

Using tangible user interfaces for technology-based assessment – Advantages and challenges

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Abstract

Assessing higher order thinking skills should measure knowledge, procedure, as well as attitudes and dispositions. It can be considered as multidimensional regarding the cognitive processes involved to solve a complex problem, for instance. This paper summarises first experiences made with a so called tangible user interface (TUI) for assessment purposes. Due to the haptic dimension and the shared space of a TUI, the understanding of a problem can be improved and skills can be assessed in a collaborative context. A simple matching item, suitable for measuring recall of factual knowledge, as well as a simulation item with the potential to assess higher order thinking skills are presented.

Introduction

Innovation cycles get shorter and shorter. This impacts the way in which products and services are developed, but also influences how people access, process, and use information during daily work. The need and pressure to develop innovative solutions put more light on specific skills and competencies. These so-called 21st century skills refer to skills, such as, complex problem solving, creativity¹, critical thinking, learning to learn, decision making, etc. (Binkley et al., 2012). Besides this, learning and

¹ Center for Creative Learning, <http://www.creativelearning.com/> (accessed 22 June 2012).

Using tangible user interfaces for technology-based assessment – Advantages and challenges

working in a collaborative, connected context requires communication skills, negotiation skills, and skills for learning in the digital network (Griffin, Care, & McGaw, 2012). Educational frameworks on a global or national scale support teachers to cope with these new challenges – however, the knowledge about how to assess these skills still suffers of a very low level of understanding. Bennett and Gitomer state that "... knowledge about acquisition of 21st century skills and their development is very limited. Developers of assessment do not yet know how to create practical assessment using even this partial knowledge effectively (Bennett & Gitomer, 2009)".

Technology-based assessment may avoid existing time constraints, ease the comparison of results, reduce measurement errors, etc. (Csapó, Ainley, Bennett, Latour, & Law, 2012; Grundwald Associates LLC Report, 2010). Nevertheless, most of the research in technology-based assessment dealt with the improvement of assessment of traditional skills (Binkley et al., 2012).

The purpose of this paper is to present first experiences of a so-called tangible user interfaces used for technology-based assessment. Exploratory, design-focused studies have suggested that TUIs provide some learning benefits, due to the additional haptic dimension, the better accessibility, and the shared space that can be used in collaborative situations (Marshall, 2007).

Section 2 refers to 21st Century skill frameworks developed recently and reflects upon higher order thinking skills (HOTS). It will allow us to elaborate for which skills a TUI can be useful for assessment and how it should evolve in the future from a technical perspective. Related work on TUI for learning and assessment is presented in Section 3. Section 4 summarises first experiences made with a so-called tangible user interface (TUI) for assessment in science. Section 5 concludes our work.

21st Century skills

The OECD² developed several programs such as PISA (Programme for International Student Assessment), PIAAC (Programme for the international Assessment of Adult Competences to assess skills on a large scale. A program for Assessment of Higher Education Learning Outcomes (AHELO) is planned for the future.

Binkley et al. have organised the 21st Century skills into four groups and have proposed a model to assess those (Binkley et al., 2012): ways of thinking, ways of working, tools for working, and living in the world. For our work, ways of thinking is the most relevant. These skills refer to a) creativity and innovation, b) critical thinking, problem solving, decision making, c) learning to learn, metacognition. Ways of working covers communication and collaboration (i.e., teamwork).

Projects, such as, the ATC21S³ are developing methods to assess skills, which are part of 21st-century curricula. It concentrates on collaborative problem-solving and learning in digital networks (Haladyna, 2004): a) *Collaborative problem solving* is defined as the capacity to recognise the perspective of other persons in a group, participate in a group and contribute knowledge, experience and expertise in a constructive way, recognise the need for contributions and how to manage them, identify structure and procedure in resolving a problem, and build knowledge and

² Organisation for Economic Co-operation and Development, <http://www.oecd.org/> (accessed 22 June 2012).

³ Assessment and Teaching of 21st Century Skills, <http://atc21s.org/> (accessed 22 June 2012).

Using tangible user interfaces for technology-based assessment – Advantages and challenges

understanding as member on a collaborative setting; b) *Learning through a digital network* consist of learning as consumer and producer of information, learning in the development of social and intellectual capital (Griffin et al., 2012).

