Build your own virtual photonics communication system: a Photonics Simulator for high school students

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Abstract: *In our community outreach activities, we have been developing teaching tools to inform high school students about Optics and Photonics. While there is research supporting the idea that incorporating computer games into education can create a 'strong cognitive effect', others suggest that games should merely be used as a teaching tool, rather than as a primary vehicle for teaching. Thus we chose to develop an open-ended Photonics Simulator using* Flash, *employing photonic components as building blocks to form a communications system, within a classroom lesson including an illustrated talk with a simple optical fibre demonstration. The virtual photonics components have the same properties as the devices used in actual telecommunications links and in our research laboratories. The software is available to download.*

We trialled the Photonics Simulator during a single lesson (lessons ranged from 50 minutes to 90 minutes) with five Year 9 or Year 10 classes (from three schools - coeducational, girls only and boys only) during 2007. We gave them a short survey before the lesson to establish their level of knowledge of photonics, and then administered a slightly longer survey, including some repeated questions, after the lesson. The level of knowledge of photonics was significantly improved in every class and in every subgroup tested. (For example answers on 'the function of an optical amplifier' improved from 40% correct/partly correct to 70% correct/partly correct). Furthermore, the 'hands-on' nature of the simulator was effective in engaging the students, (94% 'enjoyed playing the game') and showing them the basis of the communications systems that underpin the Internet.

Introduction

The Australian Research Council Centre of Excellence, CUDOS, researches and develops optical and photonic components for communications and other applications. We aim to introduce photonics and optics as elements of communications systems to high school students to raise the profile of photonics within our highly connected and communications-reliant world. We have developed a presentation and simulation to introduce secondary students to photonic communications systems, by showing them the principles of coding and transmitting information, explaining the function of each individual component within a communications network, and then allowing the students to create and test their own photonic network on the computer. The properties of each of the components are as close as possible to those of real components. A subsidiary aim was to demonstrate to students how science and technology contributes to society, encouraging them to study science and technology to HSC and beyond, to continue the work of today's pioneers.

We created a simulator based on *Flash* which can be used on both PC and Macintosh computing platforms. It incorporates a glossary of terms to introduce the main components and concepts used in the simulator, as well as offering short movies and animations to demonstrate concepts more vividly. It is intended to become part of the teacher's toolkit for introducing science students to photonics. We incorporated the simulator into our presentations to secondary students. We deliberately did not direct students as to how to set it up, as we wanted to give the students an open choice as to how to interact with the simulator. Indeed, we found that most students preferred to 'hack' rather than be issued with instructions, and many would open the simulator when they were supposed to be busy on another aspect of the presentation. We also included other activities such as an animation of a photonic chip or a freeze-frame movie showing how various photonic components work, and a 'real' demonstration of a laser with optical fibre.

Effective software for education

As is commonly acknowledged, effective teaching and learning do not always co-exist in the classroom. Until recently educational software has mostly focussed on the teaching aspects, which can make integration of such software into the classroom difficult (Hinestroza and Mellar 2001). Whereas teaching focuses on conveying ideas, learning requires the user to be engaged in the process. Hence for educational software to be successfully integrated into the classroom, the designer needs to consider both teaching and learning aspects of the software. It is essential that the needs and requirements of teachers, as well as students, must be considered in order for the software to be adopted within schools (Crosier, Cobb and Wilson 2002). According to Polonoli (2000), building on the work of Robertson (1994), there are seven building blocks that are needed to create effective educational software, as portrayed in Figure 1. Educational software must be appropriate for the age, gender and learning style of the students it serves.

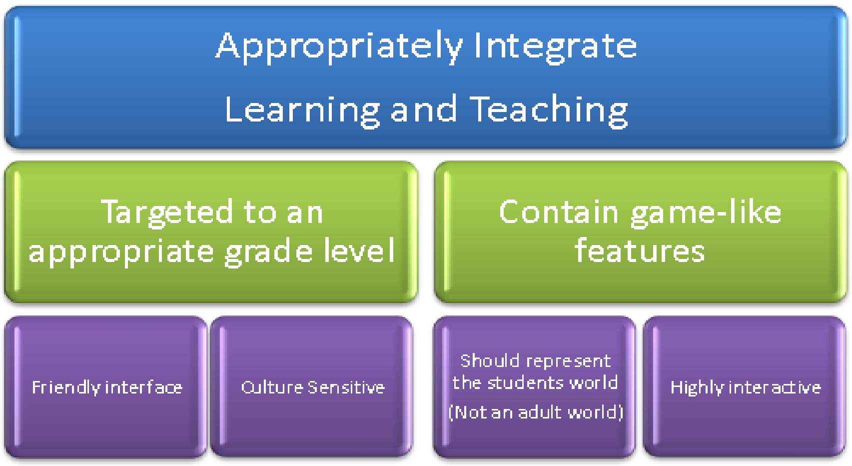

Figure 1. Seven factors to be considered in the design of an effective software educational tool. These factors have been compiled from suggestions by Polonoli (2000) of the elements of effective software, and suggestions for eliciting maximum usability from educational software (Robertson 1994).

