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Using information and communication technology (ICT) to the maximum: learning and teaching biology with limited digital technologies

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Background: The ubiquity, availability and exponential growth of digital information and communication technology (ICT) creates unique opportunities for learning and teaching in the senior secondary school biology curriculum. Digital technologies make it possible for emerging disciplinary knowledge and understanding of biological processes previously too small, large, slow or fast to be taught. Indeed, much of bioscience can now be effectively taught via digital technology, since its representational and symbolic forms are in digital formats.

Purpose: This paper is part of a larger Australian study dealing with the technologies and modalities of learning biology in secondary schools.

Sample: The classroom practices of three experienced biology teachers, working in a range of NSW secondary schools, are compared and contrasted to illustrate how the challenges of limited technologies are confronted to seamlessly integrate what is available into a number of molecular genetics lessons to enhance student learning.

Design and method: The data are qualitative and the analysis is based on video classroom observations and semi-structured teacher interviews.

Results: Findings indicate that if professional development opportunities are provided where the pedagogy of learning and teaching of both the relevant biology and its digital representations are available, then teachers see the immediate pedagogic benefit to student learning. In particular, teachers use ICT for challenging genetic concepts despite limited computer hardware and software availability.

Conclusion: Experienced teachers incorporate ICT, however limited, in order to improve the quality of student learning.

Keywords: biology; genetics; multimodalities; ICT

Introduction

School students are digital natives (Prensky 2001). The presence of digital technologies in schools makes it possible to enhance students’ understanding and exploration of biological concepts and phenomena that were previously too slow, fast, small or large. The emergence of new understanding in molecular genetics, for example, with its reliance on information and communication technology (ICT), implicates two issues: multimodal ways of knowing and representing and more open-ended, experimental, exploratory investigations. What is important is awareness that the representation of new disciplinary knowledge and understanding

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is embedded within emerging digital technologies and so new concepts are situated within new representations and formats (Hedberg 2008). In their seminal work on the use of multimodality in the learning and teaching of science in classrooms, Kress et al. (2001) emphasise that communication about science is undertaken by teachers through written and verbal means, through body language and movement, gestures and eye contact and now, more frequently, through digital representations.

The Australian Curriculum Assessment and Reporting Authority (ACARA) was set up in 2008 by the Australian Government. ACARA is charged with the development of Australia’s first national curriculum for all subjects. The science curriculum is centred on three interrelated strands: science understanding, science inquiry skills and science as a human endeavour. The three strands provide the basis for learning science that engages students in meaningful ways and prepares them to use science for life and active citizenship. In addition, there are seven mandatory, general capabilities including ICT competence described by ACARA (2011). Given that the curriculum for the senior years is still under development in late 2011, students who choose to study biology will be likely to be working with new content, multimodal digital representations of contemporary biological research, and relevant practical and computing skills.

The premise of the study was that ICT facilitates high-quality learning and teaching; that student engagement with technology with available technologies has the potential to enhance the learning of difficult topics. ICT ensures quick and easy access to superior photographs, images, diagrams and other two-dimensional (2D) representations along with three-dimensional (3D) simulations, animations and video clips for teachers and students. Computer modelling of 3D objects, scientific processes and concepts are all examples of learning and teaching objects that are now available (Oakes 2009).

**Literature review**

Some writers have critiqued the role of ICT and its potential in science education for authentic learning. McFarlane and Sakellariou (2002, 220) examined how ICT might support or replace practical work and how multimedia and the Internet could be used to develop scientific reasoning. They argue that ICT is suitable for developing theoretical understanding through data interpretation where technology captures and displays data to give access to accurate information in an easily interpreted form, often in real time, as related phenomena are witnessed (McFarlane and Sakellariou 2002, 223). They report young people reacting favourably to technology in science classrooms. How teachers can make positive use of computers and mobile devices in classrooms is important, but no less important is how teachers adapt and optimise what limited ICT is available. In a review of the role of ICT in schools, Wellington (2005, 32) provides evidence to indicate that ICT adds value to learning by reaching parts of the curriculum that other teaching methods do not. For example, the use of animations in the learning and teaching of molecular genetics now makes it possible for senior high-school students to compare and contrast 2D and 3D representations of nucleic acids and protein. The work of Wellington (2005) continues to suggest that caution is needed in claiming that ICT, while having the power to improve pedagogy and learning, does influence and sustain student attainment. The organisational boundaries of the secondary school, curriculum coverage and assessment can inhibit and retard more widespread use of ICT in
teaching practice. Three factors influence the sustainability, development and dissemination of practice: whole school characteristics, motivation and pedagogy (Deaney and Hennessy 2007).

