The Application of Tangible User Interfaces for Teaching and Learning in Higher Education

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3 authors:

Clifford De Raffaele
Middlesex University Malta

Serengul Smith
Middlesex University, UK

Orhan Gemikonakli
Middlesex University, UK

Chapter X

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Background

The proliferation of smartphone and tablet technology has seen consumers opting to move further away from the classical interaction notions of keyboards and mice, and closer towards physical interactions using their fingers (Ozkan & Gokalp-Yavuz, 2015). Furthering this drive, Tangible User Interfaces (TUI)s present an augmented interaction domain whereby real-life physical objects are used to interact and manipulate digital information (Ullmer, et al., 2005; Ullmer & Ishii, 2001). This inherent ability to interplay between the physical and digital domains makes TUI systems even more intuitive and thus has gathered interest for application in numerous domains.

Within teaching and learning, the notions of computer-based education have long been in the centre of technologically enhanced learning initiatives (Nasman & Cutler, 2013) which consistently underline the benefits of active learning and student engagement (Blasco-Arcas, et al., 2013; Mellecker, et al., 2013). The facilitation of computer usage to students coupled with additional benefits such as collaborative interaction has consequently made TUI systems an interesting and attractive technology to be employed in classrooms (Ras, et al., 2014). The ability to captivate student attention as well as provide physically engaging activities led to numerous studies investigating these benefits in young children whilst learning mathematical concepts (Price & Rogers, 2004), spatial reasoning (Rogers, et al., 2002) and musical impressions (Xambo, et al., 2013).

The proposal of this work lies at the confluence of the introduced streams. Whilst the majority of TUI research in literature target subjects covered by young children, more complex adaptations are restrained to industrial contexts in which simulation scenarios are made use of (Maher & Kim, 2006; Underkoffler &

Hiroshi, 1999). As a contrast to such TUI literature, this proposal considers the innovative adaption of TUI systems for the integration within Higher Educational Institutes (HEI)s. The contribution lies in investigating the suitability and relevance of such tangible systems in explaining complex abstract notions within university courses. Specifically, the proposed TUI system is evaluated on its appropriateness for aiding teaching and learning of threshold complex concepts in the disciplines of Science, Technology, Engineering and Mathematics (STEM).

The deployed implementation, highlighted within this research, assessed the effectiveness of the proposed technique with respect to traditional lecture-based delivery within the undergraduate programmes of Computer Science and Information Technology. The efficacy of concept delivery was hence assessed by using this modern technology in explaining the threshold concept of database normalisation. This compulsory topic within computer studies was principally chosen since it routinely presents a tough challenge for lecturers to deliver and students to grasp successfully within their university's studies.

The Practice

In light of the above requirement, and in tandem with the TUI and active learning literature, the system was designed so as to present students with the ability to interactively manipulate and visualise the presented concept. Specifically, students were enabled to interact with the various databases and table attributes during the normalisation sequential processes whilst visualising the underlying principles being adopted throughout each stage.

System Overview

To this end, the tangible table-top system was designed in line with the MCRpd interaction model (Ishii, 2008) and ReacTIVision framework (Kaltenbrunner & Bencina, 2007). The developed physical construction as illustrated in Fig 1, comprises of a wooden enclosure with a semi-transparent acrylic glass panel is placed on top. The table was designed at a height of 80cm and with a workable area of 1m x 0.7m. These dimensions were implemented to explicitly enable a collaborative approach whereby a number of users were allowed to view and comfortably interact together on the system. Inherently setup further provided a platform where teaching and learning can occur simultaneously both from a tutor instructive perspective as well as from an experimental learning approach by students.

