Design Implications for a User Study on a Tangible Tabletop

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Abstract
This paper presents some implications about designing a collaborative problem solving task on a tangible user interface (TUI) for gesture analysis. We present our initial work within the European Horizon 2020 Marie Curie project Gestures in Tangible User Interfaces (GETUI). This project involves mainly creating a gesture taxonomy used in relation to a tangible tabletop. A preliminary user study showed that gesturing encourages the use of epistemic actions by lowering cognitive load. Our current user studies will enhance 21st Century skills and provide insights about the impact of gestures on collaboration, while also identify cultural differences of gestures.

Author Keywords
Assessment; gestures; PISA; tangible user interface.

ACM Classification Keywords
K.3.2 Computer and Information Science Education
H.5.2. User Interfaces.

Introduction
The IDC community has shown an increasing interest and focus on embodiment as an alternative perspective in HCI (Schaper et al. 2015). Gesturing is a natural and intuitive communication means and gestures have been indeed analyzed often in the literature both from a

philological and an HCI perspective. However, to our knowledge there is no systematic analysis of gestures in the specific application field of HCI: the TUIs. The SIG "Tangible User Interfaces for Children" is an excellent initiative to foster the development of a community of researchers and practitioners who focus on designing and developing tangible interfaces for children (Revelle et al. 2005). In this paper we describe how collaborative problem solving is incorporated in the *Programme for International Student Assessment* (PISA) and how our research attempts to evolve this framework by enhancing the children's collaborative problem solving skills through gesture analysis.

The paper is laid out as follows: firstly we present related work on different aspects of gestures and continue with the collaborative problem solving and the current framework of PISA. Then our preliminary study is presented with an initial gesture taxonomy. Based on related work and our preliminary study, our current user evaluation studies with relevant research questions and design implications are discussed. We conclude with a discussion about the overall impact of our research and particularly on PISA and the 21st Century skills.

Related Work

Gesture Taxonomies

There are many gesture taxonomies in the literature; one of the first goes back to 40s. Efron (1941) studied the conversational behaviors of Jewish and Italian immigrants in New York. The most prominent philological taxonomy, which we also follow in our research, is that of McNeill (1992). McNeill (1992) categorized the gestures into *gesticulation*, *emblems*, *pantomimes*, and *sign language*. For our research purposes, we focus particularly on *gesticulation*, the unconventionalised hand-and-arm movements that are almost always accompanied by speech.

From an HCI perspective, Karam and schraefel (2005) made a classification of the literature about gesture interaction research since the early 90s. This classification investigated gesture interactions to explore the relationships between categories, characteristics, and their effect on interactions. As for gesture taxonomies in HCI, we follow the taxonomy of Quek (1994) who classified meaningful gestures into *communicative* and *manipulative* gestures.

Gestures as language-culture combinations

Gestures can be interpreted very differently in different cultures. The cultural differences of gestures have been examined, among others, by Kita (2009). Very often it can be embarrassing or even offending using a non-appropriate gesture in a specific culture. We define a *locale* as combination of language and culture, and thus *gesture localisation* as follows: "*Gesture localisation is the adaptation of gestures to a target locale in order to transfer the same meaning as in the original locale*". (Anastasiou, 2011). Cultural differences in gesture have been often systematically examined in human-human interaction, but not in HCI, excluding a few exceptions.

Children's' gestures in learning

Gesture's role learning process has been documented a lot in the literature in the past (Roth, 2001; Goldin-Meadow, 2004). Cook et al. (2008) stated that gestures reflect a child's readiness to learn and consequently improve learning. Gestures have been examined also through gaming. Moser and Tscheligi (2015) explored

Figure 1: Collaborative problem solving framework with chat interaction at PISA

Figure 2: Collaborative problem solving at a group collocated setting

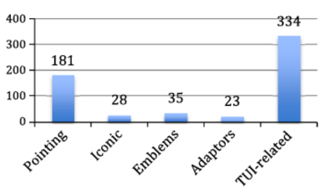

Figure 3: Distribution of gestures in our preliminary study

touch vs. mid-air gestures on the game *Cut the Rope*. They compared touch gestures on a tablet and mid-air gestures using a *Leap* motion. They observed difficulties with accuracy for small and precise gestures or only partial recognition of very fast swipe mid-air gestures. Xie (2008) compared children's enjoyment and engagement comparing three interaction modes while playing a jigsaw puzzle: physical, traditional, and tangible. Children took longer and had more difficulty completing puzzles in the GUI condition. Moreover, they found that the tangible condition was more of a benefit for the collaborative problem solving.

