Tangible E-Learning

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Abstract. Tangible User Interfaces increasingly gain attention for their supportive potential in cognitive processes. More and more often the terms e-Learning and tangible interaction are been referred to in one word as Tangible e-Learning. This paper gives a general overview on the topic in reference to development history, research and effectiveness. It explains how epistemology, together with its idea that physicality enhances learning and that the cognitive process can happen in expressive or exploratory manner, motivates the emerging of TUIs and acts as a basis for the classification of Tangible e-Learning Systems. The benefits of TUIs in comparison to classical GUIs in terms of their contribution to the learning process, engagement, enjoyment and collaboration are empirically proven, although poorly. Nevertheless, it is not known whether TUIs have stronger potential than common Physical User Interfaces that are not electronically augmented. Still, TUIs that support learning have a strong potential to be integrated into real world scenarios.

1 Introduction

The modern society we live in has brought along many changes and innovations. One of them is the requirement for education not to be about teachers and teaching anymore, but rather to put the learner and his learning activity in its center. (Tavangarian et al., 2004; Williams and Goldberg, 2005) Metaphorically speaking, learning began as a live stage performance in form of classroom trainings and became comparable to modern motion pictures, as nowadays we increasingly run across concepts of e-Learning. At a first glance, e-Learning seems to be a revolution in our era, but looking back on its history and giving it a second thought, it rather concludes to have an evolutionary character. (Tavangarian et al., 2004) After online tools and software replaced educational CD-ROMs, all commonly designed to use personal computers, Graphical User Interfaces and traditional Human Computer Interaction, the evolution finally takes a new turn, exploiting the possibilities of Tangible User Interfaces in favor of education and learning. This paper aims to provide a broad coverage of the topic, starting off with defining the terms “e-Learning” and “Tangible User Interfaces” in chapter two. The
subsequent chapter dives deeper into the topic of tangible e-Learning by first motivating its emergence, then offering a classification of Tangible e-Learning Systems. Furthermore the effectiveness of Tangible e-Learning Systems in comparison with classical, GUI based, learning shall be discussed. Chapter four will give examples of several Tangible e-Learning Systems, will explain how they work and apply on them the theoretical knowledge from precedent chapters. An outlook on future research and development and possible employment scenarios of Tangible e-Learning Systems in contexts drawn from life will wrap up the topic.

2 Terms and Definitions

2.1 E-Learning

Getting a clear idea of what exactly the term ”e-Learning” is supposed to define is a complicated undertaking, as there are numerous different definitions available throughout literature. What is not sufficient in order to call learning as ”e-Learning” is the simple use of electronic equipment, i.e. a microphone during a lecture, because a proper definition should require that the electronic media has to enhance the learning process in a way, which wouldn’t be possible with other media. (Tavangarian et al., 2004) In some definitions e-Learning comprises all learning enhancing software(Baumgartner et al., 2002; Tavangarian et al., 2004), in other definitions it is a networked form of learning based on Internet technology (Rosenberg, 2002; Tavangarian et al., 2004). Still, all these definitions do not combine all aspects of e-Learning. The definition rather needs to emphasize the differences of e-Learning in comparison with traditional learning, should not resume to software or the Internet and also has to justify the benefit of the electronic media to the learning progress:

e-Learning “[is] all forms of electronic supported learning and teaching, which are procedural in character and aim to effect the construction of knowledge with reference to individual experience, practice and knowledge of the learner. Information and communication systems, whether networked or not, serve as specific media (specific in the sense elaborated previously) to implement the learning process”. (Tavangarian et al., 2004)

E-Learning aims to give students a greater autonomy regarding the point in time, the content and the method by which they learn by providing on-demand-learning, that eliminates the barriers of time and distance. (Tavangarian et al., 2004) Hence, for covering today’s expectations from e-Learning, a paradigm shift is needed. Contemporary technology and pedagogical skills, brought together as an effective combination, can achieve this shift of focus towards the learner.

2.2 Tangible User Interfaces and Tangible Interaction

Tangible computing can be understood as a historical evolution from Human Computer Interaction (HCI) aiming to design user interfaces that expand the
abilities humans have when interacting with computers. (Dourish, 2001; Marshall et al., 2003) Early definitions of Tangible User Interfaces (TUIs) in 1997 already focused on the idea that HCI should move away from the interaction with a Graphical User Interface (GUI) on a desktop computer to interaction where the world itself becomes the interface, giving physical form to digital representations. (Ullmer and Ishii, 2000) Thus,

TUIs can be defined as everyday objects or environments that augment the physical world by being coupled to digital information. (Ishii, 1997; Ullmer and Ishii, 2000) They give humans the possibility of grasping and manipulating digital information through objects from the physical space (Ishii, 1997; Fishkin, 2004).