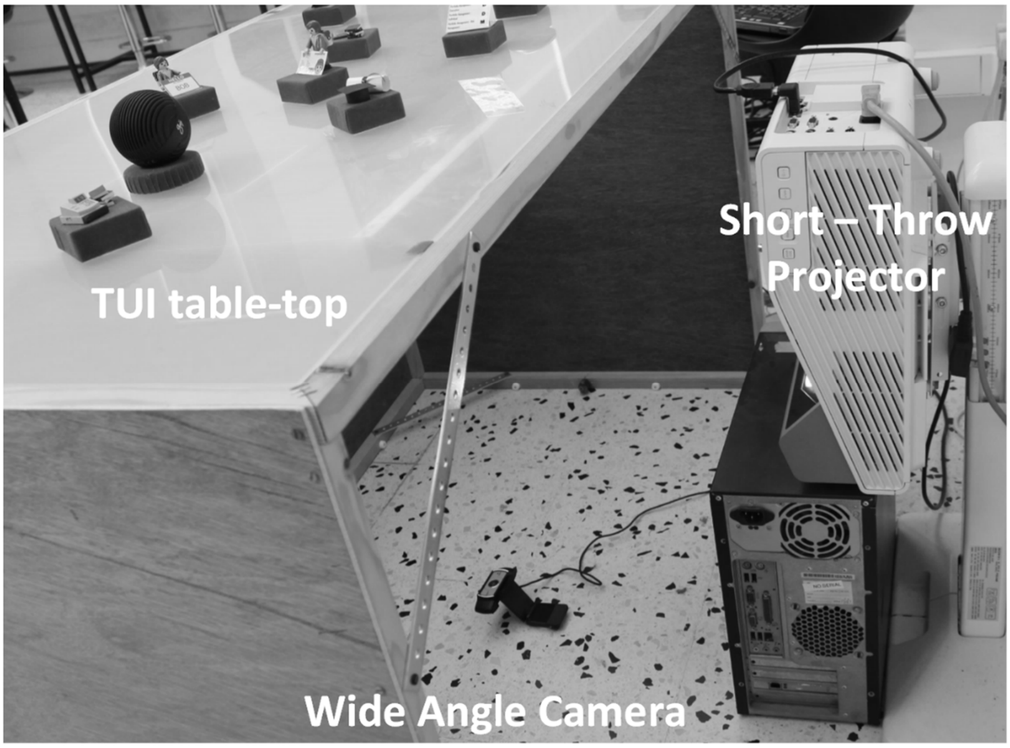

Figure 1: Hardware used for Interactive table-top setup

A wide angle camera was installed beneath the table to wirelessly monitor interactions and a short-throw projector used to illuminate the interactive surface with digital data. This enabled the TUI design to also provide perceptual coupling to the users, allowing students to visualise and interact on the same surface hence directly promoting system feedback. Intrinsically, this functionality aids to provide a consistent and concretise understanding of the system's state allowing peer students to comprehend better the highlighted concepts being interacted with.

The interactive engagement of students with the system was achieved via the manipulation of dedicated 3D objects. These physical components, shown in Figure 2, were aptly selected to represent concrete real-world models and thus embody the various attributes qualities of data fields used in the considered database. These physical objects were therefore sourced from familiar student environments so as to represent an inherent understanding on their meaning and association, thus allowing students to focus on the normalisation task without needing to decode or shift attention towards the utilising the computer interface.

In order to aid further the assimilation of data, a university programme transcript was considered as the database scenario for engaging with in normalisation. Apart from reflecting commonly used attributes and inherently familiar data for undergraduate students, this domain further enabled the creation of evermore relatable tangible devices as described for Figures 2a-2d. This strong embodied cognition allowed for a more engaging interaction with the abstracted data fields as well as an augmented focus on interacting with the described normalisation processes.