Collaborative problem solving

Collaborative problem solving is defined as the capacity to participate, contribute knowledge, recognize the need for contributions, and build knowledge and understanding as member on a collaborative setting (Ras et al., 2013). As far the technology-based assessment (TBA) of collaborative problem solving skills is concerned, most of the research deals with the improvement of assessment of traditional skills. However, the focus should be on the so-called 21st Century skills, such as complex problem solving, creativity, critical thinking, learning to learn, and decision-making. Orr et al. (2015) provided several cases where open educational resources can facilitate learning that is appropriate for the 21st century, including the Khan Academy[1] material to support peer-to-peer learning.

PISA Programme

PISA is run by the Organization for Economic Cooperation and Development and is the most comprehensive international large-scale assessment testing approximately half a million students in 3 year cycles. PISA assesses the extent to which students have acquired key knowledge and skills that are essential for full participation in modern societies[2]. In the attempt to move towards 21st Century skills, collaborative problem solving was an innovative domain in PISA 2015. In practice, the problem solving units include chat-based tasks where students interact with one or more agents, or simulated team members, to solve a problem (see Figure 1) [3]. In our opinion, collaborative problem solving should involve a face-to-face setting with collocated people; Figure 2 shows the setting of our user studies.

Preliminary Study

A preliminary user study (Anastasiou et al. 2014) was conducted with 30 participants; 10 groups of 3 children each tried to affect the production of windmill's electricity by manipulating parameters (e.g. speed, number of wheels) on a tangible tabletop using six physical objects made of cardboard. Based on gesture annotation using the software ELAN (Wittenburg et al. 2006), we categorized gestures into five main categories:

1. *Deictic/pointing* gestures: point something/somewhere;
2. *Iconic* gestures: indicate distance, depth, or height or describe the shape of an object;

[1] https://www.khanacademy.org/, 15.01.2016

[2] http://www.oecd.org/pisa/keyfindings/pisa-2012-results.htm, 15.01.2016

[3] PISA 2015 Released Field Trial Cognitive Items: https://www.oecd.org/pisa/pisaproducts/PISA2015-Released-FT-Cognitive-Items.pdf, 17.05.2016

3. *Emblems*: have a direct verbal translation and can be interpreted differently by different cultures;
4. *Adaptors*: are not used intentionally during a communication or interaction;
5. *Manipulative/TUI-related* gestures: occur in interaction with TUIs.

Our pre-study proved that problem solving task on the TUI encouraged the use of rapid epistemic actions by lowering cognitive load. This could be deduced from the fact that (1) almost half of the gestures were not manipulative and therefore did not modify anything in the simulation, and (2) in case of a gesture, the other participants reacted with gestures too (85.4% manipulative gestures).

Figure 4: Current collaborative problem solving scenario on a power grid.

Current User Studies

In this section we provide our current work-in-progress on designing user studies involving children as participants while solving a collaborative problem on a TUI. The evaluation user studies are planned in May-June 2016. Our research questions and first design implications follow:

Research questions
RQ1: Which are the contextual demographic and social factors? (age, language, proximity)
RQ2: How should be a collaborative problem solving task modelled for children?
RQ3: Which gestures should be recognized and how? How should the gesture taxonomy be structured?
RQ4: What should be evaluated and which are the evaluation measures?

