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# Teaching Complex Theoretical Multi-Step Problems in ICT Networking through 3D Printing and Augmented Reality

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This paper presents a pilot study rationale and research methodology using a mixed media visualisation (3D printing and Augmented Reality simulation) learning intervention to help students in an ICT degree represent theoretical complex multi-step problems without a corresponding real world physical analog model. This is important because these concepts are difficult to visualise without a corresponding mental model. The proposed intervention uses an augmented reality application programmed with free commercially available tools, tested through an action research methodology, to evaluate the effectiveness of the mixed media visualisation techniques to teach ICT students networking. Specifically, 3D models of network equipment will be placed in a field and then the augmented reality app can be used to observe packet traversal and routing between the different devices as data travels from the source to the destination. Outcomes are expected to be an overall improvement in final skill level for all students.

**Keywords:** mixed media visualization, networking, augmented reality, 3D printing, ICT

## Introduction

As educators, we are increasingly surrounded by a new breed of individual - those that have never known a world where computers weren't commonplace. These so-called 'Digital Natives' (often defined as those born after 1980) are described as being naturally fluent with a variety of digital technologies, with a distinctive set of characteristics that seems to be natural, including preference for speed, nonlinear processing, multitasking, and social learning thanks to their embedded life in digital technology during childhood and adolescence when neural plasticity is high (Prensky, 2001; Thompson, 2012). This new generation of students, later described as "Digitally Wise" by Prensky (2009), approach learning using multiple different types of available technology (Thompson, 2012), working with technology and their applications from a technology understanding rather than from a classical educational understanding. In particular, Jones, et al. (2009), points out that these students expect to be engaged by their environment, with participatory, interactive, sensory-rich, experimental activities (either physical or virtual) and opportunities for input. They are more oriented to visual media than previous generations and they prefer to learn visually by doing rather than by telling or reading.

Students studying Information Communication Technology (ICT) could reasonably be expected to be the epitome of the "Digital Native" described above. 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 multi-step processes in the classroom is still a developing issue. For instance, in ICT the pedagogical approach of teaching programming has been discussed at length over a number of years by a number of researchers (Krpán, Mladenović, & Rosić, 2015; Pears et al., 2007), with the literature acknowledging that it is hard to teach students the problem solving and complex multi-step tasks required in the ICT discipline. In the teaching and learning of computer networking (the context for this study), this has been investigated with the development of virtual environments for modeling the processes (Dobrilovic, Jevtic & Odadzic, 2013; Powell et al., 2007) and abstract video based visualizations (<https://youtu.be/-6Uoku-M6oY>). 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 a potential issue with interpretation of these models by students from varied cultures, as per previous work by the author on international students (Cowling & Novak, 2012).

This paper therefore presents a pilot study rationale and research methodology to examine a mixed media visualization intervention using 3D printing and a mobile augmented reality application

programmed through freely available commercial grade visualization tools. The aim of the paper is to present a method to assist students in theoretical model understanding and applied use. In particular, to address the problem that these models are not physical in our existence but rather logical models used to describe packet behaviour at the software and hardware level.