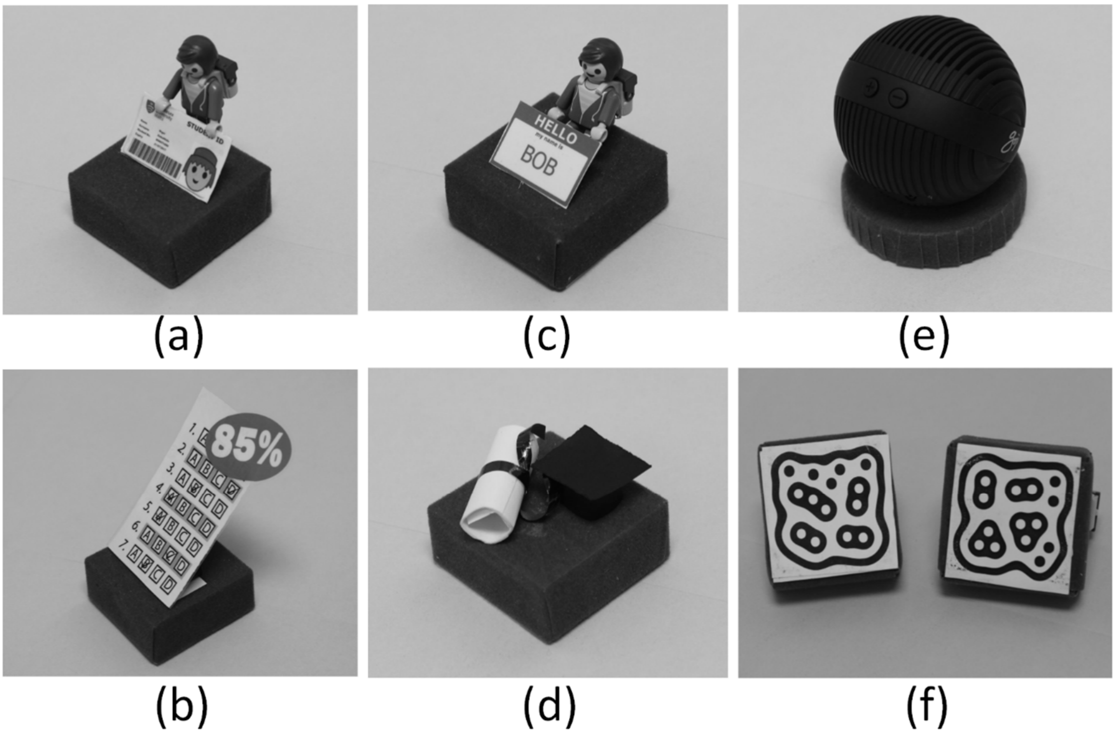

Figure 2: Tangible objects representing the attribute fields of selected database
a) Student ID - Small figurine holding university identification card
b) Grade Achieved – Corrected multiple choice questionnaire with score
c) Student Name – Small figurine holding nametag
d) Degree Programme – Miniature graduation cap and certificate scroll
e) Setup Controller – Rotatable speaker with Bluetooth® connectivity
f) Tangible objects underside – ReacTIVision 'amoeba' fiducial symbols

As shown in Figure 2, each object was mounted on a wooden platform (6cm x 6cm) onto which a reacTIVision 'amoeba' fiducial was attached (Kaltenbrunner & Bencina, 2007) as captured in Figure 2f. The size of tangible devices was determined to enhance the usability and comfortable interaction with devices by students, whilst occupying minimal spatial area on the interface so that to allow for virtual projected data. The reacTIVision 'amoeba' symbols, specifically designed with inter-symbol orthogonality, further assisted the system camera to locate and identify each object on the interactive surface. This allowed for multiple objects to be used in conjunction, whilst providing the user with the ability to spatially drag the components on different areas of the screen.

The other aspect of the system, which was undertaken subsequent to the physical construction described, was the design and development of the software component. The latter was responsible for embedding the necessary concepts of database normalisation which the students would be subject to. Furthermore, the digital element interlaced within the TUI system dynamic data on the tangible objects, hence providing students the ability to augment their understanding of the manipulated objects.

