CONNECTING PHYSICAL OBJECTS WITH SOFTWARE. TECHNOLOGY ENHANCED PLAYING WITH BLOCKS TO FOSTER LEARNING.

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ABSTRACT

The innovative shaping of human-machine-interfaces includes technological implications for consumer behavior and could result in significant paradigm changes for the way computers are used for business, for private and for learning purposes. If we use trends in the entertainment industry (e.g. Wii or Kinect) as an indicator for a new need for physicality in interaction with digital media, we can determine the potential of this physicality for learning and creativity. In this paper the theoretical assumptions and practical implications of tangible user interfaces (TUIs) for learning issues are discussed. For that we propose a new input device named STID that takes haptic skills of human body into account.

1 INTRODUCTION

Starting point for the following paper is the widespread thesis, that active object-lessons facilitate learning processes. The child actively constructs knowledge by interacting with its environment and everyday objects [1]. This means primarily physically-active actions in relation to and with physical objects ("objects-to-think-with") [2, p. 2] - therefore instructions are getting reduced while exploring and experimenting are being challenged [3]. Accordingly we attempt to involve these possibilities in human-computer-interaction.

2 THE RELEVANCE OF PHYSICAL EXPERIENCE IN THE (DIGITAL) LEARNING PROCESS

Based on Piaget's developmental psychology research in the early 20th century it is assumed that "[…] mental action is grounded in a physical substrate" [4, p. 1713]. This suggests that cognition initially arises from actions and operations. When children and adolescence grow up, individual experience forms cognitive patterns, which determine how and what we perceive and feel, what we remember, how we judge and argue [5]. There is some evidence for the assertion that we better remember those experiences in which we were constructively involved. The generation-effect for instance proposes an improvement in memory performance if the learner is permitted to elaborate and construct the knowledge content [6] [7] [8]. More over studies showed that if physical activities are embedded in this elaboration and construction process there will be a higher probability to remember absorbed knowledge, in contrast to the knowledge gained only by listening [8, p. 12]; [9, p. 404]. This is based on the fact that memory encoding through physical activities occurs multi-modally and automatically – no special strategy is needed [8, p. 30ff]. This implies that there is a functional relationship between kinesthetic driven interactions and learning objectives that influences the learning process positively and leads to a knowledge structure that can be accessed independently of the presented modality.

Supported by these evidences we emphasize the introduction of additional multi-sensory stimuli, most especially for haptic movements, in digital learning contexts to augment the audio-visual modes. Cognition, driven by audio-visual perception is not the only ability needed to process symbolic information; our brain requires a body as an additional resource to support mental abstractions with respective tactile and/or spatially perceived information. Therefore we propose a useful connection of real objects to digital learning software in a way that ordinary objects serve as input devices to virtual processes.

3 TANGIBLE INPUT DEVICES IN THE LEARNING SECTOR

Emphasizing naive physical skills and body awareness in the Human-Computer-Interaction (HCI), are typical for what Jacob et al. [10] describe with *Reality-Based Interaction*. Thus, the direct manipulation of physical objects – the so called 'natural interaction' – can help to reduce the mental load in the HCI and accelerate learning processes [11].

The innovative development of tangible-user-interfaces is a forward-looking research field, which includes new implications for user behavior and the way that computer software needs to evolve, to be used in this new model of interaction. We understand the trends in the entertainment industry (e.g. Wii or Kinect) as an indicator for a new need for physicality in interaction with digital media. Thus our approach tries to take up these trends to determine what kind of physicality is appropriate for learning. The empirical results analyzing the haptic perception in digital contexts are mixed. These indicate, that explorative learning efficiency correlates with the (useful) integration of haptic objects [12] [13]. Manches et al. also found advantages for physical materials in a numerical partitioning task compared with using a graphical interface [14]. More over Antle attests hands-on input interaction to be conducive to learning if they are audio-visually enhanced [15]. Triona and Klahr [16] and Marshall et al. [17], however, didn't notice any differences in learning with physical and virtual materials.

Nevertheless, the relevant research findings in cognitive psychology seem insufficient to develop workable models. More general the influence of different body movements for cognitive processes is investigated under the heading of *Embodiment*, but the influence of activities of the whole body while learning with digital media is still massively underrepresented. First positve results in this regard has been made in the acquisition of factual knowledge, learning motivation and self-efficacy of the learners [18].