While GUIs draw a clear line between input devices and output devices, TUIs explore the conceptual space created by the reduction of this distinction. (Ullmer and Ishii, 2000) Since the introduction of the term TUI, conceptual frameworks that should help researchers, designers, and developers to classify them and understand the various ways in which the coupling between physical objects and digital information can be realized, continued to be proposed. (Koleva et al., 2003)

In order to understand the concept of TUIs, two defining attributes are of outstanding relevance: the degree of embodiment and the metaphor the information coupling underlies. (Fishkin, 2004) Embodiment features four degrees (Fishkin, 2004):

- **full embodiment**, where input and output device are one and the same object (Fishkin, 2004; Ullmer and Ishii, 2000),
- **nearby embodiment**, for instance a display placed in immediate proximity of the TUI, showing the effects of the tangible interaction,
- **environmental embodiment**, example given loudspeakers playing sound as a reaction to the user’s input via the TUI
- **distant embodiment**, which is comparable to conventional HCI, having an output device placed more or less close to the input device (Fishkin, 2004).

The second relevant concept is the metaphor of the activity the user carries out while interacting with the TUI. The high impact of the metaphor is justified by findings of cognitive anthropologists, stating that the ability to use metaphors is what sets modern humans apart from their early ancestors. Various properties of the TUI, like size, shape, color, weight, smell, texture and temperature can be used to create such an interaction metaphor, which, in turn, can concentrate only on the tactile sensation and visual appearance of the object, but also on its movement or even use both. (Fishkin, 2004) Whether a strong metaphor, like the exact mapping of the real world, or a weak to no metaphor at all holds stronger cognitive potential is still to be discussed. Some researchers share the view that the absence of metaphors has the benefit of not constraining the user to a particular thinking scheme and thus produces the most compelling TUIs. (Fishkin, 2004) Contrarily, there are views sustaining that stronger metaphors
create a higher degree of coherence, which is advantageous for successful inter-
action. (Koleva et al., 2003)

Measuring the performance of a TUI thus consists of analyzing the extent to
which the embodiment and metaphor criteria are fulfilled, concluding that TUIs
underlie a gradient principle of “tangibility”, being more or less tangible. Hence,
tangibility can be considered a multi-valued attribute. Nevertheless, when it
comes to understanding the importance of metaphors in Tangible Interaction,
TUI research still is at its beginnings and can collect valuable knowledge from
industrial design, where the high relevance of metaphors and product semiotics
has shaped the research process from its very starting point. (Fishkin, 2004)

3 Tangible E-Learning

3.1 Motivation of its Emerging

E-Learning emerged from the use of Information Communications Technology
(ICT) in classrooms, which gives the learner more the position of an “onlooker”
than to attribute him an active role as “participant” in the educational process.
Price and Rogers concluded that introducing physicality into learning could solve
this problem. (Price and Rogers, 2004) From an historical point of view, the im-
portance of physical objects in the cognitive process has been noticed relatively
recent, as until the 19th century education was conducted exclusively using lec-
tures and recitations. (Resnick et al., 1998) Swiss educator Johann H. Pestalozzi
is the one, who in 1803 set the foundation stones for learning through physical
manipulation. He stated that students need to learn through their senses
and physical activity, that “things [should come] before words, concrete before
abstract”. (Pestalozzi, 1803; Resnick et al., 1998) TUIs present the advantage
of the ability to unify the concrete and the abstract. Consequently, they are
gaining popularity as an effective approach to the design of systems suited for
learning. (Marshall, 2007) In 1972, developmental theorist Jean Piaget found
out that children construct their view and understanding of the world based on
their interaction with the physical environment they live in (Zuckerman, 2004),
a process that is encouraged by TUIs through the learning benefits of physical-
ity(Marshall, 2007).