## Pilot Study Rationale

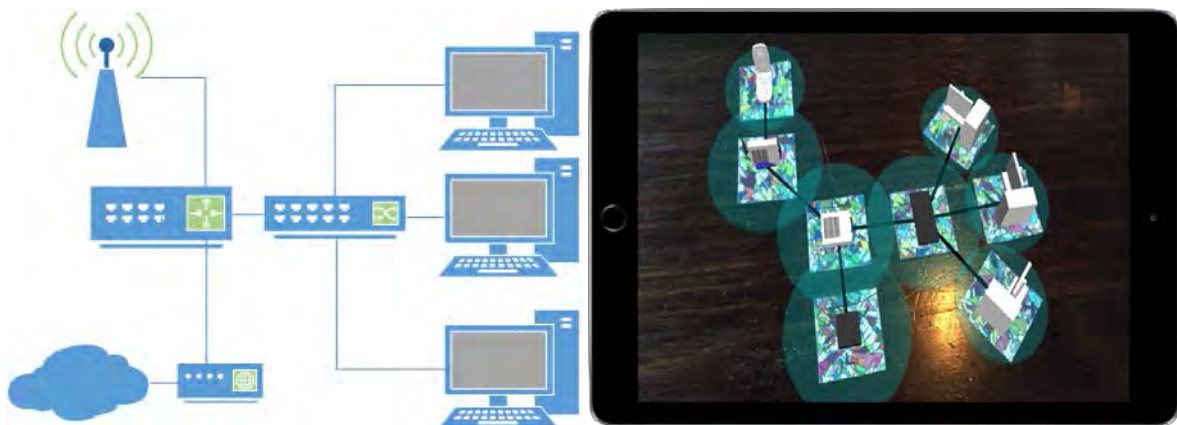
The use of visualizations as positive learning support tools are well documented and accepted (Mayer, 2005, 2008). Numerous academic disciplines incorporate a variety of 2D and 3D visualizations and haptic manipulations including medical anatomy, architecture, geography, chemistry and media/game design (Freitas & Neumann, 2009). This work also builds on previous work by the authors in multimedia design (Birt & Hovorka, 2014) studying the effects on learners building 3D models with applied mixed media visualizations, and paramedic science (Cowling, Moore and Birt, 2015), which studied the application of emerging technologies and comparative mixed media visualization on trainee paramedic science students studying airways management.

The fundamental difference between this proposed study and the previous work of the authors is the availability of a direct physical real world model. In networking, and in particular in modelling packet flow network diagrams, this is not the case, with no corresponding physical model that represents the various layers of the networking model in a visual fashion for students. Tasker & Dalton (2008) argue that this creates a mental gap for students, providing a disconnect between their understanding of the concepts and their visual mental model. Further, they argue that visualisations can assist with this by providing students with an appropriate mental model that they can use to understand the “hidden” concepts, as outlined by Williamson et al (2012).

This project therefore takes the work done by Tasker et al. and the previous work by the authors and extends it, with an aim to demonstrate that kinesthetic tools can be used to better form mental models (Paas & Sweller, 2014) and deliver improved pedagogy to teach networking concepts to 21st century students from varied cultures. Specifically, a combination of augmented reality through a mobile device and 3D printed models will be used to visualise how data travels through various network components from source to destination, addressing the following research questions: i) How does 3D printing and augmented reality impact 21st century student learning in ICT networking courses?; ii) How does 3D printing and augmented reality affect learning for students from varied cultures?; and iii) How does 3D printing and augmented reality assist ICT networking students in visualising complex multi-step processes?

## Experimental Design

Participants in this work are students enrolled in the undergraduate networking course at the lead author's institution. To conduct the experiment, the 3D printing and augmented reality intervention will be implemented into three standard tutorial exercises for the class. For each exercise, the student cohort will be split, with some students being given access to the new tools and some students using the traditional approach to the exercise. The groups completing the exercises with the new tools will be rotated to ensure that each individual student has equal access to both the intervention and the traditional methods.



**Figure 1:** An example simple network model & the equivalent view using augmented reality markers on an iPad

The specific intervention involves the use of 3D printed networking components that are scanned by a mobile device using the Qualcomm Vuforia plug-in ([www.vuforia.com](http://www.vuforia.com)) and an app developed in Unity3d ([www.unity3d.com](http://www.unity3d.com)). Whilst previously being limited to game development and high end engineering projects, these tools are now becoming available to education. Specifically, 3D printing has seen an explosion in the past five years due to low cost fused deposition modeling (FDM) systems by makers such as MakerBot™ ([www.makerbot.com](http://www.makerbot.com)). 3D printing at its basic level uses an additive manufacturing process to build objects up in layers using plastic polymer. Although the process is slow, 3D printing creates direct links between a virtual 3D based model and the formation of an accurate, scaled, physical representation from that model (Loy, 2014). This direct linking of object making to computer modeling changes the relationship of the learner to the making of the object and subsequent use, that is, it creates and enables a haptic feedback loop for learners.

