Embodied Learning About Time with Tangible Clocks

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Abstract. Time is a complex concept to grasp for elementary students and time related competencies take years to fully develop. In this article, we present and evaluate an instructional approach for learning to read and write time through embodied interactions with tangible clocks. The instructional approach consists of four "time learning stations" that may facilitate groups of 12 students (separated in teams of 3) to learn about time. The "time stations" include (a) a game with a big tangible 3D clock, (b) a game with a miniature tangible clock, (c) two notebooks with learning games about time, (d) a set of typical hand-written worksheets about time. Each team explores each station for 10 min and afterwards students move in a circular pattern to the next station. In order to evaluate the instructional approach, 84 students participated in a pilot study forming 7 groups of 12 students that used the time stations for approximately 45 min. Focus groups were conducted after each round of runs. Students supported that the whole setting greatly helped them to get acquainted with time and clock reading. Students underlined that the big 3D tangible clock was the most useful and entertaining activity and pinpointed that the specific interface was more engaging, the interactions were more kinesthetic and unexpected while the learning representation was significantly different from any other that they have used in the past.

Keywords: Embodied learning · Learning about time · Clock reading
Tangible interfaces

1 Introduction

Time is one of the most fundamental concepts that permeates all aspects of our lives. Yet, the way we count and record time lies more on a series of social conventions, rather than on concrete and objective factors. That is why time is a very complex concept for children to grasp and time related competencies take years to fully develop. Despite the difficulties in teaching time and all relevant concepts, it seems that this problem has not been tackled frequently [1, 2]. Researchers began to study time understanding more as developmental psychology began formulating new theories, emphasizing the children's natural development in the early 80's [3], but research from a pure educational perspective was started somewhat later [4, 5].

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The learning process for the concept of time spans all childhood years and ends when the student reaches adolescence. During elementary school, the pupil's understanding of time is confined to intuitable situations [6]. Children can use "time words", and learn to tell the time, but temporal operations are difficult. Mastering the concept of time and performing temporal operations is an iterative/evolving process, in the sense that children slowly improve their perception of time, proportionally to their development stage. Temporal concepts become more understandable and easily usable as children grow.

According to Piaget, young children can grasp time only through space, velocity and movement, as they cannot perceive "durations" independently [2, 5]. Burny et al. [6] underlined that time comprehension is not an isolated cognitive competency, but rather a skill that relies on a set of other developing competencies like literacy, numeracy, memory and spatial abilities [7]. This leads teachers to blend the development of time related concepts with other subjects, such as history (chronology), geography (deep time), mathematics (clocks and mechanical time) and literacy (time-related vocabulary).

Research in the field of time-related competences lack evidence and most times are rather driven by ideology, politics and marketing than by empirical evidence [8]. Even more the tools used in clock training have remained similar for many years while the technology supported interventions are few. For example, Wang et al. [9] used touchscreen tablets based on the embodied theory for learning to help children tell time with positive results.

In this paper, we propose an instructional approach which is also based on embodied learning and tangibles and consists of four "time learning stations" that may facilitate classrooms of 12 students to learn about time. The "time stations" include (a) a game with a big tangible 3D clock, (b) a game with a miniature tangible clock, (c) two notebooks with learning games about time, (d) a set of typical hand-written worksheets about time.

2 Embodied Interactive Learning

Embodied cognition theory and several relevant frameworks suggest that thinking and acting (or else mind and body) are intertwined in nature and that tangible engagement with objects or exploring spaces affects the way we think about them and vice-versa. Grounded Cognition describes that mental representations are grounded in motor areas of the cortex and that the perceptual and motor states acquired through experience are reactivated through simulation when knowledge is needed [10]. Similarly, the Embodied Metaphor theory suggests that abstract concepts and conceptual metaphors are based on image schemas that derive from physical actions [11]. And many more theoretical frameworks propose that full-body interaction has the potential to support learning by involving users at different levels such as sensorimotor experience, cognitive aspects and affective factors. The physical world seems to underpin one's internal mental representations [12]. The design rationale is that having learners act out and physicalize the systems processes, relationships, etc., will create conceptual anchors from which new knowledge can be built [13].