Through the assignment of a metaphor to each object/activity, TUIs build
upon a concept that is deeply engrained in human consciousness: the concept of
noun (the way an object looks) and verb (the way it can be interacted with),
which reflects even in deaf-mute children. (Fishkin, 2004) Regarding this, TUIs
might present higher accessibility and intuitiveness, particularly for people with
handicaps, learning disabilities or young children. (Marshall, 2007) Especially
when working with children, the design of TUIs that use toys children are deeply
familiar with and passionate about as manipulatives, could result in serious im-
provement of the learning process(Resnick et al., 1998), as, according to con-
structivist research, people learn most effectively when involved in projects they
care about(Zuckerman et al., 2005). Furthermore, familiarity is a crucial cri-
teria for accessibility, thus accordingly designed TUIs can extend the range of
concepts that children can explore through direct manipulation, even those concepts considered too advanced for them (Resnick et al., 1998), lowering the age at which children gain access to complex knowledge.

Again, the employment of metaphors and the novelty of links, resulting from the flexible combination of manipulatives and digital representation, allows access to different information than is normally available in immediate physical environments (Resnick et al., 1998) and therefore can increase reflection in children (Marshall, 2007), in conformity with the old saying “Give a person a hammer and the world looks like a nail” (Resnick et al., 1998). The learner receives contextually relevant information based on an abstract concept, information which might not be available in a real environment, hence this information can disclose new ways of engaging with learning (Price, 2008).

TUIs are said to support increased playfulness (Marshall, 2007; Marshall et al., 2007), as physical engagement creates an involvedness that passive listening and watching does not (Price and Rogers, 2004). Involvedness partially increases the level of motivation and interest in the learning activity and it is this engagement and motivation that, in turn, can exert a positive effect on the cognitive process, in terms of attention, curiosity and reflection. (Price and Rogers, 2004) Furthermore, when observing children, one can take notice of the social and collaborative connotation of the playing activity. Collaboration, achieved by talking about the learning content and thus encouraging social interaction supports active learning. (Price and Rogers, 2004) TUIs create a shared space with increased visibility of actions, encouraging effective turn taking by offering multiple access points for multiple learners and the facility of increased awareness because of the ability of monitoring the activity of all the other participants. (Marshall et al., 2007; Marshall, 2007)

Because of the children’s willingness to learn and in conformity with cognitive research, the majority of Tangible e-Learning Systems are developed to support children’s education (Xie et al., 2008), which also reflects in the typical learning domains for TUIs, that follow to be discussed in chapter 3.3.

3.2 Classification of Tangible e-Learning Systems

3.2.1 Epistemological Background

Epistemology, a branch of psychology, is the science concerned with the nature and scope of knowledge. (Encyclopedia of Philosophy, 1967) In early epistemology there exist two perspectives on how children’s cognition can be extended. They emerged subsequently as a result from the other.

Pestalozzi’s demonstrations on concreteness preceding abstractness strongly influenced German educator Friedrich Wilhelm Froebel, founder of the world’s first kindergarten in 1837, to develop special toys for children. The twenty so called “Froebel Gifts” (Zuckerman et al., 2005), consisting of balls, blocks and sticks, aimed to help children recognize and appropriately appreciate common patterns and forms existent in nature (Zuckerman, 2004) by using the gifts to create representations of these forms and patterns. Around 1912, Italian educator
Maria Montessori extended Froebel’s gifts to suit the needs of older children by picking up his initial idea and developing new materials and activities for the toys. The intention was of putting the children in control of their learning activity, enabling them to learn through personal investigation and exploration, it was intended to perform an “education of the senses”. (Zuckerman, 2004)

While Froebel’s approach supports the concept of constructivist learning, where children get to express their personal understanding of the world, Montessori’s idea consisted in building knowledge through exploration. It is these two keywords, expression and exploration, that shaped the criteria by which Tangible e-Learning Systems can be classified, as depicted in Fig. 1 under “learning activity”.

3.2.2 Expressive Learning and Froebel Inspired Manipulatives

Expressive learning implies expressive activities, where learners create an external representation of a domain accordingly to their own understanding and idea of the topic, by which they make the understanding explicit. The resulting representation serves as an object for reflection on how accurate the representation depicts reality. By this analysis, identifying inconsistencies, conflicting beliefs and incorrect assumptions is facilitated and triggers the revision, rectification and thus increase of the learner’s knowledge. (Marshall et al., 2007) Tools, that are coupled to digital information and that support this type of activity are called Expressive Tangible Systems or Froebel inspired Manipulatives (FiMs). FiMs are building tools offering the possibility of designing real-world objects and physical structures(Zuckerman et al., 2005), on which the learner later will reflect upon.
There are several reasons why it can be assumed that TUIs support this type of learning activity. First, in compliance with the novelty of links discussed earlier, they are innovative media allowing constructions, that might result to be impossible with classical manipulatives. Second, the coupling to digital data, providing additional information to what is extractable only from the construction, can contribute to the effectiveness of the analysis of the external representation. Finally, by keeping track of the aspects of the learner’s interaction with the manipulatives, TUIs can enable the passive construction of representations, allowing the learner to concentrate on another task. (Marshall et al., 2007) In current development, FiMs hold the main share of Tangible e-Learning Systems. (Zuckerman et al., 2005)