Using the 3D printed components as a tool, the app will then identify each component and use them to construct a custom network on the device based on the placement of the 3D printed items in the field by students. For instance, instead of using a traditional and static 2D model, 3D models of computers, switches and routers will instead be placed by students to construct a network that will then be imported into the mobile device (Figure 1). Once the network is in the mobile device, students will be able to simulate network traffic, visualising the complex multi-step process of the OSI and TCP/IP model (see Table 1). Students will also have the ability to rearrange 3D objects to understand how changes in the network infrastructure affect the performance of the network, providing them with a mental model for this complex process, in line with Tasker & Dalton (2008).

**Table 1: The Internet Protocol Suite (commonly TCP/IP model)**

TCP/IP Model	
5. Application Layer	Includes protocols used by most applications (HTTP, FTP etc)
4. Transport Layer	Data Channel creation (end-to-end services, error and flow control etc)
3. Internet Layer	Multiple network level (internetworking)
2. Data Link Layer	Local network level
1. Physical Layer	Actual physical wires and connections

## 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, and the in-classroom implementation of the 3D printing and augmented reality intervention supplemented by research conducted with students to assess their feeling about the technology and its use in the classroom. The action research paradigm is appropriate because the researchers will work as practitioners in the classroom, implementing the change whilst simultaneously performing research to determine its effectiveness. Action research as a framework also implements an interactive inquiry process well suited to answering the research questions on student learning, teaching practice and visualisation of complex multi-step processes.

To provide research data, a pre-test will first be conducted with students to assess their base knowledge, and then selected students will be asked to volunteer to complete an intervention. After the implementation of each exercise all students (both those completing the intervention and those completing the exercise in the traditional way) will be given a small post-exercise quiz to assess their knowledge of the concepts being covered. This will provide useful data on whether the implementation has made a difference to student results and address the research question "How does 3D printing and augmented reality impact 21<sup>st</sup> century student learning in ICT networking courses?". It is anticipated that approximately 50 students (domestic and international) will be able to participate in the experiment in total, after ethics approval is given and consent is sought from the students.

In addition to this experiment, at the end of the term students will also be issued with a survey asking how they felt about the use of the new tools and how they felt that they enhanced their learning. Survey questions will be developed based on existing theory on the digital competency of students and will include demographic questions as well as Likert scale quantitative questions to assess student feeling on the new tools, allowing for correlation between student demographics (such as international and domestic student details, age, gender etc) and the attitude to the research, amongst other factors, and answering the research question “How does 3D printing and augmented reality affect learning for students from varied cultures?”.

Finally, as part of the end of term survey, an open-ended qualitative question will also be included for students to provide additional detail on their use of the new tools as desired, and it is here that answers may be found to the research question “How does 3D printing and augmented reality assist ICT networking students in visualising complex multi-step processes?”. However, due to the complexity of this question, and depending upon the survey results, an online focus group may also be conducted to collect further rich data on student experiences that relate to this research question. Ethics approval for this survey and the possible focus group will be obtained from the Human Ethics committee prior to administration.

A combination of both quantitative and qualitative data will be collected from the quiz results and the survey instruments. Quantitative data will be analysed using SPSS to identify significant levels of difference in student satisfaction and to analyse whether a significant difference in student outcomes was identified. Qualitative data will be analysed using NVivo and coded to identify significant themes present in student comments.

## Conclusion

This paper has presented a proposed pilot study involving a learning intervention using mixed media visualisation (3D printing and Augmented Reality simulation) to help teach complex multi-step problems to students studying computer networking in an ICT degree. Through the use of an action research paradigm, several tests will be performed at various stages to assess this assertion and student performance at the simulated task. In addition, a survey will be conducted to assess student attitude towards the intervention methods. Future work will report on the results of this study 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. Through this work, a greater understanding of the use of innovative technology tools and games simulation in the education space will be obtained, providing a foundation for future research.

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