The Graphical User Interface (GUI) of the system was developed using the Unity platform in the C# programming language. As portrayed in several screenshots within Figure 3, the projected digital interface makes use of a number of graphical components to provide the student with the necessary ability to undertake the different conceptual alternations at each stage of normalisation technique. Different GUI's and visualisation cues are thus employed, to aid students in understanding their current stage-related task as well as receive visual feedback on their interactions. The digital interface, as captured in Figures 3a-d makes use of graphical placeholders to assist students in understanding the physical movements expected at each normalisation stage. These are accompanied by virtual messages that instruct the student on the TUI operation and database normalisation related tasks. Hence, two types of messages are employed, with static instructions relating mostly to the current normalisation stage aspects, whilst dynamically changing messages change continuously in relation to the operations done by the user.

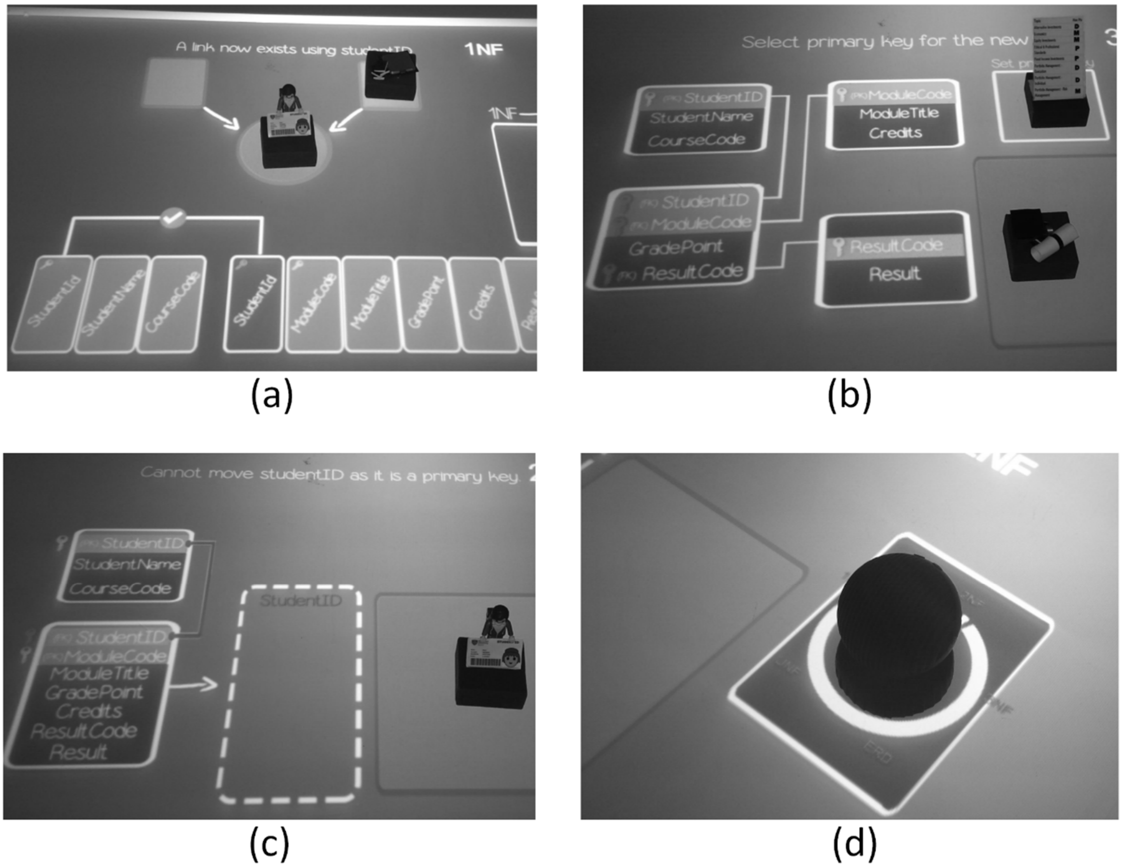

Figure 3: GUI screenshots of proposed TUI system
a-c) Different instructions provided to students in order to progress through the processes and concepts of normalisation with various placeholders and visual cues dynamically displayed
d) Setup Controller – Projected information prompting the user to rotate the tangible object so as to change normalisation stages adjacently displayed

