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TANGIBLE USER INTERFACES FOR TEACHING BUILDING PHYSICS

Towards continuous designing in education

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Abstract. This paper follows our evaluation and research into designing tangible physical media for the purposes of teaching building physics to undergraduate architecture students. These media interfaces make use of a virtual environment to promote an understanding of the cycles, which govern architectural and urban projects (for example solar studies, the flow of heat, air and water). This project aims to create an ecology of devices which can be used by students to self-direct themselves and harbour critical making in their research methods (with the explicit intent of dissolving the barrier between design and research). The basic premise of this research, is that in light of growing student numbers, more students lacking confidence in numeracy skills as well as the desire to have self-directed or group-directed learning, tangible media has a promising role to play. There are several reasons for this optimism. The first is that a better sense of intuition is gained from an interactive model over reading notes from a lecture or textbook. The second is that tangible media engages in other modes of learning, being valuable to students who have an aptitude for kinesthetic and spatial learning over text-dominant learning.

Keywords. Pedagogy; tangible user interfaces; augmented reality; internet of things; designing for teaching.

1. Introduction

Tangible User Interfaces (TUIs) were popularised in research by Ishii and Ullmer (1997) who present them as a way of coupling digital information to physical objects. Several researchers have written about the benefits of tangible user interfaces in pedagogy. Marshall (2007) describes their use as allowing for expressive and exploratory activities. Shaer et al (2010) present a general framework for the use of tangible interfaces in education. Fishkin (2004) presents a framework for analysing TUIs. It is believed that incorporating TUIs into teaching can benefit students who have an aptitude for kinaesthetic, visual or haptic learning over symbolic manipulation as well as those who have English as a second language (due to the reduction in reading and increase in interactive learning). Park (2001) presents studies showing that kinaesthetic and tangible learning is significantly preferred by children of seven different ethnic groups with a significant preference also shown by female students.

As a measure towards balancing our ever-increasing demands on students to learning, new fields (such as life-cycle assessments, energy analysis, deconstruction, BIM, simulation tools) we are looking towards supplementing the traditional class with new interactive media with a focus on intuitive as the goal. At the same time, however, it is important to keep in mind that this is a Tertiary course and therefore the content should be advanced enough to match. The interactive models used in places such as museums designed largely for children) are therefore not insufficient to achieve this goal. One way to open a path towards enriching the content of a TUI is to incorporate augmented reality. Augmented reality is proposed as a bridging tool to allow for an increase in the complexity and flexibility of what can be talk within a single module.

The surveys gathered indicate that students are enthusiastic for other modes of lesson delivery. We have sufficient cause to believe that interactive learning methods will be well received.

When embracing this mode of learning, educators are left with an interesting challenge – the designing of these tangible artefacts.

Design as a mode of academic research or pedagogical tool is still to receive recognition in the broader scope of academia. The status of design as an academic pursuit is examined by Downton (2003). In this research we look at following through with design as a mode of pedagogical delivery and strategies that can be used by educators to frame these as design projects.

2. A proposal for interactive media for education

> "Play is the answer to how anything new comes about." - Jean Piaget

Our key proposition in this research is that the use of mixed media – note that this is not limited to audio and video – can lead to an improvement in student engagement as well as experimentation. Our case study for this proposition, is a second year unit, part of the Bachelor of Architecture degree which is dedicated to teaching building physics and principles of sustainable (energy efficient) design. The proposed course will keep many traditional elements (lectures, workshops, an online Blackboard and assessments) but will supplement them with a series of experimental environments, where students use tangible media to interactively learn about the key concepts of each weekly lecture as well as experiment with these media in order to gain an intuitive understanding before more formal methods of simulation are performed.