New interaction technologies can prove an excellent guide to perform physical actions that serve as “conceptual leverage” [13]. Under the umbrella of terms like embodied interaction, full-body interaction, motion-based interaction, gesture-based interaction, tangible interaction, bodily interaction, and kinesthetic interaction, several interactive learning environments based on novel interaction modalities have been developed. Following similar theoretical underpinnings, these interactive environments try to facilitate an embodied experience of a certain concept, to represent an abstract concept as a concrete instance or operationalize actions as means to express specific content, or try to use space as a semiotic resource or even try to become embodied metaphors. The new mediated environments seem to increase learner engagement since body-based experiences are more perceptually immersive and learners may feel that they are in a more authentic and meaningful educational space [14]. Following these theoretical underpinnings, tangibles are frequently used to teach children abstract concepts, in science and mathematics [15]. For example, Button Matrix [16] uses coupled tactile, vibration and visual feedback to highlight features of a physical experience with arithmetic concepts and cue reflection on the links between the physical experience and the mathematical symbols. Tangible Interactive Microbiology environment [17] also offers students an interface with microbiological living cells and tries to promote artistic expression and scientific exploration.

However, there is also another stream of research which indicates that “physicality is not important” and rather “their manipulability and meaningfulness make them [manipulatives] educationally effective”. In many situations, children do not transfer performance with physical to symbolic representations of problems. Indeed, it has been suggested that previously identified virtues of physical manipulatives—learning through concrete and perceptually rich physical practices—are not the drivers of learning (e.g., [18]) and can even be detrimental to learning (e.g., [19]). However, a recent meta-analysis found that the use of physical manipulatives in math education tends to improve retention, problem solving, and transfer [20]. Additionally, the context of use seems also to have detrimental effects. For example, unconstrained physical manipulation has also been shown to be suboptimal for learning [21] or high interactivity can be overwhelming and may lead to a lower learning performance embedded learning, whereas self-guided problem-solving strategies can be effective, but seem to be moderated by the perception of possibilities for action on manipulatives (e.g., [15, 21]). Hence, the design of tangibles still holds great difficulty. Tangibles may differ in terms of the degree of metaphorical relationship between the physical and digital representation or may range from being completely analogous, to having no analogy at all and may also differ in terms of degree of ‘embodiment’. Small representational differences may have great effect on performance differences [22].

In order to achieve the goal of designing efficient and effective learning tangibles, designers and researchers have to bring together specific knowledge about children’s cognitive, physical, emotional, and social skills, the idiosyncratic characteristics and prior experience on each field domain and the opportunities provided of tangibles environments.

3 An Instructional Approach with Tangible Clocks

In this study, we propose an instructional approach for learning about reading and writing time which exploits the following design principles:

- Create new visual-spatial representations of an analogue clock since time-related competences are strongly connected with the related concrete representations.
- Exploit embodied interaction with the new tangible representations.
- Offer an authentic context of interacting with time-based activities since due to its abstract nature, time must be taught through realistic activities and authentic problem solving.
- Provide lots of activities with a constant switching between reading and writing time.
- Create a chain of activities which trigger different modalities and enable students to interact with several types of time representations.

The proposed approach consists of four "time learning stations" and targets classrooms of 12 students separated in four teams of 3. The four "time stations" are the following:

(a) *A tangible game with a big three-dimensional clock* (Fig. 1): In this game, one of the students becomes the hour indicator, the other one becomes the minutes indicator while the third one sits in the center of the clock and has to touch both of them and an orange (fruit) when they are ready to form a specific time in order for the program to evaluate their input. For the very first time, students become a part of a working clock and view an analogue clock from an unprecedented perspective. The program narrates different time activities and students have to form

Fig. 1. The big tangible clock with three students

the right combination of the two indicators (i.e. “the time is 12:00”, or “let’s say that 12 h and 10 min have passed”). If students answer wrongly, different layers of help are available. Students walk inside the clock, observe the position of their co-mates, discuss with them and try to answer to the presented challenges as fast as they can.