JISC⁴, for example, funds a huge number of technology-based assessment projects in the UK. The *Learning Literacies for the Digital Age* project (LLiDA) reviewed the kinds of capabilities valued, taught for and assessed and defined in competence frameworks. Their “framework of frameworks” emphasises on components of digital and learning literacy, which covers also communication and collaboration skills, as well as problem solving (Leighton, 2011). A comprehensive report on *assessment in the digital age* highlights outcomes of case studies conducted in the UK. The authors conclude that assessment should also capture the process in addition to the learning outcome, that it is important to explore the potential of technology to enable more efficient use of practitioners time and effort, and should provide a digital environment in which all learning and assessment related activities take place where evidence is consolidated (JISC e-Learning team, 2010).

Higher order thinking

The term thinking is difficult to define and depends on the view on thinking and the purpose it should serve. In the book of Schraw et al. on assessing higher order thinking skills (HOTS) they state that thinking and human cognition in general is a goal-oriented activity: “Thinking is related to gather and evaluate information that is relevant to this goal; It requires constructing a meaning and conceptual representations that support the analysis of events around us; and it requires that we engage in strategic decision making and judgments that enhance our ability to self-regulate (Schraw & Robinson, 2011)”. According to Schraw et al. HOTS can be refined to *reasoning* skills, *problem solving* and *critical thinking, argumentation* skills, and finally *metacognition* (i.e., thinking about thinking).

The assessment of thinking skills is related to three different outcomes: knowledge, procedure, as well as attitudes and dispositions (Schraw & Robinson, 2011). The first focuses on the assessment of facts, concepts, or mental models. Procedural outcomes refer to specific thinking skills and strategies, self-regulatory processes, or as stated by Schraw et al., content-based procedural skills. For real-time problem solving, for example, so-called learning traces, which log the actions performed by a learner. Analysis of notes taken, think aloud protocols, or eye tracking are just a few examples for assessing real-time problem solving skills.

Computer-based simulation can assess complex thinking skills that cannot be measured by more traditional assessment methods (Lane, 2011). An additional value of simulations is the way how students interact with the tools provided in the problem solving space and the possibility to record how students use them. Both outcomes, as well as strategies and processes can be measured.

In the following, the tangible user interface will be explained by means of a matching and a simulation item.

Tangible user interfaces for learning and assessment

While current, web-based e-assessment frameworks exploit multimedia capabilities of graphical user interfaces to support a large range of different questions types,

⁴ Joint Information Systems Committee, <http://www.jisc.ac.uk> (accessed 22 June 2012).

Using tangible user interfaces for technology-based assessment – Advantages and challenges

their possibilities for supporting and measuring team-oriented, creative, and communication skills in a collaborative context are extremely limited. Even if some platforms (e.g., TAO (Ras, Swietlik, Plichart, & Latour, 2010)⁵ which is currently used in PISA and PIAAC) are designed to accommodate multi-test-taker networked assessments together with log collection and analysis capacities, they still lack delivery modes that can capture human-to-human collaboration in a natural setting. Hence, we need to explore new technologies that better support and allow collaborative activities, enhance understanding through more natural activities and realistic problems, and finally allow us to gather activities traces. If proven effective, they might open new avenues for innovative modes to be included in the assessment platforms.

Using a new technology in assessment requires first a deep understanding with regard to the actions the users perform, the group dynamics in collaborative settings, as well as the required digital literacy to use such a new technology. These aspects may impact in which the results of assessments are obtained (i.e., measured) or they may produce undesired effects (i.e., measurement errors).

Tangible user interfaces (TUIs) are an approach to create new types of interactions combining physical artefacts with digital visualisations in a common interactive space. The idea of TUIs is to make computer bits tangible and to allow users to grasp and manipulate them with their hands (Antle, 2007). This concept has a number of advantages for social and contextual interactions, such as collaboration (Hurtienne, Weber, & Blessing, 2008).

The use of TUI is twofold: 1) using the TUI for innovation and modelling tasks: creating new services is an innovative, creative, and collaborative way; using TUIs for complex modelling tasks in industrial settings, for example, modelling business process models; 2) the previously mentioned tasks rely on 21st Century skills and hence provide an ideal setting with realistic problems to assess those skills.

In literature, we can find a number of examples, demonstrating learning environments using TUIs, without emphasising on assessment. For example, the Chromatorium (Rogers, Scaife, Gabrielli, Smith, & Harris, 2002) is an environment where children may discover and experiment with mixing of colours. In a similar type of setup students may learn about the behaviour of light (Price, Pontual Falcão, Sheridan, & Roussos, 2009). Through physically manipulating a torch and blocks on a table surface, the students could explore how projected light beams react and understand the concepts of reflection, absorption, transmission, and refraction. Another interactive tabletop called TinkerLamp provides a simulation environment for learning purposes where students design a warehouse (Do-Lenh, Jermann, Cuendet, Zufferey, & Dillenbourg, 2010).