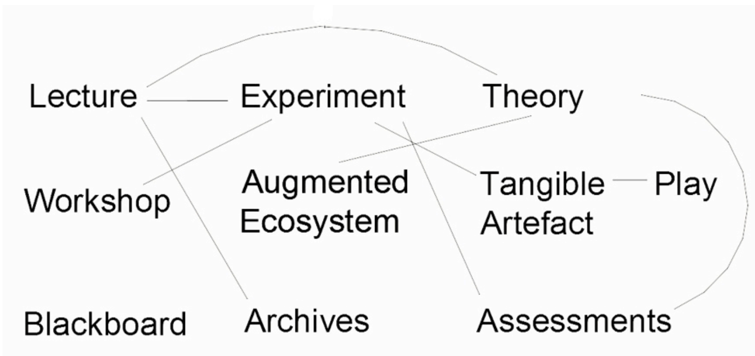

Figure 1. Elements of Each Module

2.1. GORDON PASK AND CONVERSATION THEORY

The great pioneer in the realm of using tangible media and interactive learning devices is the British cybernetician Gordon Pask. Pask is most famous for his development of Conversation Theory as well as interactive models such as ThoughtSticker and Saki (Haque, 2007). As with Piaget's constructivism, Pask shared the view that knowledge is constructed. Central to Learning Theory are models of analogy (relationships between elements) and entailment meshes which record the knowledge gained through interactions. Interactions play a big role in Pask's methods and are formally recorded elements of the system. Interactions between 'actors' (an actor can be a person or a machine) form the basis of a conversation. Therefore, knowledge (knowing) is never reduced in an abstract way to either facts or relationships between elements, but required kinetic action and energy. Pask is of particular interest in the teaching of design as rote learning is largely irrelevant to learning design concepts.

2.2. COMPLEXITY AND SCALABILITY

Tangible interfaces are now very popular in learning centres such as museums and exhibitions. The two areas which need development when being adopted in tertiary education are their scalability and the level of complexity that they can be used to teach. With complexity, there has to be a layering of concepts over other concepts, gradually building a high level understanding of ideas to the standard of a tertiary education. For this reason, we look at tangible media as augmenting the class and being a stepping-stone towards more complex simulation. Regarding scalability, there has to be room for experimentation outside of the bounds of the class and one method that is being explored, is in encouraging students to design elements that can interact with tangible devices. The microcontroller platform Arduino has been incredibly successful in this regard, they created an ecosystem that fostered the Maker movement, people adapting and sharing designs.

3. Analysis of class and other local conditions

As part of this study, a census was taken with the class that is to participate in this course (in early 2016), in the year prior to the study. A later survey and focus groups will take place at the conclusion of the class in 2016.

3.1. SURVEY

The class was found to be typical (compared to previous years) in the age distribution, the level of prior experience and the number of students with English as a second language. The majority of students are under 21 years and most recorded no experience within the architectural industry. 57 % of students agreed with the statement that they were confident in their numeracy skills. 73% agree with the idea that lecturers should use physical and computer models in their teaching with 71% also saying that experimentation was an important aspect of learning. 65 % strongly agreed with wanting a hand-on approach over a theoretical approach.

3.2. USEFULNESS

It is encouraged within teaching culture of the participating university, to relate the content of lectures directly to the assignments of the course as well as criteria (and skills) that are considered necessary for employment in practice. This has met with mixed feelings from academic staff especially as architecture is both a discipline and a profession. There is an intentional aim in this class to find a balance between theory and practice.

3.3. OBJECTIVES OF THE COURSE

This course will be the students' first encounter with simulation and energy analysis, it is therefore particularly important in regard to their education of sustainability in architecture. Buildings consume approximately 40% of the world's energy and resources. This unit therefore has a special place in the overall strategy of increasing knowledge regarding energy efficiency and sustainable design strategies. As the majority of students are in the early stages of their studies, the importance of inclusiveness is also seen as a priority. Tangible models can be used collectively and can therefore assist in learning through collaboration and discussion. It is also important to recognize that there is a need for teaching methods that cater for those students who are better suited for kinaesthetic, tangible and interactive learning. Many researchers in education promote using inductive modes of teaching – to ask students to make predictions and form hypotheses before examining a case. Using tangible models support this form of learning and there is the potential to turn students to active participants. An increased use of models and other visual and interactive media would support students with English as a second language compared to modes of learning which text-heavy. The design and building of each tangible user interface also presents the opportunity to design and distil the key lessons into each model, which would structure each lecture and workshop.