In Australia, monetary investment by the Commonwealth government in school ICT provides all Year 9 students with personal laptops. Since 2007 there has been increasing media and community commentary about the provision of ICT-embedded education for all young Australians. Similar investments in ICT have been reported internationally, by the UK Government through DfES (Deaney and Hennessy 2007; Burkett 2008; Baggott la Velle et al. 2007) and in Malaysia through the Smart Schools (Ong and Ruthven 2010), with the hope that a close match between educational and technological development will lead to the rapid development of an ICT infrastructure and increasing deployment of leading-edge technologies.

Webb (2005) identifies a range of different affordances, opportunities and interactions provided for users in ICT based-learning environments. She describes four main effects: promoting student cognitive development; enabling a wider range of experience so that students can relate science to their own and other real-world experiences; increasing students’ self-management and enabling them to track their progress so that teachers can focus on supporting and enabling student learning; and facilitating data collection and presentation of data. These effects help students to understand and interpret the data, thereby providing them with more time to focus on developing conceptual understanding.

Multimodal representation is part of science discourse (Jaipal 2009). Graphs, tables, diagrams, flowcharts, animations and simulations are part of the repertoire of practice with scientific meaning dependent on the reader’s ability to make sense of different semiotic modalities both singularly and in conjunction with text. Emerging knowledge and understanding in the biological sciences can be represented in a wider range of formats. For science teachers charged with the implementation of new curricula, this means rethinking current practice to incorporate new knowledge and understanding, whose representation is in digital formats with new language in classroom communication (Kress et al. 2001). For molecular genetics, this translates from a reliance on verbal language (gesture, language and written text) as the prime communication mode to a multimodal communication mode (complex 2D and 3D graphics, animations, simulations) reliant on the ICT capability. Changing the mode of communication is well illustrated by both the Genetic Science Learning Center at the University of Utah (http://learn.genetics.utah.edu/) and the Dolan DNA Learning Centre (http://www.dnalc.org/about), two organisations that have developed a suite of digital learning objects specifically for the learning and teaching of molecular genetics for schools (Jaipal 2009).

**Research purpose**

The purpose of this research was to explain the choice and use of limited digital technologies made by three experienced high-school biology teachers to address concepts of molecular genetics and to report on the rationale these teachers made for the incorporation of available technologies into classroom practice. The research was part of a larger study that explored teachers’ current and developing expertise and understanding of digital options to represent and communicate molecular genetics concepts. The tasks of the larger study were to understand from a learning and teaching perspective the importance of digital technologies for learning and teaching
biology, to seek out opportunities for student mastery of knowledge in multimodal and open-textured task domains, to document the learning and teaching of molecular genetics concepts and the pedagogical reliance on digital technologies and, finally, to develop a theory about the learning and teaching of such concepts with senior high-school biology students.

**Research design**

The larger study involved two phases: an observation phase (Phase 1) and an intervention phase (Phase 2). Ten experienced biology teachers participated in each phase, with five involved in both phases (staffing and school changes meant that five teachers were unable to participate in Phase 2 and so five replacements were recruited). Class sizes were between 12 and 22 students aged 16–18 years. Teachers represented both government and non-government schools in New South Wales (NSW), where the curriculum is prescribed and focuses on content and skills, a range of teaching experience (5–20 years), available ICT resources and student backgrounds (low to high socio-economic status and ethnicity).

Video recordings were made of lessons covering DNA replication and translation, protein synthesis and the timing of gene expression within a module entitled Genetics: The Code Broken (Office of the Board of Studies 2002). Teachers agreed to be interviewed about their biology teaching practice, student work samples were collected with student permission, and lessons were analysed into phases and coded as per Kress et al. (2001).