A look into the established learning theory models provides no detailed findings for this area. For example the common Cognitive Load Theory model examines only visual and auditory stimuli [19]. A deepening of scientific knowledge about haptic and learning seems therefore to be a desideratum. The interest of the proposed project is, to generate empirical evidence on the relationship between haptic perception and acquisition of knowledge in the digital context. These studies are primarily used for STID (Shiftable Tangible Input Device) to elicit the potential of the concept and to formulate specific user groups and context-specific requirements.

The STID concept includes the idea to involve ordinary haptically manipulable objects in the interaction with the computer to different learning purposes. This approach has already been implemented in similar forms [20] [21] [22]. However, such approaches require items that are either connected with a wired connection to a computer or even are equipped with electronics, thus cannot be described as everyday objects.

4 NEW LEARNING APPROACH WITH A TANGIBLE USER INTERFACE

4.1 STID (Shiftable Tangible Input Device)

We call the actual concept, to that this paper is directed, STID. The goal is to build a bridge between physical and digital world combining both by letting the physical world authentic. The physical world should be fully perceptible and not only projected or simulated through tactile feedback like in some augmented reality approaches, while the virtual world reflects the real world and adds digital options. By combining - but not scrambling - both worlds, the concept STID can push an important criterion for creative thinking and learning: The ability to find new relations between non-related experiences.

For the purpose of combining the physical and virtual world advantages, ordinary physical world objects will be placed in front of a digital system which recognizes the objects with a webcam and visualizes them directly on the computer screen in the same arrangement as in the physical world. If, for example, an object is added or taken away in the physical world this activity can be seen on the screen showing the parallel virtual world. Thus we focus on the idea of parallel actions of physical objects and their equivalents mirrored on a computer screen - according to the concept of mixed reality [23].

The variety of the computer input opportunities will be significantly enhanced that way and accordingly the possibilities to find a solution to a given problem and to complete a quest. Creative processes of thinking can take place using physical objects to access a greater potential of human cognitive capabilities. For us it is not about the dichotomous logic: either physical or virtual world; rather we plan to investigate new forms of human-computer-interaction by involving both worlds, using the advantage of both to reach additional options: In addition to the possibility for such haptic manipulations in physical space, a “metrical assistance” shows the three-dimensional size of the respective object. Moreover the virtualized objects in the digital environment can be stored and duplicated; further the physical attributes of the object, such as motion / color / size / function / gravity / magnetic charge, etc. can be changed in the virtual world, conceivably in a way that would be impossible or impractical in the physical world. Thus the action potentials of both "worlds" are taken into account. With STID new learning scenarios for different domains are possible: For example experimental chemistry lessons where students can use physical test tubes and bottles filled with colored water to do different experiments. The students handle the tubes and the water, but the system pours and mixes chemical reagents. Thus they see on screen what would actually happen. Or in mathematics lessons could the assembly of conventional wooden bricks be used to illustrate principles of geometry and calculation transmitted by the visualization skills of the digital system. Students could explore chemical processes

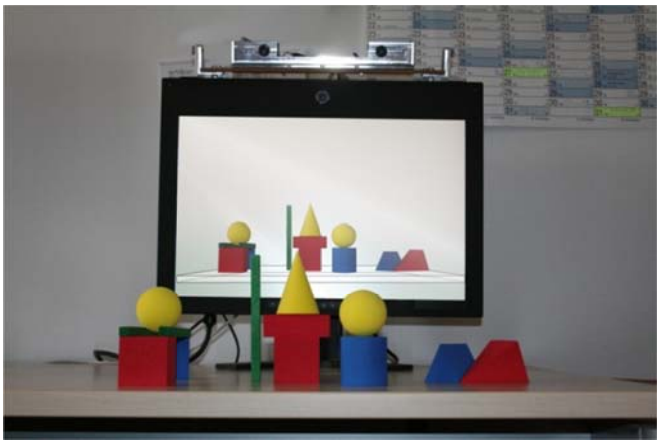

Figure 1 *The virtual 3D images, the physical objects and the cameras for the object recognition*

and mathematical laws, instead of reconsidering them mentally.

The tactile feedback just emerges through the active haptic perception, meaning the contact with the physical objects. If a tactile feedback that corresponds with the virtually changed attributes (e.g. gravity) is not given directly (in the real world) it would be important to evaluate the consequences for the cognitive performance. According to above mentioned theory we assume that the dissonance between real objects and virtually reflected objects leads to a better understanding by exploring which fosters a process of reflection and therewith of learning.