3.2.3 Exploratory Learning and Montessori Inspired Manipulatives

Still, researchers emphasize the need of expanding the presence of TUIs that support exploratory learning activities. (Zuckerman et al., 2005) In contrast to expressive learning, where representations are built from the learners personal knowledge, exploratory learning has its roots in a representation provided by a teacher or domain expert. The learner afterwards explores this representation by observing the effects of the manipulations he carries out, eventually concluding with the assimilation of information because of a conflict with the already existent knowledge, again leading to revision and rectification of this knowledge. (Marshall et al., 2007) Therefore, Exploratory Tangible Systems, also referred to as Montessori inspired Manipulatives, are as well building tools, but are intended to facilitate the modeling of conceptual and more abstract structures. (Zuckerman et al., 2005) Arguments that speak for the suitability of TUIs as support for exploratory learning consist, for example in the assumed high accessibility. If tangible interaction indeed concludes to be more intuitive and natural than interaction with other types of interfaces, it might create a particularly suitable learning environment by enabling rapid experimenting and feedback gaining. Through the assistance offered by the digital information and effects of manipulation, less cognitive effort is required and the focus shifts to the underlying domain. (Marshall et al., 2007)

3.2.4 Hybrid Systems

Not to be excluded is the idea of combining expressive and exploratory approaches in one Tangible e-Learning System. While giving learners the possibility of exteriorizing the explicit representation of their understanding of a topic through some physical structure or model, a TUI can afterwards encourage the exploration of this model in order to fill knowledge gaps, eventually even trigger a repeated re-building and refinement of the expressive representation and subsequent analysis. Considering hybrid tangible systems as holding similar potential in promoting learning thus seems plausible. (Marshall et al., 2007)
3.3 Learning Domains for TUIs

Frameworks kept identifying the possible domains where TUIs could come into operation for educational purposes. Fig. 1 briefly summarizes some of the results: molecular biology and chemistry (Marshall et al., 2003, 2007), programming (McNerney, 1999, 2004; Wyeth and Purchase, 2002), narration and rhetorics (Orth and Ishii, 1998) and finally systems dynamics (Resnick et al., 1998; Zuckerman and Resnick, 2003), latter being a particularly discussed domain in Tangible e-Learning research. When browsing through current research papers, there is a variety of other domains that additionally show up, like maths (Scarlatos, 2006; Girouard et al., 2007), more precisely arithmetics and geometry, computer systems (Crease, 2006), astronomy (Morris, 1999), also domains like music (McNerney, 2004) or art history (Döring and Beckhaus, 2007). The high flexibility of TUIs even make it possible to use one system to cover several domains (Terrenghi et al., 2006; Orth and Ishii, 1998).

3.4 On the Effectiveness of TUIs in Learning Environments

While many frameworks for TUIs focused on conceptualization and classification (Xie et al., 2008), little of them adopted the challenge to empirically prove whether tangibles achieve better learning results than other interfaces. Technical development outran empirical work (Fails et al., 2005), leaving it far behind (Marshall, 2007). Therefore, there’s an imminent gap and researchers calling for a greater focus on empirical work in order to close it (Marshall, 2007). The following sub chapters will describe the results of two empirical comparisons between desktop and physical environments in order to get an answer on which interface is better suited for learning.