In Phase 1 (baseline data), videoed lessons showed teachers working together with students on topics including DNA structure and function. Semi-structured interviews were held with teachers about their use of ICT and their teaching of genetics using student work samples collected from each lesson videoed. Phase 2 began with an intensive professional development workshop that teachers attended where the use of digital technologies to enhance the learning and teaching of molecular genetics was presented. The workshop was a cooperative and comprehensive exploration and discussion about challenging molecular biology concepts and the potential of digital technologies to enhance deep conceptual understanding by students. Later in Phase 2 lessons were videoed, student work samples collected and teachers interviewed. Up to eight lessons of 60-minute duration were gathered for each participant. In addition, the teacher administered a common pre- and post-test before the relevant section of the teaching programme was presented to students and again on its completion (analysis of these data is in progress). The purpose of the test was to assess students’ understanding of a variety of digital representations pertaining to molecular genetics. Copies of all videoed lessons, field notes and lesson summaries were sent to each teacher for comment.

This paper reports the use of digital technologies to support the learning and teaching of molecular genetics made by three teachers in Phase 2. The research did not have permission to publish photographs of students at work. For this reason lesson and teacher interview transcripts are presented as evidence to support research claims.

**Analysis and findings**

Qualitative data analysis was based on Huberman and Miles (2002) and Braun and Clarke (2006). Video data were converted to QuickTime movies for fine-grained analysis. All lessons and teacher interviews were transcribed and transcripts checked.
by the researcher. Preliminary analysis and written notes were developed by ‘moving back and forth between recordings and transcripts’ (Davidson 2009) during several viewings of each video and interview. Themes were developed by their simple identification from the data (Rubin and Rubin 2005). All video data and their analysis were sent to each participant for comment. The three teachers are S, L and A.

School context
Teacher S taught in an all-boys’ non-government school rich in ICT. Students had laptops provided and the classroom was equipped with a data projector, an electronic whiteboard, DVDs and wireless Internet. Software was downloaded with the help of ICT maintenance technicians. The selection of ICT tools by Teacher S depended on relevance and suitability to syllabus requirements, student interest, and revision and extension lessons to maintain engagement. Teacher L taught in an academically selective, government, co-educational school with limited ICT. Three ageing computers with Internet access were available. The classroom had a digital projector with sporadic Internet access that connected to the teacher’s laptop that she had purchased. Teacher A taught in a comprehensive, government, co-educational school with little ICT. Two stand-alone ageing computers were for students’ use. Many students were able and found biology interesting, including those from non-English-speaking backgrounds. The classroom had a digital projector linked to a teacher-only-use computer with Internet. In both government schools, computers were maintained by Teachers L and A without assistance or support from ICT technicians. Both teachers maintained the hardware and avoided downloading software in case of computer failure. No electronic whiteboards were available.

This section draws on data from lessons about DNA structure, protein synthesis, point mutations, recombinant DNA and cloning. It illustrates the many and varied ways in which these three teachers transformed and enhanced learning and teaching using available ICT. Teachers were confident and creative in their use of ICT and the opportunities ICT provided for the use of multimodal digital representations. Teachers were able to seamlessly integrate ICT with discourse about multimodal representations both between themselves and students, and between students themselves.

Teacher S
Teacher S had 15 years’ experience, and was confident in the breadth and depth of her biological content knowledge and its pedagogy garnered from science journals and reputable websites. She reported that the professional day in Phase 2 was an excellent opportunity to gain knowledge and understanding about the pedagogy underlining the use of digital representations for learning and teaching genetics, to raise her confidence in using whatever technologies were becoming available and to integrate these technologies within her practice while meeting curriculum requirements. In her view, ‘they [ICTs] were easy to use once you knew how’ and, more importantly, in the past she had not been thinking in terms of a biology–technology link. She had begun to incorporate PowerPoint presentations (PPP) with embedded YouTube clips and other web-based resources, digital animations and interactives accessed from textbook websites that could be used by individuals or small groups
of students, and the interactive whiteboard, all in ways she had either not previously known or was hesitant in using to full effect. Using the technology to enhance student learning had become part of her practice. During her time as a research participant she had developed confidence in using technology to assist with presenting multiple representations of molecular genetics concepts. Teacher S articulated this as follows:

Because one representation, half the kids might go yeah yeah I get that and ... and some don’t. So by using multiple representations ... which I never really thought of using extensively ... I just found that really good. So that’s what I learnt from it and I thought it [ICT use] was excellent.