(b) *A tangible game with a miniature clock* (Fig. 2). The second learning station is the miniature of the first one with different however time-related activities such as calculating durations and time-intervals, pre-night and after midnight times, etc. Similarly, in this station, the one student is the hour indicator, the second one the minutes indicator and the third student is the interacting one. The activities relate to events of a girl’s daily routine presented in a multimedia way. In this tangible clock, the difficulty is the exact opposite to the big clock since the hands of the students have to fit in a very limited space.

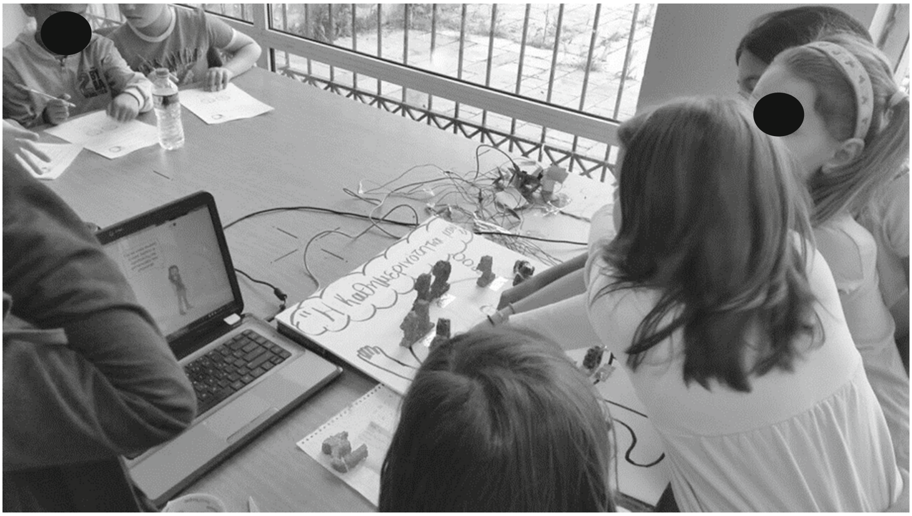

Fig. 2. The small tangible clock

(c) *Two notebooks with 3 learning games about time* (Fig. 3). The third learning station is based on common PC games about time which focus on converting digital to analogue time and vice versa. Multiple time representations coexist in the game screen and help students to make the required connections for the conversions.

(d) A desk with hand-written worksheets about time. The last learning station provides worksheets about time which have to be completed in a short period of time by the students. The worksheets include exercises addressing the objectives of the curriculum for 4th grade students and the related book.

Each team had to use each station for 10–12 min. After completing one station, students moved in a circular pattern to the next one.

Fig. 3. The other two clock stations

The two tangible clocks were developed having in mind simplicity, affordability, and ease of replication. Thus, the interfaces were created by exploiting 4 Makey Makey boards connected to two laptops running the web version of Scratch 2. Both platforms are easy to use even for primary school students while the Makey Makey board is an affordable and powerful prototyping solution. Such a setting can be reproduced and enhanced with new activities easily by teachers and students.

4 Methodology

4.1 Participants

The sample of the pilot study consisted of 84 students, from five 4^{th} grade classes which were organized in 7 groups. The interventions were performed in a two-day activity in the context of an interactive exhibition related to Tangible and Mixed Reality Interfaces for Elementary Schools.

4.2 Data Collection

Each group of 12 students, after completing a full tour in all the learning stations lasting about 45 min, was gathered in a quitter place and a short focus group was conducted. The questions posed aimed at determining whether the proposed instructional intervention is effective and joyful way of learning, which of the four learning stations was the preferable and why and whether the tangible interfaces offered them new perspectives in time understanding, reading and writing. Exemplary questions of the focus group included

- Did these four games help you to become more familiar with clock reading?
- Which one did you enjoy most and why?
- Is there something new that you learned through this brief activity?
- What’s new and useful in these games?

5 Results

According to students, the proposed instructional activities helped them to get more acquainted with time and clock reading. In their words

"We realized the exercises and thus learned to tell the time better."
"We exercised our time telling skills through games and the tangibles given to us."