Both desktop and physical/tangible environments have proven over the years to exert a positive effect on children’s learning process (Fails et al., 2005). While the effectiveness of desktop environments is empirically grounded and physical environments have received theoretical confirmation of a better interaction than in the two dimensional context of desktop environments (Fails et al., 2005), only little empirical work systematically explores the benefits of tangible systems (Xie et al., 2008). There is little work that explicitly engages in comparative studies of the two environments. (Xie et al., 2008; Fails et al., 2005)

3.4.1 Study Scenarios and Setup

The two studies that will be discussed had different purposes. The first, consisting of a desktop and physical implementation of a game called “The Hazard Room” intends to find out which interaction provides more effective learning and better fixation of knowledge. The learning domain refers to environmental health hazards and knowledge is transmitted by telling stories about each hazard, what damage it causes and how to appropriately react in such a circumstance. Each story is connected to a sound segment, each sound segment being supported by the use of a certain prop. The same props, respectively pictures of
them, the same hazards and the same stories are used in both desktop and physical environment. A detailed implementation is depicted in Fig. 2. The study was conducted on a quantitative as well as on a qualitative basis, by using measurable data, respectively by evaluating answers from interviews. For the quantitative data participants took pre and post tests and the quantitative data consisted of the difference amongst the scores. Children were given scenarios similar to those during the game and were asked what they would do and why. In the second part of the test, they were given a list of items and were asked to identify those that could be exposed to a given hazard. The qualitative analysis leaned on notes and video taken during the dialog between researcher and participant after each correct story sequencing. The children were asked to reproduce the story in their own words and to explain what the story taught them. The answers were analyzed in reference to whether a verbal response was given or not, the number of “I don’t know” answers a child gave and the depth of response, according to its accurateness and inclusion of causal dependencies, the number of prompts required to obtain the information from the child, the frequency of interaction with the props (pointing and touching) and the subjective interest level of the child. (Fails et al., 2005)

Fig. 2. The Hazard Room in tangible (a) and desktop (b) execution. (Fails et al., 2005)

The second study is oriented towards finding out which of the two environments releases more fun and engagement. It consists of a simple jigsaw puzzle without any further aim to facilitate a cognitive process. The desktop version of the jigsaw puzzle provided the interaction through a GUI and a mouse. Simple drag and drop manipulation changed the position of the puzzle piece, clicking the right mouse button enabled rotating it. The physical/tangible implementation, as shown in Fig. 2 (a), consisted of new versions of traditional puzzle pieces placed on tabletop prototypes, having an infrared web camera recording the participants’ movements. Also this experiment collected both quantitative and qualitative data. Engagement was measured by the evaluation of time logs and counts of play times, enjoyment resulted from the statistical analysis of the
results of a post questionnaire, whereas qualitative findings are based on data collected via observational notes, audio and video recordings. (Xie et al., 2008)

![Fig. 3](image1.jpg)  ![Fig. 3](image2.jpg)

**Fig. 3.** Jigsaw Puzzle in GUI(a) and TUI(b) execution. (Xie et al., 2008)

### 3.4.2 Study Findings

The findings from the Hazard Room Game study concluded with physical environments showing clear advantages over the desktop environments. The number of researcher prompts needed to receive the expected information from the children was fewer for the physical environment, as well as the number of “I don’t know” answers. The answer depth increased in the physical environment and the average subjective interest was higher. A correlation between number of prompts, number responded and number of “I don’t know” answers on the one hand and answer depth, intensity of interaction (number of pointing or touching) and the subject’s interest on the other hand is observable. These two groups furthermore are negatively correlated, which means that in desktop environments, more prompts caused more “I don’t know” answers insted of increasing answer depth, thus indicating the existence of disparity between the two environments. These qualitative results are also supported by the quantitative statistics reporting that the mean score differential between pre and post tests was greater in the physical environment than in the desktop one, in other words the contribution of physicality to the learning process is stronger. (Fails et al., 2005)

The Jigsaw Puzzle Game concluded that the children’s self report of enjoyment was similar for both TUIs and GUIs. Still, measurements showed that they had more difficulty in solving the puzzle in the desktop environment, eventually due to single user access and also because of difficulties with indirect mouse interaction in combination with the constraint to 2D space. Engagement was lower in desktop environments, as 48% of the GUI players didn’t manage to complete the puzzle even once within the given time, two of the pairs even quitting before the time elapsed. In comparison to this, TUI players not finishing consist of only 17% percent of the participants, with none of the pairs quitting before the end
time. The number of repeat plays was significantly higher on TUIs than on GUIs. Qualitative analyze concluded that different collaboration strategies were taken on the distinctive interfaces. In tangible interaction each child actively participated, working on his own area of the puzzle, area which often was decided upon through verbalization. Although each participant was absorbed by his own part, collaboration also reflected in observing the other’s actions and expressions and often copying them. Also in GUIs collaboration was noticeable, despite the single user access through mouse interaction. Commonly one participant would perform the interaction with the system, while his partner would collaborate by verbal suggestions or by pointing at the screen. Nevertheless, frequent verbal interaction, commonly arguing on the position of the piece, whether it is the needed one and looking for a certain piece, was present during the plays in both environments. When it comes to physical manipulation, GUI and mouse-based interaction caused difficulties in rotating the puzzle pieces, reflecting the need of a more direct style of interaction. TUIs provoked much more activity in terms of body movement and offered alternative possibilities of solving the puzzle, for example by moving around the puzzle itself instead of moving its pieces. Some participants made the puzzle from an upside-down perspective, which was not also supported by the GUI. Although arguments pro TUIs often state that having input and output integrated in space brings perceivable benefit, the study didn’t confirm this assumption. (Xie et al., 2008)