Five lessons of 90 minutes’ duration were recorded, covering DNA structure, protein synthesis, the lac-operon, recombinant DNA technology and point mutations. Segments from three lessons have been selected to showcase her use of ICTs to enhance student learning: the first segment from a lesson dealing with DNA structure and protein synthesis, the second from an animation of recombinant DNA and the third from base mutations – consequences for the amino acid sequence.

Lesson 1: DNA structure and protein synthesis

The class began with Teacher S presenting her own PPP using graphics and animations from the professional day. She explained each DNA representation (moving from simple to complex), each RNA and then protein synthesis. Throughout, Teacher S sought student comments, questions and feedback, as illustrated in the transcript below from part of the lesson. Her use of digital representations is accompanied by gestures and voice modulations.

So let’s assemble our nucleotide together. So in our stylised diagram here you can just see we’ve got our phosphate which was our round circle, we’ve got our deoxyribose sugar and we’ve got our base and sometimes we actually sort of draw the base coming off and that’s fine. A chemist will draw it – there’s our phosphate group okay and it’s still in the green so that you can identify the colours. Um here is our deoxyribose sugar and there’s our base. Yeah. Look at these diagrams these representations cause we’ll be seeing at the end which ones you found the most useful as we go through. DNA’s not just made up of one nucleotide is it? It’s a very, very long molecule made up of lots of nucleotides strung together or bonded together. Um and it’s made up of these um nucleotides we talk about them in terms of being a covalent bond in fact it’s a phosphodiester bond but you can call them covalent and that’s fine cause you know that.

In the second part of this lesson Teacher S asked two class members in turn to draw their understanding of DNA transcription and translation on the whiteboard. Teacher and peer feedback was provided to both students on the accuracy of their work. This part of lesson 1 has been selected because it exemplifies the way in which Teacher S provided opportunities for students to construct and display a visual representation based on their own mental model of protein synthesis and how the teacher checked students’ knowledge and understanding. Software for doing this task digitally was unavailable. The following quote is part of the dialogue between Teacher S (T) and her students (S1, S2):
T: Great. Now let’s go over, okay before we do this, what I want is some volunteers. And as he goes through he’s going to tell us what’s happening.

S1: Right, so that’s the DNA.

T: Great, label it.

S1: And here comes complementary RNA going out the nuclear core so a – that’s r mRNA, right?

T: You tell me!

S1: It’s mRNA. That forms complementary bases with the DNA so next is that and say that’s just random bases but they’d be complementary so say that’s say that’s thiamine. That’d be adenine. And there’s um DNA helicose uns-is unzips the ge ah genes. DNA helicose unzips it. Maybe it’s ligase.

S2: The DNA replication. Um alright so just say that comes back out here Um you’ve got a big ribosome (chuckles). Huge ribosome. So you reckon bases are … Yeah they’re pretty dodgy bases but yeah … you got your t-RNAs out here

T: Mm-hm, cool.

S2: That’s your anti-codon (writing on board) um they come down and um associate with the MR oh the mRNA strand. So little person, they come down here and their anti-codon associates with that codon and they’ve all got amino acids. I don’t really know how to draw it but um and as they associate their amino acids um they lose their amino acids and the amino acids form a chain.

These selected transcripts show students’ abilities to transform digital modalities into their own representations. Teacher S’s intent was not about the recall of facts, rather for students to use their knowledge and understanding for personal insight, to explain this to their peers, for them to provide feedback and seek clarification. The lesson ended with more complex and detailed animations and explanations of protein synthesis from the Dolan website. Teacher S has maximised the use of available ICT and in this lesson engaged students with content previously only available as written text, 2D diagrams or physical models.

