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Published in:
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Piloting Mixed Reality in ICT Networking to Visualize Complex Theoretical Multi-Step Problems

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This paper presents insights from the implementation of a mixed reality intervention using 3d printed physical objects and a mobile augmented reality application in an ICT networking classroom. The intervention aims to assist student understanding of complex theoretical multi-step problems without a corresponding real world physical analog model. This is important because these concepts are difficult to conceptualise without a corresponding mental model. The simulation works by using physical models to represent networking equipment and allows learners to build a network that can then be simulated using a mobile app to observe underlying packet traversal and routing theory between the different devices as data travels from the source to the destination. Outcomes from usability testing show great student interest in the intervention and a feeling that it helped with clarity, but also demonstrated the need to scaffold the use of the intervention for students rather than providing a freeform experience in the classroom.

Keywords: mixed reality, visualization, networking, augmented reality, 3d printing, ICT

Introduction

The term 'digital native' is widely considered as having been debunked over recent years (Bennett, 2016). Yet, despite this, it's obvious to those in the research community that the continued use of the term indicates that there is some perceived difference in the way that the 21st century student learns (regardless of their age or generation). Indeed, in recent years, there has been a slate of research into the way that today's generation of students use technology (Corrin, Bennett, & Lockyer, 2013), suggesting that as educators, we are increasingly surrounded by a new breed of individual that tackles problems in new and different ways. As an example, Jones, et al. (2009), points out that students today are more oriented to visual media than previous generations and they prefer to learn visually by doing rather than by telling or reading, through participatory, interactive, sensory rich, experimental activities (either physical or virtual) and opportunities for input.

With this in mind, students studying Information Communication Technology (ICT), and especially those that have chosen to study computer networking, could reasonably be expected to be the epitome of the *Digital Native*. Yet despite this new breed of student with a preference for learning visually, the representation of theoretical concepts without a corresponding real world physical analog model and the simulation of complex mental models in the classroom is still a developing issue. In the teaching and learning of computer networking, this has been investigated with the development of virtual environments for modeling the processes (Dobrilovic, Jevtic & Odadzic 2013; Powell et al., 2007) and simplistic video based visualizations (https://youtu.be/-6UokuM6oY). However, networking models are complex to set up with software and require extensive reworking of existing network facilities. Abstract visualizations also don't capture the complexity of the logical models, specifically the complexity and multi-step nature of the traversal of packets along the layers of the fundamental OSI-TCP/IP packet networking model. There is also evidence to suggest that presenting computer science concepts using a physical analogue can be useful (Bell, 2014).

This paper therefore presents results of a pilot study and qualitative usability testing that examines the use of mixed reality, specifically represented using physical 3d printed models and a mobile augmented reality (AR) application, as a tool to help students with these concepts. The specific aim of the paper is to present a method, supported by usability results, to assist students in theoretical model understanding and applied use.

Pilot Study Rationale

Areas as diverse as architecture, medical anatomy, chemistry, geography, and media/game design all benefit from the use of visualization (Freitas & Neumann, 2009). Work by Mayer (2014) also shows that visualization can be used in education as a positive learning support tool. This work also builds on a previous concise paper by the authors in computer networking looking at network building and the TCP/IP model (Cowling & Birt, 2015) presented at a previous ascilite conference, which studied the application of mixed reality visualization and emerging technologies on a range of teaching and classroom contexts.

Building out from this work, this study looks at how mixed reality, specifically 3d printing and AR, can be used to help students to understand theoretical multi-step complex problems, especially those without a real-world analogue. This in particular looks to provide the scaffolding indicated by Tasker & Dalton (2008), who argue that a mental gap is created for students through the lack of physical model, providing a disconnect between their visual mental model and their understanding of the concepts. It also supports work by Williamson et al. (2012), who argue that visualizations can assist with this gap by providing students with an appropriate mental model that they can use to understand the *hidden* concepts, as well as the work of Paas & Sweller (2014), who argue that *kinesthetic tools can be used to better form mental models*.