Design implications
As far as **RQ1** is concerned, the participants of our studies will be between 15-18 year old students, similar to the PISA target group. As one of our project's goal is to explore any cultural differences in gesture, we recruit participants speaking three different languages (participants will speak in their mother tongue), e.g. 20 francophone, 20 germanophone, and 20 anglophone. The recruitment has already started; the authors visit schools in the context of promoting research at schools and in parallel, inform educators and students about the purpose and the set-up of the study. The informed consent forms and instruction sheets are written in three languages (English, German, and French) and the consent forms have to be signed by both parents. We decided on a small group of 3 pupils solving a collaborative problem; the children in each group will be of similar age (attending the same class) and in a mixed-gender team.

Designing a collaborative problem solving microworld scenario for children is definitely a big challenge (**RQ2**). In our opinion, the selected scenario should have a learning educational impact, but should still be enjoyable for the children. The scenario should not require any previous knowledge from the children and the task should not be difficult to solve. As a follow up user study of the pre-study, we expanded the scenario on modelling a whole power grid. The three children will be provided with physical objects which represent industrial facilities that produce electricity, e.g. a wind park, solar park and a coal-fired power plant. By placing the objects on the TUI, there are two parameters changing: i) the power generation and ii) CO_2 emission. The output values of changing the parameters will be displayed on the TUI. See a visual representation of the scenario in Figure 4. Towards the end of the study, the children will be given collaborative tasks, e.g. use all types of facilities to reach 5 GW of electricity. Our software framework TULIP uses an abstraction layer to receive information from computer vision frameworks (reacTIVision[4]) and a widget-model based on model-control representations (Ullmer and Ishii, 2000). The scenario is partially based on the MicroDYN framework of Greiff et al. (2012), a new approach for computer-based assessment of complex problem solving based on linear structural equations. This methodology allows to formally describe everyday activities by means of variables, outcomes and their interconnectedness.

As for the kind of gestures that should be recognized (**RQ3**), we focus mainly on hand gestures. We sub-categorize hand gestures in manipulative gestures, physical gestures (pointing, iconic), and affective gestures. These categories have, in turn, sub-categories: single-handed or bimanual pointing, and the animate or inanimate object where the person is pointing to (table, widget, participant). In addition, we want to explore the so-called cooperative gestures (see Morris et al. 2006; Tang et al. 2006) with regards to symmetry, parallelism, number of users vs. number of devices etc. The physical/mid-air gestures gestures will be recognized by using *Kinect* and the manipulative gestures through the log files of the TUI.

In fact, there are many aspects that can be evaluated through such a study (**RQ4**), both from a human and an HCI perspective. As aforementioned, we focus on gestural behaviour made by the children both to the other children and to the tabletop; the main objective is to analyse the impact of both these kinds of gestures on collaborative and complex problem solving. Based on the gesture analysis which will follow, we will explore their learning effects, particularly whether the children as a group achieved the task faster and more effectively performing some specific types of gestures compared to other groups. We decided to evaluate the cognitive load using the Nasa task load index (Hart, 2006), which is a subjective workload assessment tool with ratings on mental, physical, temporal demands, as well as own performance, effort and frustration. Moreover, we will evaluate the usability and design of the scenario on the TUI through *Attrakdiff*[5]. The user acceptance of the TUI in an educational environment will be tested through the SUS (Brooke, 1992). Last but not least, a pre- and post-test questionnaire with regards to knowledge on the specific scenario (power grid) will provide us with insights about the learning effect of the study.

Discussion and Conclusion

The topic of our research is interdisciplinary, connecting HCI with analysis of gestures and localisation, and interaction design with TUIs. Given the widespread use of TUIs as an interaction modality in many application domains, including this of education, our research will have an impact on technology-based assessment (TBA). Collaborative problem solving was a major domain in PISA 2015 and the MicroDYN framework of Greiff et al. (2012) was used as its conceptualization. Our research will provide insights on how gesturing can enhance collaborative problem solving skills through a collocated group setting around a TUI.

[4] http://reactivision.sourceforge.net/, 21.01.2016

[5] http://attrakdiff.de/index-en.html, 19.01.2016

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