3.4.3 Critical Examination of the Studies

Especially the study using the Hazard Room Game shows several conceptualization errors that might have affected the results. In first place, the few participants, more precisely only sixteen, gives reasons to doubt on the significance of both quantitative as well as qualitative data. In contradiction to this, the Jigsaw Puzzle study had 132 participants. Second, the quantitative data from the Hazard Room Game study is based on the score differences between identical pre and post questionnaires. There is the issue, that the questionnaire results could be distorted by a learning effect among the participants, as they are always faced an identical questionnaire both before the game and inbetween the different sessions. These questionnaire scores are not independent data, like time measurement or repeated cycle count. The Jigsaw Puzzle study, instead, used quantitative data resulting from time measurement and counts of play, which seem to be more accurate for this purpose. On the other hand, the aim of the study was to identify the degree of enjoyment children experience and, in this context, it is doubtful that task time could give accurate feedback on enjoyment but rather on the cognitive difficulty of the game. Furthermore, some children reported to have felt pressured by the time limitation for completing a task. In some cases, this might have affected their performance. Despite possible distortion factors, these two studies set the foundation for the empirical comparison of GUIs and TUIs, as they are some of the very first of this kind and encourage more significant studies in the future.
4 Examples of Tangible E-Learning Systems

4.1 Expressive Systems: Topobo - A Constructive Assembly System with Kinetic Memory

The tangible system called Topobo is a 3D constructive assembly system coupled with kinetic memory that allows the recording and playback of physical motion. It is designed to facilitate modeling of both form and movement of dynamic structural systems in order to help understanding how balance, leverage and gravity affects moving structures. There are two type of assembly parts children can use when interacting with Topobo, as depicted in Fig. 4 (a): the Passives, these are just static components forming static connections(“T”, ”90 degree”, ”elbow”), and the Actives, the motorized and networkable components that are able to record and replay motion.

When using the system, the child chooses his preferred components, snaps them together into desired shape, e.g. animals, regular geometrics or even abstract shapes, and connects the Actives with small cables. Usually, Topobo is designed to have every Active recording its own motion. After a button on the Active is pressed, the creation is twisted and moved to program a sequence of behaviors, that are saved in the kinetic memory immediately as the button is pressed again. In a creation with various Actives, pressing the button of one Active will activate the recording mode on all Actives, so that they all record at the same time and also can save information on the dependancies between components when motion occurs. Fig. 4 (b) illustrates the modeling and programming of a horse model with the Topobo system.

![Fig. 4. Topobo components(a) and modeling and programming with Topobo(b). (Raf- fle et al., 2004)](image)

After finishing the motion programming and pressing the button on the Active, the construction automatically switches to the playback mode, reproducing the motion sequences over and over again.
Topobo is a typical illustration for an Expressive Tangible e-Learning System. As explained in anterior chapters, expressive systems are based on creating an external representation of existent knowledge and the subsequent reflection upon the accurateness of this representation. With Topobo, children create a physical model of how they think an object is supposed to look and behave. By snapping together the components they create the physical structure, by programming the Actives they set up a representation of possible motion behavior of this physical structure, all of this based on their own cognitive assumptions. In the next step, the playback mode triggers reflection on the previously built representation and the analysis of the degree to which the representation covers reality. With appearing dissonance between representation and reality, the children get the chance to rectify their assumption and by this increase their knowledge.

The evaluation of the system gave concrete hints on the concepts Topobo can help learning about. Students learn about the center of mass and gravity, when for instance a very tall creation tends to fall over when moving, find out on the difficulty coordination implies, when having a dog model supposed to shake its head and wagging its tail at the same time and get a notion on relative motion, finding out that movements in a connected system are relative to one’s frame of reference.