A kind of learning system implements the concept of digital manipulatives (Resnick et al., 1998), computationally enhanced building blocks, which allow the exploration of abstract concepts. This principle is followed by SystemBlocks and FlowBlocks, two physical, modular interactive systems, which children can use to model and simulate dynamic behaviour (Zuckerman & Arida, 2005).

The approach of concept mapping for self-regulated learning is used in (Oppl, Steiner, & Albert, 2010): A tangible tabletop allows users to reflect and evaluate their learning tasks through externalising and representing their knowledge on concept maps represented through physical and digital elements. Users can, for instance,

⁵ <http://www.tao.lu>

Using tangible user interfaces for technology-based assessment – Advantages and challenges

place physical tokens, assign names, make connections, and use tokens as containers.

Only a few systems go beyond the learning aspects, and implement possibilities for assessment. The Learning Cube (Terrenghi, Kranz, Holleis, & Schmidt, 2006) acts as a tangible learning platform where multiple choice tests can be done. By turning the cube, the user selects the right answer for a given question and then shakes it to select it. Another example provides new possibilities for assessing spatial and constructional ability. The Cognitive Cubes (Sharlin et al., 2002) are a set of construction cubes that are provided for building a 3D shape shown on a screen. The change of each shape is recorded and scored for assessment.

Although a number of publications can be found that describe different kinds of strengths of TUIs for learning environments, there is still a lack of knowledge for using TUIs as tool for assessment. To the knowledge of the authors, there is no prior work addressing the development and measurement of higher order thinking skills in a mixed physical – digital environment, such as TUIs.

First results with a tangible user interface

Two example test items with a TUI are presented next. The first one, a matching item assesses recall of factual knowledge, whereas a second example is a performance item using simulation, which shows potential to measure HOTS in the future. The purpose of both studies was explorative, which means to observe the users human-to-human behaviour and interactions with the objects of table. The goal was not to develop a comprehensive assessment model and method, which will be targeted in the near future, after having observed the system in practice first.

Matching item

The implemented task was to assign the correct name of a planet to the correct image of a planet (according to QTI⁶ standard: *associate* item). When a user places a card onto a planet, the user gets an immediate feedback in form of a red (false answer) or green (correct answer) circle that is shown around the planet. During the solving of the task, the system counts the number of attempts (i.e., wrong pairing of a card and a planet's image was counted as one attempt), and the time needed to solve the task.

The matching item allows recalling factual knowledge about a particular topic. According to the revised taxonomy of Bloom, such a task can be classified under the level "remember" and the cognitive process "recognise" (Anderson & Krathwohl, 2001). Facts are recalled from long-term memory and associated to the projected images of the planets. Hence, the task consists to match verbal or pictorial representations of the solar system objects.

For the experiment, we set up a tangible tabletop system, based on the optical tracking framework reactivation⁷. The worktop has an interactive area of 75x100cm. On the table, we projected an image of the solar system, showing the sun and each of the nine planets. The position of the planets did not reflect the distance to the

⁶ IMS Question & Test Interoperability Specification, <http://www.imsglobal.org/question> (accessed 22 June 2012).

⁷ A toolkit for tangible multi-touch surfaces, <http://reactivision.sourceforge.net/> (accessed 22 June 2012).

Using tangible user interfaces for technology-based assessment – Advantages and challenges

sun. We further created nine cards, each showing the name of one of the planets. A camera and projector had been placed underneath the table to track the positions of the physical objects and project feedback onto the semi-translucent tabletop surface.

A between-subject controlled experiment was conducted with a control group of 11 individuals solving the test items alone, as well as 24 subjects divided into 8 groups of equal size (i.e., experimental group). The subjects were randomly selected from the research department and assigned to both groups with an average age of 32 years.

The experimentation was video recorded and at the end we distributed a questionnaire. The questionnaire consists of questions asking the background knowledge on astronomy and the System Usability Scale (SUS) with ten questions. Further, we took notes on the performance of the group and how the users placed themselves around the table.