Lesson 2: Animation of recombinant DNA

As in other lessons, Teacher S provided students with a rationale for her choice of ICT using the web application from the University of Delaware website. Here, the animation begins the lesson for ‘… coming to grips with some of the key and important features of recombinant DNA, bacterial plasmids and restriction enzymes’ (Teacher S), showing a representation of recombinant DNA technology, transfer of genes between species, preparation of the host cell’s E. coli and the removal of plasmids.

Throughout, Teacher S stopped and started the animation to highlight important content. For example, she gestured (pointed) to the two yellow and light blue coloured areas of the bacterial plasmid to indicate where the antibiotic-resistant genes are located, gestured again (moving her hands across each other) to explain DNA sticky ends, demonstrated blunt ends (clapping of hands), deconstructed the language
(such as the meaning of *cleave* and *restriction* enzyme) and re-presented the content in plain English without compromising biological content. The lesson concluded with the teacher drawing a summary diagram showing the insertion of donor DNA into a bacterial plasmid, with students answering low-level recall questions. This lesson illustrates one affordance of digital animations: the ease of the stop, start and replay facility for the purposes of clarification, questioning and discussion.

**Lesson 3: Base mutations – consequences for the amino acid sequence**

In lesson 3, Teacher S used a flowchart she had developed of various mutations uploaded onto an electronic whiteboard. She highlighted key words and made annotations using an electronic pen. This work was then captured by the software and used for revision. Later in the lesson, Teacher S used an animation sourced from the Internet to support her explanation and encouraged students to demonstrate their understanding verbally or to ask questions for clarification. For example, one student asked, ‘if there was a stop codon in that area [referring to the DNA base sequence such a junk DNA] that was not doing anything, and there was a frame shift or base substitution in that area, would that create an extra protein?’ As in other lessons, the animation was then replayed for summative purposes. Capturing screenshots of class work for later discussion is a facility that was not previously available; now, ICT can be used for summation and revision.

Overall, the features of Teacher S’s use of ICT were her ease of ICT use, her movement between the digital and non-digital representations of these biological concepts, and the opportunities provided for students to display their newly acquired knowledge and understanding.

**Teacher L**

Teacher L had 5 years of experience and became involved in the study because she wanted to further improve the engagement of her very able students. To do this she believed that up-skilling in the integration of digital technologies with her genetics research background would benefit students. For Teacher L, digital technologies had the potential to engage students with their own meta-cognition and higher order questioning. Informal and formal dialogue showed that she spent considerable time preparing digital resources, ordering and checking the limited ICT equipment and thinking how her students could use ICTs to engage with in-depth thinking about molecular genetics. This included the use of group work and a ‘stations approach’ when the required ICT needed to be supplemented with DVDs and her personal laptop.

For Teacher L, the professional day in Phase 2 cemented ICT as an integral part of practice. Digital technologies made it possible for high-ability students to explore their preferred learning styles in ways that had been previously unavailable. Using these technologies allowed content knowledge and understanding and pedagogic expertise to be used to full effect. In her opinion, when used appropriately, digital technologies fostered students’ sustained engagement with biology because they presented a variety of learning approaches that explained content and extended their cognitive skills. In one interview, Teacher L emphasised:

… where they’re rote learning a lot, then they tend to become um, disconnected a little from what we’re doing, so we’re always looking for more um, analytical type data processing type things in place.
From Teacher L’s perspective, digital technologies made possible the analysis of large data sets that were previously unavailable. For example, in Lesson 1 (detailed below) involving models of DNA with their multiple representations, she remarked:

it’s [digital technologies] [that] allowed other students to come in from different viewpoints and um, be able to learn more effectively in the genre that they prefer …. 

Segments from two lessons are presented to illustrate the depth of student thinking that can be achieved when students are provided with appropriate digital representations.

Lesson 1: DNA structure using static and animated representations

Teacher L began with her own prepared PPP using images from the professional day, presenting a number of increasingly more detailed images of DNA structure and asking for student comments. The segment below illustrates part of her talk with the whole class about the original Watson and Crick (1952) DNA model.

… Okay. This slide’s going to show you a number of different ways that we can … what kind of information do you feel that you can get from that model? Is it very informative or is it just a pretty picture? Hands up if you think it’s just a pretty picture, in the way that it’s formulated there. Yeah? Who thinks that you can gather some information from that picture? Just by looking at it, the way it is right there. What kind of information can you get, S1?