The illustrated GUIs in Figure 3 automatically changes the component colour scheme (from orange to purple) throughout the procedural execution, allowing the user to appreciate when a tangible object has been correctly placed and/or identified by the system. Furthermore a number of dynamic links, arrows and messages as illustrated in Figures 3a-c are presented by the system indicating to the users what is expected and even visualising some of the underlying processes occurring.

Additionally, the proposed TUI system makes use of a further feedback channel; audio. This is integrated within the 'setup controller' tangible devices, shown in Figure 2e and Figure 3d. This device is able to provide additional information and instructions to students via the internal speaker and voice messages are played telling the user details on the respective stages of the normalisation system. Incorporating and carefully integrating these interactive approaches, hence provides the TUI system the ability to gain a substantial cognitive and social advantage for students. It also allows a more engaging teaching and learning activity whilst allowing students to explore, assimilate and express their knowledge on the subject.

Teaching and Learning Session

The proposed TUI system was implemented at Middlesex University Malta within the undergraduate degree programmes of Computer Science and Information Technology. The identified normalisation concept, is present as a compulsory scheduled topic within the databases course, and is traditionally perceived as a particularly difficult topic to teach and learn. To this end, once the TUI system was assembled, programmed and implemented as described in the previous section, the innovative practice was able to integrate naturally within the academic curriculum of the identified course.

The session was directly scheduled to coincide with the formal introduction to the main threshold concept of normalisation within the databases course. Sixteen (16) first year students, who were all enrolled for this course, were selected based on a convenience sampling technique. To establish an a-priori baseline of student knowledge before the evaluation session, a multiple choice questionnaire was provided to students so as to test their former knowledge on the subject. Following this test, the class was randomly split such that seven (7) students would serve as a control group, whilst the remaining nine (9) students formed the experimental group. The former would undergo a traditional tuition session whereby normalisation was explained and exemplified using a traditional lecturing approach using projected slides and whiteboard setup. The experimental group on the other-hand undertook an introduction of normalisation concepts using the proposed TUI system by the same lecturer as illustrated in Figure 4.

Figure 4: Evaluation session of the proposed TUI system for teaching and learning database normalisation concepts

Outcome

The teaching and learning effectiveness of the proposed TUI system was evaluated using both summative and formative techniques. Diverse examinations were designed to audit the ability of students to answer both theoretical and practical sessions on the topic whilst a number of probing questions were posed to derive a more formative assessment of the system.

Summative Appraisal

Following the teaching sessions on database normalisation using either the TUI framework or traditional lecturing, both cohorts of participants were subjected to a second different multiple choice questionnaire re-examining their acquired knowledge on the identical concepts covered within either session. These post-test results have been compiled for both teaching methodologies and illustrated in Figure 5a adjacent to the respective pre-test scores achieved by the same students