In this project, mixed reality, through both an AR app and physical models, will be used to visualise how data travels through various network components, aiming to deliver an improved pedagogy to teach networking concepts to 21st century students from varied cultures.

Experimental Design

Flowing on from the background research, an intervention was developed to help students conceptualise the TCP/IP model through a process of building and simulating packet routing along a computer network. The intervention was developed specifically to be a two-step process for students, with a physical component provided first to allow students to build a network, as per the work by Bell (2014), followed by an app that could be used to simulate network operations over the physical network that was built by students (see Figure 1).

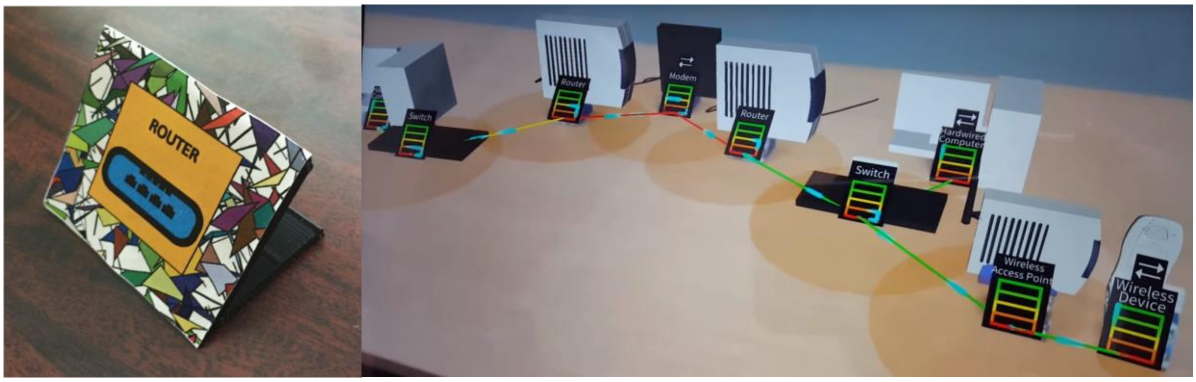

Figure 1: An example 3d printed marker of a router, and augmented simulation view visualizing multiple markers and packet flow (see https://youtu.be/0pHJWjG4-aQ for simulation example)

For the physical component, the intervention uses 3d printed stands overlaid with an image target marker. The use of these stands makes it possible for students to build a network by moving physical pieces around, shuffling them back and forth to create the configuration desired and adding/removing pieces as required for different network designs. This direct linking of object making to computer modeling changes the relationship of the learner to the making of the object and subsequent use, enabling a haptic feedback loop for learners (Paas & Sweller, 2014).

Once the physical network has been built using the physical objects, students can then simulate a working network using the AR app loaded onto a tablet or smartphone. This app allows students to see how packets flow through the network and to simulate packet flow between specific end devices. Specifically, the intervention scans the image target markers via the mobile device camera using the Vuforia AR plug-in (www.vuforia.com) for simulation development in Unity3d (www.unity3d.com).

The overall purpose of the intervention is to provide students with a mixed reality approach to the building of networks, that uses a two-step process to allow students to benefit from having physical representations of the traditionally theoretical TCP/IP model that they can lay out as components of a network. They can then simulate this network using the app in a way that would not be possible using just the physical components. Using the physical components as a tool, the app will allow students to identify each component and use them to construct a custom network on the device based on the placement of the components in the field by students. Most importantly, once the network is in the mobile device, students will be able to simulate network packet routing and visualize the complex multi-step process of the TCP/IP model. Students will also have the ability to rearrange 3d objects to understand how changes in infrastructure affect the performance of the network, providing them with a mental model for this complex process, in line with Tasker & Dalton (2008).

Research Method

The theoretical framework underpinning this work will be action research (Kemmis, 2006), with each *loop* in the research being conducted within a single term and with a different cohort of students. As a paradigm, action research is appropriate because the researchers are also practitioners in the classroom, leading to a situation where the change can be implement in the real classroom whilst simultaneously being researched to determine its effectiveness. The interactive inquiry process involved in action research also suits the objectives of the project in relation to teaching practice, student learning, and visualization of complex multi-step processes.