Teacher L redirected students’ comments and questions back to the class, articulated their summation and gave feedback about the depth of their understanding. Students then moved to class computers to consider more challenging digital DNA representations, discussing among themselves the pros and cons of each model, preparing their group critique using Microsoft Word and emailing this to L for feedback. For example, one group was confident about their understanding of one particular DNA model and its limitations and informed Teacher L about the limitation of the DNA model as follows: ‘… not enough chemistry detail is the argument so you can’t get a really good understanding’. These students had mentally pulled the models apart, discussed their pros and cons, reconstructed the diagrams and now viewed them in their entirety. This sequence of student activities demonstrates their holistic advanced understanding.

Lesson 2: Recombinant DNA

In this lesson, Teacher L simultaneously combined viewing a DVD with a PPP she had developed on recombinant DNA. The two technologies allowed students to question the content of the video, to seek explanations and clarification and to question Teacher L about her own understanding and interpretation of the content. Moreover, combining the DVD with a PPP allowed Teacher L to discuss why visual representations were useful for learning and allowed her to add content thought to be missing from the DVD. She stopped and started both the DVD and PPP, indicated the meaning of symbols and diagrams via gestures and changes in her voice, and answered higher order questions from students about the history of the Human Genome Project (HGP), whether recombinant DNA technology was known before the HGP, whether recombinant DNA happens naturally in bacteria and the purpose of this research for humans.
Teacher L reported that much of her formal preparation time was spent sourcing and reviewing high-quality, content-rich and content-demanding digital resources that could be integrated into lessons. If these resources were used in her teaching and student engagement with cognitively demanding content was high, then Teacher L believed that the lessons were successful. Her students had mastered the intended learning outcomes.

Teacher A

Teacher A had 20 years’ experience and had recently completed postgraduate studies in molecular genetics. She relished her new-found knowledge and the opportunity to use the digital technologies and resources that were accessible and available at her school. Like Teacher L, she spent much of her lesson preparation time sourcing digital resources that could be used despite the lack of class computers. Lessons were characterised by PPP with embedded YouTube clips, and images and animations from the Internet and school textbooks. Written texts were used to support visualisations and visa versa.

Like Teachers S and L, Teacher A made use of ICT for most lessons either in her preparation (graphics, images, animations from Internet) or in the classroom (data projector, school Intranet, YouTube and television broadcasts). Limited availability of classroom computers meant that individual and group work was always compromised. Other than at home, students had no opportunity to work digitally alone in her lessons, as illustrated below in a lesson dealing with cloning.

Lesson 1: Controlling the patterns of formation in embryos

The lesson began with general information and lower order questions about how embryos might develop and the role of DNA in that process. This was followed by her own PPP embedded with an animation from the Internet showing a developing Drosophila embryo. Teacher A then explained the main points of the animation before it was shown to the class. The animation was stopped and restarted for explanation purposes while students looked, listened and posed questions. The dialogue and language exchange between the students and the teacher ebbed and flowed from informal, plain English to formal biology terminology as students began to understand the concepts. The animation was then shown a second time without stops and at the end students posed higher order questions, including the probability of errors and the consequences for the developing embryo. Students then constructed their own flowchart with limited teacher assistance, and submitted work samples for assessment.

Lesson 2: Gene cloning

Teacher A began the lesson again with her own PPP (embedded with hyperlinks and uploaded on the school website) with static diagrams of plasmids with sticky ends accompanied by text and flowcharts; the images came from the professional day in Phase 2. She sought understanding via questioning of students’ prior knowledge using several diagrams of bacterial plasmids and the insertion of possible genes of interest, along with photographs of familiar cloned organisms (e.g. plant tissues, KopyCat and Dolly) as stimulus material. The lesson focused on DNA cloning, the use of viral vectors, DNA plasmids, restriction enzymes and antibiotic resistance. Considerable verbal explanation employing gestures and voice
modulations was provided for each diagram accompanied by an explanation of terms, arrows and other symbols. A selection of this dialogue from the first 10 minutes, linking what students had studied previously about cloning at the macro-level with learning on gene cloning, is provided below:

T: … can anyone tell me what that might be an image of, what it’s representing?

