The light diodes symbolise the specific game-pieces.

Overview of the embodied toolbox

Below is an overview of the various digital interfaces, which support embodied interaction, see the figure below:

Humanoids and Robot Technology	Wearables and Body Area Networks	Handheld devices – tangibles	Surrounds and Bigger Objects
•LEGO Mindstorm •NAO - the programmable humanoid	•The physical traing apps (Endomondo) •Interactive shoe sole for physiotherapy	•Sifeo cubes •Smartphones •Tablets	•The interactiv Playground •Motion sensors (Asus and Kinect)

Figure 11. Various categories of physical-digital interfaces

The toolbox is a work in progress, and we haven't yet found a fully adequate toolbox model.

SUMMARY AND CONCLUSION

Enrichment in learning processes support new and multiple ways of participation. In the embodied field, we basically focus on the three major sensory modalities: auditory, visual and kinaesthetic. Embodied interaction integrates multiple sensory modalities, physical, symbolic, social, and digital interaction. Embodied technologies make it easy for the designers, to bridge modalities. The multisensory and multimodal approach supports enrichment in learning processes. The feedback of the embodied system is situated and based on "here and now" sensations.

We unfolded the embodied interaction model, using a motion sensor in the development of a painting application. The motion sensor, Asus Xtion, was promising for exploratory design of gesture-based and full-body interaction. The available software package made it possible for the students to design interactive prototypes. In the beginning, they had all kinds of practical installation problems, but soon they were all up and running. In our study we experienced a minor delay in the initial hand recognition routines.

In the second part of the article, we introduced the embodied toolbox: Robot technology, Touch and Tangibles, Interactive Wearables, Interactive Surroundings, and Bigger Objects. The toolbox can be used as inspiration for future research and teaching in the field of embodied interaction. Question for future research: How can embodied technology support and bridge modalities in learning processes? – And how do specific technologies bridge modalities?

REFERENCES

Akker, J. V. d., Gravemeijer, K., McKenney, S., & Nieveen, N. (2006). *Educational Design Research*: Routledge.

Bateson, G. (2000). *Steps to an Ecology of Mind: Collected Essays in Anthropology, Psychiatry, Evolution, and Epistemology*: Chicago Press

Borenstein, G. (2012). *Making Things See. 3D vision with Kinect, Processing, Arduino, and MakerBot*. Maker Media, Inc.

Brooks R. A. (1991). New Approaches to Robotics. *Science* (253), September 1991, pp. 1227–1232.

Christensen K., Monsen E., Hansen, J. V., Andersen, M., Safiri. S. (2013). Physical-digital Interaction Design for Children. *Proceeding of the 9th Student Interaction Design Research (SIDeR 2013)*, Aarhus

Choquette, S. et al (2008). Accelerometer-based wireless body area network to estimate intensity of therapy in post-acute rehabilitation. *Journal of Neuro Engineering and Rehabilitation 2008*, 5:20 doi:10.1186/1743-0003-5-20

Dourish, P. (2004). *Where the Action Is. The Foundation of Embodied Interaction.* A Bradford Book. The MIT Press.

Gardner, H. (1983). *Frames of Mind: The Theory of Multiple Intelligences*, Basic Books, ISBN 0133306143

Gee, J. (2003). *What video games have to teach us about learning and literacy.* Palgrave Macmillan, New York, USA.

Hsu, H. (2011).The Potential of Kinect in Education. *International Journal of Information and Education Technology, Vol. 1, No. 5,* December 2011

Jepsen, A., Dondana, M., Reiter, L., 2013. Chimecloud - An Evocative, Responsive Sound Installation. *Proceeding of The 9th Student Interaction Design Research (SIDeR 2013).* Aarhus

Jovanov, E., et al (2009). Avatar – a Multi-sensory System for Real Time Body Position Monitoring. *Proceedings of IEEE Eng Med Biol Soc*. 2009; 2009:2462-5. doi: 10.1109/IEMBS.2009.5334774.

Jovanov, E. et al (2005). A wireless body area network of intelligent motion sensors for computer assisted physical rehabilitation. *Journal of NeuroEngineering and Rehabilitation*

Lewin, K. (1946). Action research and minority problems. *Journal of Social Issues. Vol. 2, No. 4, 1946*, s 34-46.

Lund, H., Pedersen, M. & Beck, R. (2007). Modular Robotic Tiles – Experiments for Children with Autism. *Artificial Life and Robotics, 13*, s. 394‑400. Springer Japan.

Majgaard, G. (2014). Initial Phases of Design-based Research into the Educational Potentials of NAO-Robots. *Proceedings of Human Robotic Interaction Conference HRI'14*, March 3–6, 2014, Bielefeld, Germany. ACM.

Majgaard, G. (2011). Learning Processes and Robotic Systems. Design of Educational Tools using Robots as Media and Children as Co-designers. (PhD dissertation, University of Southern Denmark).

Majgaard, G., Misfeldt, M., & Nielsen, J. (2010). Robot Tech nology and Numbers in the Classroom. *Procedings of Cognition and Exploratory Learning in Digital Age*. IADIS CELDA 2010, (pp. 231‑234)

Majgaard, G., Misfeldt, M., Nielsen, J. (2011). How Design-based Research, Action Research and Interaction Design Contributes to the Development of Designs for Learning. *Designs for Learning*.

Majgaard, G. (2009). The Playground in the Classroom – Fractions and Robot Technology. *Proceedings of Cognition and Exploratory Learning in Digital Age* (pp. 10-17). International Association for Development, IADIS.