As the first loop of the action research spiral, it was determined that a usability test should be conducted with students, providing data that would be useful in subsequent trials relating to learning outcomes, as well as allowing the technical aspects of the tool to be tested. With this in mind, an undergraduate class at the lead authors institution was recruited to perform the testing. Specifically, a small class of six students was selected for this initial usability (insight) test in line with common first phase software usability testing practice (Nielsen, 2012), so that it would be possible for a single research assistant to interact with these students in depth and collect rich feedback on their use of the tool. Participants were given a primer on the skills to be covered, and then completed a survey on the applicability of the traditional method of teaching. They were then given access to the tool before being completing a survey on the use of the mixed reality intervention.

To facilitate data collection, categories were developed for both the observation of students as well as the data collection for surveys. Specifically, both the students and the research assistant were asked to assess the tools used for the intervention on measures of usability (Table 1), based on previous work conducted by one of the authors (Birt & Hovorka, 2014). Details of the results of this data collection are included below.

Results

As noted above, the usability testing of the intervention was conducted by an independent research assistant to provide a neutral third party to introduce the intervention to students. The results of the quantitative survey with students are presented in Table 1, with each item ranked on a Likert scale of 0 to 5, where 0 is not relevant and 5 is very relevant. The research assistant also took notes observing the students using the intervention that can be reported on. A summary of this qualitative data in support of the quantitative scores is also presented below.

Table 1: Measures of Usability for the Networking Mixed Reality Intervention

Question	Average		StdDev	
	2D	**AR**	**2D**	**AR**
1. **Accessibility**: Visualisation is readily accessible	3.33	4.67	1.25	0.52
2. **Learnability**: Visualisation is easy to learn	2.67	4.00	1.25	1.26
3. **Efficiency**: Visualisation is efficient to use	3.50	2.83	1.26	1.60
4. **Satisfaction**: Visualisation provides satisfaction (confidence) of the design	4.00	3.83	0.82	1.33
5. **Memorability**: Visualisation is "sticky" and memorable to support the design	3.17	5.00	1.21	0.00
6. **Error Free**: Visualisation is free from visual and design errors	3.33	2.67	1.11	2.07
7. **Manipulability**: Visualisation can be manipulated: rotation, time, lighting etc	3.33	4.17	1.70	0.98
8. **Navigability**: Visualisation allows the user to change their viewpoint	2.00	4.33	1.15	1.21
9. **Visibility**: Visualisation provides clear detail to interpret the design	3.33	4.33	1.25	0.82
10. **Real world**: Visualisation provides a match to the real world	3.17	4.17	1.21	0.98
11. **Communication**: Visualisation aids stakeholder design communication	3.50	2.83	1.26	1.33
12. **Creativity**: Visualisation allows the user to be creative with the design	3.50	4.50	1.26	0.55
13. **Engaging**: Visualisation is meaningful	4.00	4.33	0.82	0.82
14: **Motivating**: Visualisation provides acceptance of the design	3.33	4.00	2.05	1.10

The first significant finding from the data and observations is that students were very interesting in diving in and trying this intervention, with a high score for accessibility and the research assistant reporting that *students asked if they could download [the app] to their own device and whether the markers would work on multiple devices at the same time.* Students were also very interested in the augmented reality aspects of the intervention, with a high score for learnability and the research assistant reporting *students downloaded the app straight away and used it with single markers* rather than using multiple markers to build a network first and then visualising it. This reported result was a surprise to the researchers, with the intervention having been developed as a two stage process for students, with the network building anticipated to be conducted first before the simulation was activated.

The results do show that this urgency created subsequent concern with using the app, with low scores for error free and with the research assistant also reporting that students had difficulty with the simulation once they had it running, *building large networks and then having difficulty visualising these networks using the app*, due to both their complexity and the lack of planning of device placement before the networks were created. This observation is backed up by one of the qualitative comments on the surveys, where a student indicates that they liked the simulation (via their quantitative scores), but that the *technology still needs work*.