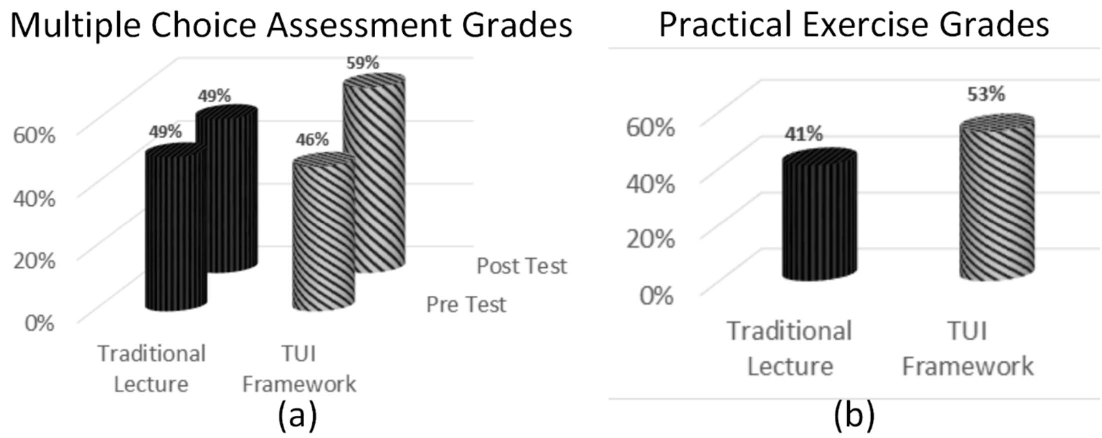

Figure 5: Comparative analysis of grades achieved in:
a) Theoretical multiple choice assessment
b) Practical case-based exercise

As can be derived from the comparative analysis of the results in Figure 5a, students being exposed to the concept of database normalisation using the proposed TUI framework were able to achieve a grade improvement of 13% (SD 22.3) was achieved with respect to their traditional lecture counterparts at a 90% confidence interval. Another assessment provided to students following their respective learning session was aimed to assess their ability to employ the learnt concept during a practical session in normalising a database scenario. The results, represented in Figure 5b, highlight that the same improvement was replicated with respect to understanding and learning the abstract concept using a TUI framework.

Formative Appraisal

The positive achievement registered from the summative assessment was further collaborated via formative feedback derived from students. Participants in the TUI demonstration highlighted that the interactive aspect of the system provided an opportunity to interact and experiment with the various stages of normalizing data which was enjoyable. Furthermore, it was commonly noted that the visualization aspect of the virtual data being manipulated, allowed for easier understanding of the abstract concepts at each normalization stage. This was further complimented by visual and audio feedback which allowed students to understand better the task being undertaken.

From a lecturing perspective, the system furthered the ability to explain and illustrate to students the different aspects of database normalisation. Moreover, the TUI system allowed for an interactive session in which students were able to express their knowledge and collaborate together in deriving the correct task processes. This inherently provided the ability to assess the individual understanding of students and deliver formative feedback instantly on the subject.

Moving Forward

The TUI framework presented within this work was developed following the recognised necessity at Middlesex University Malta to aid the teaching and learning of database normalisation within its undergraduate programmes. The proposed framework was developed using TUI based on the strong knowledge of the visualisation and interaction capabilities afforded by this novel technology.

In light of the successful outcomes obtained by the described implementation and the positive feedback received from learners and the faculty, the proposed TUI framework is currently being investigated for further application. At a system level, a number of modifications have been conceived on the tangible and digital aspects of the framework which will further capitalise on the inherent benefits afforded from the TUI system as well as add additional functionalities. On a more conceptual aspect, the adaptation of the TUI system will be analysed for its effectiveness to provide a similar benefit in teaching and learning diverse abstract concepts within the STEM disciplines offered at university. This will ultimately enable HEIs to utilise TUI systems as a value adding technology in a wide range of aspects and stem a range of creative and innovative uses of technology enhanced learning.

About the Authors

Clifford De Raffaele is Senior Lecturer and Academic Programme Coordinator in the field of Computer Science at the school of Science and Technology in Middlesex University Malta. He can be contacted at this email: c.deraffaele@ieee.org

Serengul Smith is Associate Professor and Director of Programmes of Computer Science at the school of Science and Technology at Middlesex University in London. She can be contacted at this e-mail: s.smith@mdx.ac.uk

Orhan Gemikonakli is Professor of Telecommunications at Middlesex University in London. He can be contacted at this e-mail: o.gemikonakli@mdx.ac.uk

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