3.4. TANGIBLE USER INTERFACES AND MIXED MEDIA

Ishii and Ullmer (1997) described TUIs as devices that connect the physical and virtual worlds. A distinction is generally drawn between multi-touch screen devices, which although have a physical input, are largely based in the virtual world. Tangible devices have a greater emphasis on kinetics and utilising these physical forces as part of their appeal. Augmented reality is the overlay of virtual data in the physical world (devices used by be projectors, headsets, sound or physical actuators). Schneider et al (2011) showed that tangible devices scored higher than multi-touch devices when students were later examined on concepts taught. Our interest in tangible interfaces and media stem from both the desire to increase engagement but also that each lesson has to be compressed to its core essence, which is encapsulated in the physical device. The TUI becomes the core around which the rest of the lesson and the lecture can be situated. Introducing an element where students can adapt and 'hack' is also seen as ways to improve engagement.

4. Case studies

4.1. AN INTERFACE FOR LEARNING SOLAR ANALYSIS

The first of our built interfaces is allows for the analysis of solar data. The critical piece of information for design students to understand, out of this module, is way in which light enters the structure and how this changes over the time period of a year. Additions to this include the design of light shelves, blinds, and solar tubes.

4.1.1. Observations

Comment from teacher (paraphrased): “We’re tired of seeing sun paths drawn in plans, as if this concludes all that is needed to know about the.” Solar studies have a tendency to be an area where student perform in an automated way, citing sun path diagrams or false colour solar images, presenting data with no obvious analysis to what impact or opportunities this presents.

4.1.2. Key concepts

Table 1. Elements of Solar Study Module.

Key Theme	That optimizing the different shapes in a fenestration system can have an impact on solar gain as well as the lit environment.
Other Themes	The changing of the sun angle throughout the year and how it is desirable to cut off summer sun while allowing in winter sun (depending on location).
Summary	The tangible device takes the form of a generic building section where a slider can control the depth of the solar shade. This can be replaced with another fenestration component.
Challenges	While lighting can be understood as a moment in time, thermal analysis takes place over the course of (in most cases) a year. There is also the challenge of balancing qualitative and quantitative data – the qualities of light vs the metrics of solar gain.
Augmented data	The augmented reality can map the sun path in an animated form as well as graphs showing the yearly gain. This can be dynamically linked to the state of the physical mode.
Making Opportunities	Student can fabricate different shading mechanisms.

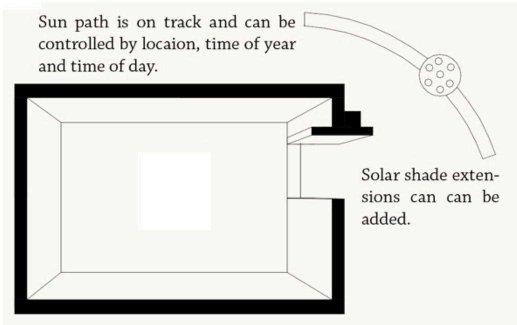

Figure 2. TUI for teaching Solar Studies.

4.2. AN INTERFACE FOR TEACHING THERMAL TRANSFER

One of the challenges of passive design comes in teaching concepts surrounding psychrometry – relating air, water and temperature together. One way this can be dealt with is in making visible the quality of temperature.

4.2.1. Observations

There are a lot of units used in the study of psychrometry (Absolute Humidity, Relative Humidity, Dew Point, Dry Bulb Temperature, Web Bulb Temperature). What is not intuitive is that temperature (regarding our perception of it) cannot be measured simply on a linear scale from cold to hot – the quantity of water in the atmosphere changes our ability to lose heat through sweating.

4.2.2. Key concepts

This particular module is meant to be used during a lecture, where an experiment with 4 glasses of water is set up and the amount of water that condensates around them are measured. Throughout the lecture, the device will take snapshots of data around it, so that at the end of the lecture, the process can be seen, in a sped up video.