In terms of the applicability of the simulation as a tool to teach the TCP/IP model, the data shows good scores for memorability, with the research assistant reporting that after the initial on-boarding reported above, *students were able to successfully use the tool to build networks and to visualise the TCP/IP model*, with students constructing simple networks and then using the focussed mode available in the tool to route packets between a source and destination computer, checking their level on the TCP/IP model as the packet was routed through the network. This observation is again backed by student comments, with students commenting in the qualitative section of the survey that *it was more clarified through this work* and *it's good to work with such networking concepts. It gives user friendly interface, easy to interact and act upon it*. This underlying theme of interactivity was supported by the score for creativity and also noted by the research assistant in their observation notes, with the ability to move items around and construct their own network, rather than being constrained by the set examples provided in the traditional instruction, being one of the main points of commentary noted.

Discussion

The results of this study reveal some useful insights that can be used to facilitate changes to the usability model of the augmented reality application, especially in the context of theoretical literature underpinning this work. Firstly, the work shows that getting students to use the software is not difficult, with many students eager to download the app to their own smartphone and try it out. This is consistent with the reported findings of Jones (2009) in relation to student use of technology, and supports Corrin, Bennett, & Lockyer (2013) in their discussion of how students use technology. It would appear from this work that getting students to use a new technology, especially a novel one placed in front of them in the classroom, is not a significant problem.

It would also appear that students felt that the tool had value and helped with their ability to build a mental model, supported by their comments about the work providing more *clarity* or being *easy to interact with*. This supports the work done by Williamson et al., (2012), who showed that students presented with a visualization could use this to improve their mental model. However, at this stage the evidence for this is anecdotal and further testing, through a larger sample size and the use of pre and post testing, would need to be conducted to see if students mental model was actually improved, and how learning outcomes were affected.

Finally, perhaps the most important takeaway from the results presented so far was that students found it difficult to use the tool in its initial stages due to the freeform nature of the tool. They also found the tool less efficient than the traditional method. This result was surprising to the researchers, but perhaps highlights that whilst the work presented nominally addresses Tasker & Dalton's (2008) thoughts on the need to bridge the mental gap for students, it does not provide enough scaffolding and structure for students to use the tool to really bridge this gap for their mental model and requires the educator *prime the user's perception*.

A possible solution to this problem in the study and *prime the user's perception* is to develop lesson materials and tutorial materials to help students to use the tool correctly when they are first exposed to it. The observations from the classroom show that, once students are familiar with the tool, it can be used effectively to help students interact with the theory and clarify their understanding, so the use of some teaching materials and lesson plans to help with onboarding the students into the simulation would likely help with this dimension, and provide further support in line with the ideals expressed by Tasker & Dalton (2008) in their original work.

Conclusion

This paper has presented preliminary results from a pilot and usability study involving a learning intervention using mixed reality visualization (3d printed physical objects and Augmented Reality simulation) to help teach complex multi-step problems to students studying computer networking in an ICT degree. Results showed that students found the intervention useful, and comments from students and from the research assistant observer supported the ability of the visualization to help students clarify concepts and interact with the model. However, they also showed the importance of scaffolding and structuring to help students with their initial experience as highlighted by the usability results. Hence, despite the small sample size, this work has proved useful as a first loop of the study to gather usability data that will be used to modify the tool in the future.

With this in mind, future work will report on further results from this study gathered after the tool has been updated to include chunked and scaffolded tutorial materials, and provide correlations of various factors related to student performance, showing whether the use of these interventions have improved learning and whether the tools were accepted by the student cohort (as the second loop of the action research approach). The use of the simulation in other disciplines will also be investigated (the third loop of the action research approach). Through this work, a greater understanding of the use of innovate technology tools and simulation in education will be obtained, providing foundations for future research.

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Please cite as: Cowling, M. & Birt, J. (2016). Piloting mixed reality in ICT networking to visualize complex theoretical multi-step problems. In S. Barker, S. Dawson, A. Pardo, & C. Colvin (Eds.), *Show Me The Learning*. *Proceedings ASCILITE 2016 Adelaide* (pp. 163-168).

Note: All published papers are refereed, having undergone a double-blind peer-review process.