Majgaard, G., & Jessen, C. (2009). Playtesting the Digital Playground. Blashki, K. (red.), *Proceedings of the International Conference on games and Entertainment technologies 2009.* (pp. 87-92). International Association for Development, IADIS.

Majgaard, G. (2012). Brug af interaktive klodser i ingeniørundervisningen [Use of interactive blocks in Engineering education]. *MONA: Matematik og Naturfagsdidaktik, (4)*, 24-40

Melgar, E. R. and Diez, C. C. (2012). *Arduino and Kinect Projects: Design, Build, Blow Their Minds*. Apress

Nielsen, J., Jessen, C., & Bærendsen, N. K. (2008). RoboMusicKids – Music Education with Robotic Building Blocks. *Proceedings of the 2nd IEEE International Conference on Digital Game and Intelligent Toy Enhanced Learning (DIGITEL),* (pp. 149‑156).

Pfeifer, R. and Bongard, J. (2007). *How the body shapes the way we think.* MIT Press

Piper, B., and Ishii, H. (2002). PegBlocks: A Learning Aid for the Elementary Classroom. *Proceedings Extended Abstracts of Conference on Human Factors in Computing Systems (CHI '02),* Minneapolis, Minnesota, USA, 20.-25. April 2002.

Rogers, Y., Sharp, H. and Preece, J. (2011). *Interaction Design: beyond human-computer interaction, 3rd Edition.* John Wiley & Sons, (UK).

Papert, S. (1993). *Mindstorms Children, Computers, and Powerful Ideas*, Basic Books.

Sharp H. et al (2007). *Interaction Design: Beyond Human-Computer Interaction*. John Wiley & Sons Ltd.

Schön, D. (1983). *The Reflective Practitioner, How Professionals Think In Action,* Basic Books. ISBN 0-465-06878-2

Villaroman, N. et al (2011). Teaching Natural User Interaction Using OpenNI and the Microsoft Kinect Sensor. *Proceedings of SIGITE'11, October 20–22, 2011*, West Point, New York, USA. Copyright 2011 ACM 978-1-4503-1017-8/11/10

Wenger E. (1998). *Communities of Practice: Learning, Meaning, and Identity*. Cambridge University Press.

Web-sites

Aldebaran-robotics (2013). Retrieved October 10, 2013 from http://www.aldebaran-robotics.com/en/

Arduino (2013). Retrieved October 10, 2013 from http://www.arduino.cc/

Asus (2013). Retrieved January 1, 2013 from http://www.asus.com/Multimedia/Xtion_PRO/

Chimecloud (2013). Retrieved October 14, 2013 from http://vimeo.com/53239679

Device (2013). Retrieved October 10, 2013 from http://www.deviceproject.eu/modules/news/article.php?storyid=6

Fremtek (2013). Retrieved October 10, 2013 from http://www.insero.dk/Uddannelse/projekter-og-aktiviteter/Fremtek

Kinect for windows blog (2013). Retrieved October 10, 2013 from http://blogs.msdn.com/b/kinectforwindows/archive/2013/05/23/the-new-generation-kinect-for-windows-sensor-is-coming-next-year.aspx

Kompan (2013). Retrieved October 10, 2013 from http://icon.kompan.com/ retrieved 2013-10-10

Leap Motion (2013). Retrieved October 10, 2013 from https://www.leapmotion.com/

Mediawatch (2012). Retrieved July 9, 2012 from http://mediawatch.dk/artikel/smartphones-styrker-kommercielt-mediepotentiale.

OPEN NI (2013). Retrieved January 20, 2013 from http://www.openni.org/

Scratch and Kinect (2013). Retrieved September 20, 2013 from http://scratched.media.mit.edu/discussions/teaching-scratch/scratch-kinect

Scratch2kinect (2013). Retrieved September 20, 2013 from http://scratch.saorog.com/

SIDeR (2013). Retrieved October 10, 2013 from http://sider2013.au.dk/

WTR (2013). Retrieved October 10, 2013 from http://www.welfaretech.dk/aktiviteter/wtr-efteruddannelse/

Key terms

Embodied Technologies:
Embodied technology is based on interactive technology where we use our bodies in the interaction. Smartphones, robots, wearables, tangibles and cars are examples of embodied technology. Embodied technologies can also be described as physical-digital tools.

Embodied interaction:
Embodied interaction is of a physical nature and unfolds between humans and physical-digital tools. Embodied interaction combines multiple modalities of interaction: physical, symbolic and social interaction, in a situated environment.

Modalities of interaction:
Embodied interaction has certain modalities e.g. auditory, visual and/or kinaesthetic. The modalities can also be broken up into Gardner's multiple intelligences: musical - rhythmic, visual - spatial, verbal - linguistic, logical - mathematical, bodily - kinaesthetic, interpersonal, intrapersonal, and naturalistic (Gardner, 1983). Meaningful embodied interaction often covers more than one modality.

Situatedness:
Situatedness refers to how the embodied technology is situated in the world and how it reacts to the "here" and "now" of the environment that directly influences the behaviour of the system (Brooks, 1991). Situatedness is a prerequisite for interaction. Interaction can't become meaningful without immediate feedback.

Contexts:
Embodied interaction takes place in a given environment. Dourish (2004) describes the context a mixture of a physical, social and symbolic reality. The interaction takes place in the physical world and perhaps partly in the virtual world, e.g. a child connects tangible interactive blocks, which

symbolically represent music instruments. The social context covers the social norms and expectations.

Wearables:
Wearables are sensors and effectors placed on the body or in clothing. Wearables are also named as Body Area Networks.

Tangibles:
Tangibles are handheld interactive tools e.g. smartphones or interactive blocks.