Table 2. Elements of Psychrometry Module.

Key Theme	That the hotter air is, the more water it can hold.
Other Themes	Conversely, air can be cooled by adding more water to it. Evaporative cooling is an example of a passive form of cooling.
Summary	The tangible environment takes the form of an array of thermal cameras that can give the temperature of objects through infrared measurements. These show false colour image with temperature distributions.
Challenges	The biggest challenge is the large number of terms introduced in this module. As with the previous module, what is being dealt with are physical and material quantities over time periods, which when formalized take the form of differential equations which present a challenge for many students.
Augmented data	The augmented map can show a fluid dynamics simulation overlaid on the objects that are placed. Particle dynamics can be used to visualize the amount of water in the air as a concentration of particles and their excitement as this temperature.
Making Opportunities	Student can fabricate (playful) mechanisms that make use of the evaporation and condensation of water.

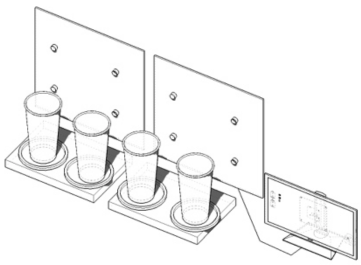

Figure 3. Psychrometry Module.

4.3. AN INTERFACE FOR TEACHING THERMAL TRANSFER

The last case study TUI that will be discussed is one dedicated to looking at thermal transfer. As with the other modules, the challenge here is to observe something takes place over a time period and in three spatial dimensions. As with the previous module there are a lot of terms involved (conductivity, specific heat, density, thermal mass).

4.3.1. Observations

The relationship between surface area and volume is not always obvious in its relationship to heat transfer. Other areas which are important to learn are the effects of insulation and thermal mass – our intuition may give us incorrect information – such as how cold water *feels* compared to measured (hence the need to understand specific heat as a material property).

4.3.2. Key concepts

Table 2. Elements of Heat Transfer Module.

Key Theme	Thermal lag can be used to great advantage in passive design
Other Themes	Water and Groundmasses can be used as sinks. The transfer of heat is dependent on surface area. Thermal breaks and their impact can also be examined in this particular experiment set.
Summary	This TUI is similar to the last in that it monitors heat, the key difference is that heat can be provided through a source such as a heat gun or radiator. Thermocouples on the other side monitor the heat travelled through the materials placed between two sliders.
Challenges	The challenge in learning mechanisms of heat transfer come in multiple forms – the changing of a buildings mode from gaining heat to needing heat, the relationship between geometry and heat transfer and the nature of composite materials. The effects of thermal mass take place over long periods of time (the duration of a day) so this required recording, if real data is to be used.
Augmented data	The augmented data shown in this module are the temperature distribution and record this over a period of data. It can also overlay false colour images onto the objects using projection.
Making Opportunities	Students can compose new material sets by sliding layers together. This includes altering composite materials to different shapes such as honeycombing cardboard or using reflective materials within the construction.

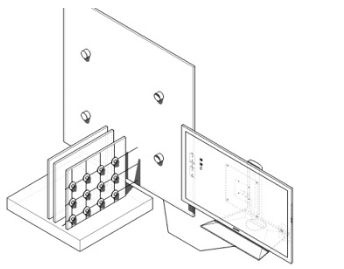

Figure 4. Thermal transfer TUI

5. Conclusion

The breadth of knowledge demanded on students of architecture has steadily increased over the last few decades. Educators do not always use all the resources available when teaching and the idea of using design as a method of producing teaching resources has not received as much attention as other modes. Designing resources gives us the opportunity to revisit teaching from the point of view of learners and think about the experience holistically. One of the key difficulties is in finding a balance between lessons that are intuitive while still remaining complex enough to be at the level of tertiary education.

The solution proposed is that tangible devices can be used to create an interactive ecosystem that has data augmented. Augmentation can be used to allow for more complex ideas while the tangible model distils the essence of the lesson and has the greatest benefit to an intuitive understanding. Having students design components within this system forms a step towards interactive learning and experimenting.

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