Educational software that uses a 'game-like' approach has been shown to aid students in learning science-based concepts (Randel, Morris, Wetzel and Whitehill 1992, Foster, Kohler and Mishra 2006). 'Game-like' software has been shown to have a 'strong cognitive effect' whereby the software induced cognitive processes similar to that of problem solving (Pillay, Brownlee and Wilss 1999). According to Randel et al.(1992) games foster greater interest from students when compared with traditional forms of instruction. If students are engaged, the game makes class time less boring (Roblyer, Edwards and Havrilik 1997) and it is more likely they will remember the concepts taught by the game (Randel et al. 1992). There is however, another school of thought that believes that despite games for education being 'engaging' for the students, they do not stimulate the 'constructive reasoning' that is required for learning (Conati 2002), as they are distracted from 'reflective cognition'. Manske and Conati (2005) suggest that little evidence exists to show that games can trigger learning, unless they are supported by other activities. Yeo, Loss, Zadnik, Harrison and Treagust (2004) showed that interactive multimedia experiences may not illuminate the key physics concepts for the students, despite interactivity and animated graphics. 'Only following researcher intervention, did students develop awareness' of the abstract physics concepts. Hence the level to which the educational software is made 'game-like' should be considered carefully, and a total reliance upon the software alone for a student's education is unwise.

Implementation of the software application

Developing an application that uses the 3D graphics pathway is complex and time-consuming. For this reason, we chose to use the *Macromedia* application *Flash*, a 3D rendering package, to automate the rendering of the graphics. In addition to handling the visual rendering of the applications, *Flash* provides a scripting interface (ActionScript) and is available to a wide range of machine platforms (important since many Australian school students use Macintosh computers). It offers useful features such as silent exception handling, garbage collection and a rich object model. However, as with many such platforms, one of the biggest problems with *Flash* is performance, and it is limited to small applications with relatively few simultaneous graphics and processes.

Overview of the application

The project has been developed with a strong focus on maintaining a balance between learning and teaching. For this reason the application does not provide students with specific directional information, rather students are provided with open possibilities which may be guided by a teacher, perhaps via worksheets, or alternatively the students may be allowed to explore different avenues on their own. The photonics simulator may be viewed at the website:
http://www.ics.mq.edu.au/cudos/outreach/photonics/Simulator.html

The application has three areas: videos and animations; optical network builder; and photonic dictionary. The videos provide an opportunity to present information on the scope of the technology, or more detailed information on the photonic components, to students in a self-directed manner. Alternatively the teacher may play the video to the class as a whole (using a zoom function incorporated into the video player). This part of the application does not provide much interactivity, but provides content for the students to prepare them for the Optical Network Builder. The network builder gives students a chance to actively learn concepts introduced by their teacher, through class discussions, or by watching the movies above. The network builder provides students with an open challenge to transfer a message they have typed to their two friends' houses. To do this they must connect their Internet Service Provider (ISP) with both friends' houses, using components from their 'toolkit' and ensure that their messages are always correctly received. The application deliberately provides little instruction on how they should achieve this, forcing the students to think about what they have been taught, and to test different approaches to the problem. The aim is to frustrate the student slightly, causing 'a mild state of cognitive dissonance that will make the content challenging' (Polonoli 2000). Another reason for the open-ended approach is to allow the teacher to provide the students with tasks or challenges to complete, say to build a network that includes a buffer and a switch. The optical network builder also achieves the project aim of introducing the students to the basics of communications networks. When the students send their messages through their optical network, the messages are converted to binary code and transmitted through the network as light and dark pulses. Bezier curves allow the photons to travel along the waveguides that were drawn by the student. There is a photon speed slider that allows the students to slow down the speed of the photons through the network so they can watch individual pulses flowing through the network, and see them translated back into 'real' characters at the receiver. Again a zoom function is provided to allow the teacher to zoom in on the network and explain in detail what is happening. Finally, the photonic dictionary allows students to quickly look up the function of a particular component, or clarify a concept such as coding. The definitions enable the interested student to explore in more depth the concepts and ideas provided by the videos and the network builder.