The students learned about time in a pleasant and entertaining way, without getting bored or frustrated. When asked which learning station was the best in terms of learning efficiency, almost all students answered that they considered the big 3D tangible clock as the most helpful one. They identified the following advantages:

– The interface was more fun and engaging than the others learning stations. Students approached the big tangible clock as a joyful learning game.

"The big clock helped us more than the others, however both tangible games were fun."
"It's a more entertaining way of learning and we prefer this way since doing the same thing on paper is not fun."

– The interaction needed was kinesthetic and that was in opposition to the paper-based worksheets and the games on the computer. It is well documented that students want to abandon their classroom desks and learn in a more embodied way.

"The three-dimensional clock because we were moving."
"The big clock since we were running."
"I was running and laughing."
"The big clock because we were running and because we learned while having fun."

– It included several unexpected and fascinating for them interaction elements, such touching students, touching the numbers of the clock, touching an orange. Students were enthused by the workings of the tangible clocks, as they couldn't understand how touching each other became an input for the program. Natural interfaces seem a good fit for creating learning representations that intrigue the students.

"We liked the part where we touched each other and then pressed the orange to check the answer."
"The big clock because it was really cool to touch the orange."
"The big clock because there were wires and pressing the orange was fun...we had to ... touch our hands and then the orange."
"We liked the part where we touched each other and pressed the orange to check the answer."

– It offered a new learning representation significantly different from any other available representation at school. The big 3D interactive clock offered a novel visual-spatial perspective of analogue clocks, and an original role-playing game with hour and minute indicators which enabled them to re-visit and re-examine how to read time.

"The large clock because it is different from ordinary watches and we can learn more easily about time."
"It helped us because we were the clock indicators ourselves and we learned more."
"It helps someone to see the indicators [from a closer look] and understand time more."

"In typical watches that we wear in our hand we see the time, here we played with [emphasis] the time."

The big 3D clock was something completely new for the students, and that was noticeable from the beginning when they were awed and couldn't explain how such a game could evolve. The students' interest was heightened by the fact that they could move inside the space of the clock and that had to role-play the hour and minute indicators. There was a single outlier, a female student, who claimed that worksheets are a more effective way to learn and practice time telling skills.

Students presented some repeated difficulties in specific activities of the big clock. The more typical examples were:

- Activities like "quarter to five" in which the hour indicator usually touched number 4 and spoke loudly "4:45".
- Activities like "10 exactly" in which many students asked where is the zero number on the watch.
- Activities like "quarter past five" in which many children put the hour indicator in 5 but the minute indicator touched number 4.
- Activities relating to time calculations i.e. 5 h passed, while the time was half past nine. Students counted with fingers where to move the hour indicator.

Most of these problems come from the conversion of digital to analogue time. It seems that the tangible clocks may also be exploited as diagnostic tool for time misinterpretations or difficulties.

Finally, as to which were the new and useful things they encountered through the activity, students said:

"The new technologies",
"That was the first time we saw a clock made of Styrofoam which helped us learn more easily."
"Very useful and unusual. It is something new that does not happen in the classroom."

6 Discussion

The proposed setting addressed concurrently the needs of a big number of students and offered them multiple new perspectives in a short period of time by exploiting different learning media, from hand-written worksheets to tangible interfaces. Natural interfaces [23] and tangible interactions showed great impact on children's attitude towards learning about time and time-related calculations, difficult to grasp notions. This pilot study underlined that tangible clock representations in combination with a role-playing game can become a creative canvas for discussing time issues and for exercising typical time-related activities under a new perspective. Of course, teaching time to children demands a solid conceptual framework taking into account the children's evolving sense of the relevant concepts and the related math skills needed.

Low cost rapid prototyping hardware together with the uprising trend of arts and crafts fairs, tinkering and inventing have created a new trend of creating tangible technologies for learning. Researchers but also teachers and students can create or replicate tangible devices such as the ones described in this study with easiness. Hence, the focus now is on the effective exploitation of physical interfaces or on identifying adequate embodied metaphors and realizing them into interaction models [24].

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