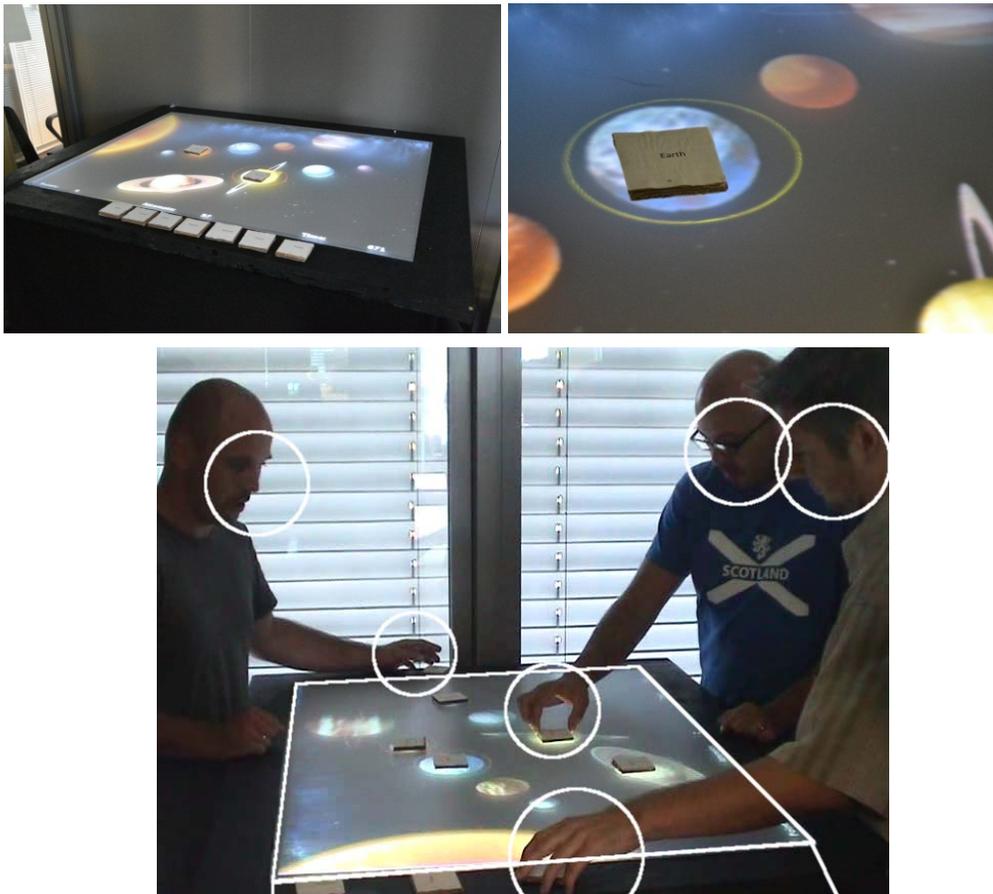


Figure 1. The tabletop provides a shared space where gazes, body postures, gestures, physical actions, interaction area and storage places meet.

An interesting outcome was that the performance on solving the test items was almost the same; only the group setting needed a slightly lower number of attempts. This was probably due to the fact that almost every group was discussing before they dropped the cards on the table. Furthermore, the individuals even rated the usability significantly higher than the subjects in the collaborative setting. Reasons for this effect need to be investigated by comparing the outcomes of the video analysis with the related answers of SUS.

Using tangible user interfaces for technology-based assessment – Advantages and challenges

A video analysis of the group situation provided a range of insights concerning the aspects of the physical space that supported collaborative problem solving on a TUI (Maquil & Ras, 2012). Using the CLM framework (Ishii, 2008), the different mechanisms of collaborative learning have been extracted and the corresponding physical aspects identified. The results revealed that the physical objects allowed users to perform a variety of actions, reaching beyond direct control of the system, for instance, coordination of next steps. A high shareability of the space was provided due to the simultaneous visibility of actions on the projection, the space between participants, and the storing place of the objects. Finally, we identified the need for non-responsive spaces, i.e., spaces where no input to the system is provided and that we used to demonstrate suggestions, exchange ideas, and set a common focus.

Simulation item

In a second prototype, we implemented a simulation task. The aim for the users was to explore and understand the relation of external parameters on the production of electricity of a windmill. In contrast to the previous application, this task can assess complex problem solving and reasoning skills, i.e., HOTS. But again, the goal was to observe the interaction between the user and system, and not to develop a perfect assessment model and method, which is of interest in the near future.

Using physical objects, users can change parameters, such as wind speed, number of wheels, and height of the windmill (Figure 2). Each of the objects represents one of the parameters; the value is increased or decreased through rotating it. The output variables (i.e., speed and energy produced) are represented through to additional physical objects. Both output parameters and the look of the windmill changed real-time based on the manipulation of the input variables. Because all of these blocks can be moved freely on the table and exchanged, each participant gets a vote and hence collaboration and motivation is expected to be improved.