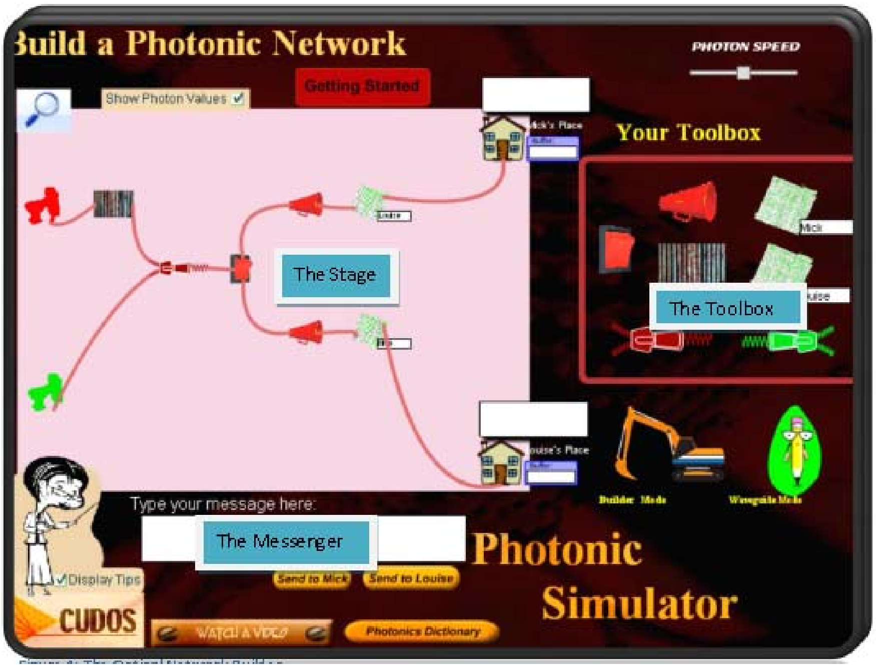

Figure 2. A snapshot from the optical network builder section of the application

Was the approach effective?

To investigate the effectiveness of the teaching approach proposed in this work, we performed several trials of the software with 100 Year 9 and 10 students from three schools. Each lesson (50 to 90 minutes) was split into the following components:

- an illustrated talk on photonics including laser and optical fibre demonstration;
- a short animation on photonic networks;
- students complete a worksheet using the photonics glossary; and
- free time to play with the optical network builder.

Table 1. Students' responses to the pre-surveys

Student group	**Question**	**Correct**	**Half-right**	**Wrong**	**Don't know**
Female = 30 students	What is photonics?	3	8	3	16
	What is function of an amplifier?	5	10	6	9
	Would you enjoy playing scientific computer games in class?	28 yes	2 no		
	…at home?	17 yes	13 no		
Male = 68 students	What is photonics?	20	16	6	26
	What is function of an amplifier?	9	15	7	37
	Would you enjoy playing scientific computer games in class?	66 yes	2 no		
	…at home?	29 yes	39 no		

Before each trial, a pre-survey was conducted by the teacher at the beginning of the lesson, and two questions from this survey were repeated in a post-survey in the last five minutes of the same lesson to test the effectiveness of the lesson. These questions were:

- What is photonics?
- What is the function of an optical amplifier in an optical network?

The change in responses to these two questions is demonstrated by the data in Tables 1 and 2. There is a significant improvement in the students' responses to both questions after the lesson and experience of the simulator. Responses have been aggregated by gender in this case. Examples of 'correct' or 'half-right' answers for 'what is photonics?' are: 'science and application of light as a means of transferring information' and 'when you turn information into light signals'. Examples of 'correct' and 'half-right' responses to 'what is the function of an optical amplifier?' are: 'produces an exact copy of a signal with increased intensity' or 'to boost the transfer of a signal'.

Table 2. Students' responses to the post surveys

Student group	Question	Correct	Half-right	Wrong	Don't know
Female = 30 students	What is photonics?	19	7	-	4
	What does an amplifier do?	16	7	1	6
	Did you enjoy the game?	26 yes	4 no		
	Did you learn anything?	28 yes	2 no		
Male = 68 students	What is photonics?	34	18	1	8
	What does an amplifier do?	21	24	8	7
	Did you enjoy the game?	56 yes	12 no		
	Did you learn anything?	51 yes	17 no		

The students were also asked what they liked and didn't like about the simulation. The most-liked aspect of the game was the interactive optical network builder section, notably the ability to create their own network, and to send messages through it. The fact that it is image-based appeals to many students – they can **see** how messages are delivered, and understand the function of each component in a network by experimenting with it. Dislikes of the game were that it was confusing, needed some more technical or graphical sophistication (e.g. 'automate the line drawing' or 'use more colour in the dictionary') or 'needs more stuff to do' or too slow. Overall the response was very positive, indicating that it was more fun than a traditional class, and interactivity helped to improve retention of information. It would be interesting to test if the knowledge was retained over subsequent days or weeks! One student correctly commented 'since it's a game, you're thinking a lot more, and so grasp the info better'. While some wanted more direction, and wanted to be shown a standard format to start, most students enjoyed the openness and self-direction in the application.

Teachers commented that:

- 'One of the main things the students learned was the application of science to the real world.'
- 'Students enjoyed the interactive nature of the simulation, but many of them commented that they would have liked more options.'
- 'They tend not to read instructions, but just want to get into it.'
- 'It is a good brief activity that can be used to consolidate knowledge of photonics, or as an introduction to expose students to the necessary components.'

Conclusions

The photonics simulator was created for use in teaching photonics to school students, with particular focus on incorporating technology into the teaching methodology. This application was used as an aid when teaching the topic, not as a stand-alone application. When traditional teaching is combined with additional resources such as a software application, students become actively engaged in the topic through the interactivity of the application, helping to achieve a better understanding of the topic. In the future, we aim to make the photonics simulator more complex, and include some scenarios for students to solve, for example noting the length of the circuit used to solve a particular task. We would also like to make a more overt comparison between electrical and photonic networks, than was possible in this simulator.

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