4.2 Technical aspects

From a technical perspective especially the technology of object recognition and visualization will be important. The objects must be identified and detected in their practical arrangement in real-time and immediately displayed on the screen. Because the detection of a three-dimensional object would require a 360 degree rotation, our approach for visualization is to apply the principles of pattern recognition. However, existing systems can detect only those patterns that were previously implemented, so at present the input is thus limited to a predetermined selection of physical objects. Technical requirement for STID is a camera system, which recognizes objects in 3D space. For this purpose, an algorithm is used that is previously trained to recognize specific objects. For receiving and transmitting the image an ordinary webcam will be used. With a resolution of 640 × 480 pixels a camera can provide a sufficiently detailed picture to test the first algorithms for pattern recognition. An important property for the selection of the camera is an open source software architecture for querying the image information. The recognition of objects should be markerless, thus the objects carry no additional identification marks, as already implemented by Ladikos et al. [24].

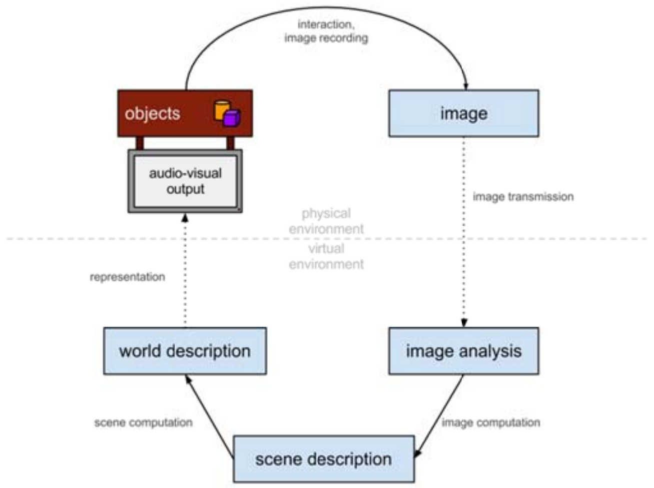

Figure 2 *conceptual program execution for the image and pattern recognition and the processing of the data*

The technical development of the application is split into two projects. The first part deals with the incoming images from the webcam. Key element will be a pipeline to detect and compute the position of several objects inside of an image by using different algorithms for image and pattern recognition. The result will be a new library for three-dimensional detection and tracking of objects based on non-stereoscopic images. Within this library image processing algorithms are implemented based on existing approaches, such as scale-invariant feature transform (SIFT) [25] and combined with algorithms for 3D reconstruction of objects in space, like Hoiem et al. [26] already described. An alternative approach is the use of 3D Distance Maps [27].

Second part of the project realized the processing of the scene and digital presentation of the physical world. The project uses a technology created for game development based on cross-language, multi-platform application programming interface (OpenGL, OpenGL ES). Main task of the project is the representation of tasks and the processed 3D models from part one. The system should be adjusted adaptively to the user for example by recognizing different object sizes. For the generation and analysis of the tasks a scripting language like LUA will be used.

4.3 Next Steps

After the technical realization a first study is being conducted to measure learning effects regarding the speed and the duration of the knowledge acquisition. The question is, what influence the haptic perception has on the acquisition of mathematical principles of the calculation of a surface and volume. Because of the already existing knowledge of older ages about this area, the age of the groups will be between 8 to 10 years. Comparing three groups of probands who learn the principles of surface and volume calculation (1) through the physical stacking of blocks, and the assistance of software (STID), (2) through the virtual stacking with a mouse and software, (3) by conventional methods of learning with pen and paper with the help of a teacher, the relevance of haptics in learning processes can be examined.

5 SUMMARY AND CONCLUSIONS

According to theoretical assumptions thus far obtained, the contributions from haptic perception and motor skills in the digital context can possibly enhance learning efficiency. However there have been not enough scientific studies about how to use and assess tangible user interfaces in special learning contexts. Theoretical assumptions support a greater consideration of physical skills since then the body will become the reference point in the interaction with digital functions as it is for the real world. It also seems obvious that physical activities are essential for any kind of experiences in our physical world and thus beneficially enhance intellectual skills acquisition. In order to continue this approach empirically, the mentioned empirical scenario will be performed. In a longer perspective it will be necessary to classify different input and output devices, the associated user actions to build new TUI-Learning taxonomies.

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