As a further result from evaluations of the system, the researchers put together a set of six design principles that the Topobo System was iteratively improved after. First of all, the system needs to provide high accessibility on the one hand, by being ergonomic and intuitive for very young children, and yet still be sophisticated on the other hand, so that it supports employment also amongst children with higher cognitive level or even amongst adults. Other two criteria are robustness and expressiveness: children shouldn’t get the impression that they might make “mistakes” that cause the system to break or malfunction or that the system prescribes them what activities are to be perceived as “wrong” or “right”. Furthermore the system needs to keep its meaningfulness even without power supply, as it should extend a toy without sacrificing its good qualities and has to be scalable in the spirit of a modular system, meaning that every component has to be complete and extensible in aspects of physicality and computing performance. (Raffle et al., 2004)

4.2 Exploratory Systems: SmartBlocks - A Tangible Mathematical Manipulative

SmartBlocks is an augmented tangible manipulative enabling students to explore mathematical concepts on volume and surface area of 3D objects. The idea is to combine the benefits of physicality with real time feedback to support the learning process. It supports more than one user at a time and offers exploration through a trial and error process.

As illustrated in Fig. 5, the system consists of lightweight cubes(a) and dowel connectors(b), which are placed on a work space, question cards(c) and a display providing feedback via a GUI(d).
The idea of the system is that when the cubes are connected, they create a shape that is recognized by the computing system, which is able to calculate the volume and the surface area of that shape, providing them via the GUI. The system is built upon two modi: the exploration mode and the question mode. During the exploration mode, students assemble the blocks and the system automatically updates the feedback on volume, surface area and number of visible cube sides as soon as the assembly is placed on the work area. The question mode consists of choosing a question card and placing it on the surface of the work area, which disables the automatic feedback provision by the GUI. The question cards require two types of tasks: the first asks the user to create a shape that matches a particular surface area and/or volume, the second asks the user to create any shape and then estimate its surface area and/or volume. After each task is carried out, the system gives feedback on the correctness of the answer. (Girouard et al., 2007)

SmartBlocks fits the classification of Exploratory Tangible e-Learning Systems, as it supports the modeling of representations meant to describe the abstract concept of volume and surface area. By checking on the feedback provided by the GUI, the student can explore these abstract concepts by correlating them to the physicality of the cubes, getting an impression on the “size” of a certain volume or surface area. It is possible to explore the impact of a changing shape on its volume, surface area and even get an idea of the relationship of the number of blocks to volume and of the number of visible sides to the surface area.

The design of the system builds upon already existent but not digitally augmented physical manipulatives used in school for teaching mathematics. A main design factor was to keep costs as low as possible, in order to make the system ideal for usage in schools someday. Further empiric work is planned, which intends to compare a tangible execution of the System Blocks concept with the execution on a desktop environment. (Girouard et al., 2007)
5 Conclusion and Outlook

This paper facilitated a general understanding of e-Learning, TUIs and the way they can be brought together efficiently, so that they complement each other in their aims and purposes. There is a strong relation between cognitive anthropology and research, stating that physicality brings high benefits to the learning process and Tangible User Interfaces which provide physical access points to digital information. Still, the effectiveness of TUIs in supporting the learning process is rather being argued in favor of it by creating hypothesis leaning on general findings on the relation between cognition and physicality. There’s a strong need for more empirical work and more detailed experiments, specifically examining whether TUIs are better than GUIs or just plain Physical User Interfaces lacking electronic enhancement.

Numerous experiments can provide new ideas on possible employment scenarios in the future of Tangible e-Learning. Also vice versa, the creation of these scenarios and subsequent experiments on their effectiveness for learning can improve tangible interaction Systems.

In future, we might encounter TUIs like the Cube to Learn in kindergartens and schools (Terrenghi et al., 2006; Kranz et al., 2006), TUIs in science museums and exhibits to simplify understanding factors that can affect the speed of a computer (Crease, 2006) or how a roboter can seem to have its own will and life by underlying a software (Horn et al., 2008). Why not explore our solar system and get to know more on the basic mechanics of planetary motion and the way it relates to the seasons in a lunarium enhanced with TUIs (Morris, 1999)?

Tangible interaction offers a variety of opportunities to learn more about the world we live in.
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