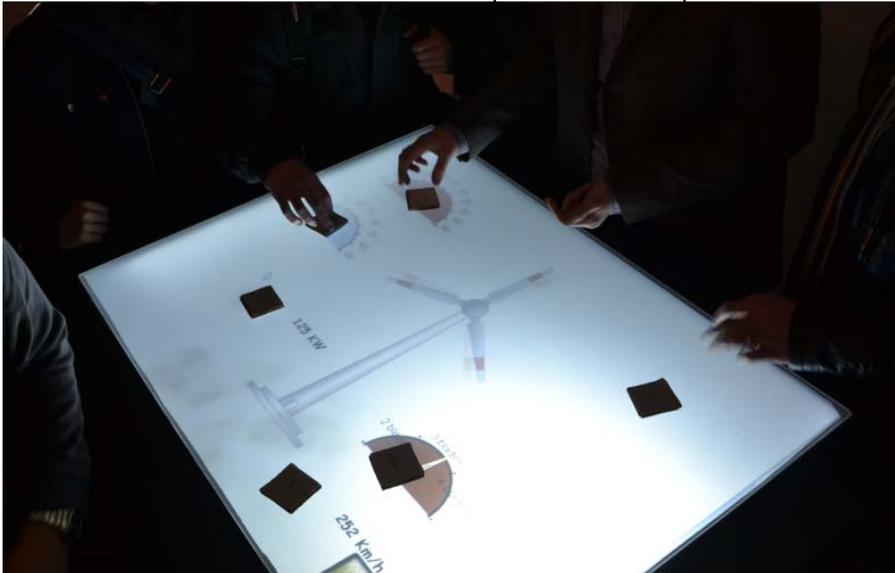


Figure 1. Simulation item "Windmill"

After exploration of the relations between the provided parameters, a multiple choice questionnaire that assesses the gained knowledge, was solved collaboratively by the test takers. The answers are selected by touching the answers on the table. The

Using tangible user interfaces for technology-based assessment – Advantages and challenges

simulation environment was not accessible anymore after moving forward to the questionnaire.

Although the system has not been evaluated yet, we were able to gather first insights based on the several demonstration sessions with students. The control of parameters through physical objects allows a flexible coordination of the solving strategies in the group. Control elements can be handed over to other users and accessed simultaneously. Further, we identified the need for clear visualisations of the parameters in order to understand the simulation environment. For instance, the projection should respect the position of the user around the table. In addition, we observed activities that did not occur directly on the tabletop, but still contributed to finding a solution. From the perspective of technology-based assessment, this means that when detecting the dynamics, we need to consider not only actions directly on the tabletop but also above the table (e.g., exchange of objects) and between participants. Further, changing parameters simultaneously, bears also risks regarding conclusions taken by the test takers when they act as individuals and not as group solving a problem collaboratively.

Conclusion

We agree with Binkley et al. who argue that technology-based assessment “has the potential to support educational innovation and development of 21st Century skills, such as complex problem solving, communication, team work, creativity and innovation (Binkley et al., 2012)”.

Both examples provided us with first insights on solving a simple and a complex item. Several spaces are used besides the interaction space on the table's surface to solve the items. Specific gestures with oral expression accompany the activities. Currently, logging the moves of tangibles has been realised, however, in order to assess, for example, self-regulatory actions or collaborative solving strategies, other spaces must be considered as well.

For the future, the table will allow the usage of learning traces and hence, support tracking of real-time problem solving items. This is especially interesting to get indicators for self-regulation behaviours. The self-regulatory component of HOTS is considered essential to develop higher order cognitive abilities (Leighton, 2011). Further, other researchers have found evidence that all human cognition, from simple *recall* to *evaluation* (i.e., see cognitive processes of (Anderson & Krathwohl, 2001)) and problem solving refers to both declarative knowledge (concepts), as well as procedural knowledge (knowledge of skills). The classification of lower or higher order thinking is based on the “organization and cohesion of networks of declarative and procedural knowledge structures (Leighton, 2011)”. This evidence must be considered for the design of TUIs for assessment purposes.

Currently, first prototypes are developed to use the TUI for modelling and innovation activities (i.e., modelling business process model and describing innovation ideas). Both domains will provide ideal settings for assessing HOTS in a collaborative, realistic setting.

When first assessment models and methods are available for this TUI, our tabletop device will be integrated in the TAO framework, which takes care of managing test items, test takers and groups, deploying test items, and of event tracing and results analysis (Ras et al., 2010).

Using tangible user interfaces for technology-based assessment – Advantages and challenges

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Using tangible user interfaces for technology-based assessment – Advantages and challenges

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