S1: DNA, a section.

T: A section, yeah good, a section of DNA. Now the next section: what has been done Robert to that gene please?

S2: It’s been cut using a restriction enzyme.

Throughout this lesson, Teacher A used readily available high-quality diagrams and photos from the Web as a tool for concept explanation and student engagement. This is highlighted in Teacher A’s explanation of genetically transformed bacteria:

T: Now if a bacterium has the ampicillin-resistant gene will it be able to grow colonies on the agar? Katie, it has the resistant gene to ampicillin – will it grow?

Katie: Yes.

T: So these ones have the ampicillin-resistant gene therefore they won’t be affected by the ampicillin and they will grow. This one, this, these, this percentage whatever it might be does not have the ampicillin-resistant gene that comes with this plasmid so, John, would you expect these ones to grow when they’re treated with ampicillin?

John: No.

At the conclusion of this explanation, a detailed diagram of the steps involved in bacterial transformation was given, which Teacher A then used for further explanation. Students continued to pose questions about content and its applications. The lesson concluded with an animation of gene cloning, used as a summary, from the McGraw-Hill website and students were reminded of the animal cloning site used previously (Genetics Science Learning Center 2011c). Both websites were used by Teacher A because they were up to date, engaging and accessible.

All teachers in this study made use of professional and similar university-based sites for content delivery and to support and/or supplement students’ practical experiences if undertaking experiments was costly. Teacher S had the financial resources for students to work with recombinant DNA and undertake gel electrophoresis, and thus used digital objects to support these practicals. In contrast, Teachers L and A relied solely on simulations or paper-based physical modelling to support learning, because of financial cost.

Discussion

Five themes about the teachers’ use and understanding of ICT emerged. These themes are: the integration of digital resources made easier by opportunities for professional development linking teachers’ pedagogic expertise, content knowledge
and ICT skills; teachers’ sustained use of available, appropriate digital resources; students’ use of digital content to think about how they learn; the interchange of language (both informal and formal) between teachers and students about the purpose and meaning of representations; and students’ use of digital technologies with ease to deconstruct and reconstruct content. Each theme is now discussed.

**Integration of digital resources made easier by opportunities for professional development linking teachers’ pedagogic expertise, content knowledge and ICT skills**

For each teacher the professional day was an opportunity to gain deeper understanding about the pedagogy associated with the multimodal digital representations of genetics. They valued the chance to listen and think about teaching and to discuss available resources (Teacher L), to gain confidence in their use (Teacher S) and to reinforce what was happening in their classroom (Teacher A).

To connect with other teachers that were like minded, that for me is really important, looking at what kind of modelling is available for students in terms of computer modelling for in-class use … what I took away was looking at the types of models and realising that no one model is going to um, explain or best describe a particular situation for all students, and that a number of models is a better way to go … (Teacher L)

It gave me the confidence to go in and use technology … I’d already been starting to use the SmartBoard because it was there but I got extra ideas … getting things off the internet and multiple representations which I never really thought of using extensively. (Teacher S)

… good to, um, to know that I was sort of on the right track, there are lots of representations that you can use say for DNA and I’ve been through all of those and the pros and cons of each. Some graphics are good for some purposes and not others, so, it was good to … to get feedback on that too. (Teacher A)

Professional development that supports teachers’ work in classrooms is a powerful factor for enhancing student learning. Evidence from this study indicates that opportunities for teachers to meet in a collegial environment, to discuss ICT pedagogic practice, in this case the learning and teaching of molecular genetics in all its multimodal representations, translates to a deeper confidence in both their use of ICT and the use of 2D and 3D representations now in digital format. The research aligns with Bingimlas (2009) and Oakes (2009), who identify barriers that teachers encounter when attempting to incorporate ICT into classrooms as part of high-quality learning and teaching. This study confirms the need for opportunities for professional training, and for two teachers (Teachers L and A) the need for technical support.

**Teachers’ sustained use of available, appropriate digital resources**

Sustainability of practice was the key. All three teachers believed that ICT was now part of high-quality teaching. Evidence from classroom data indicated that they were making a determined effort to engage with all ICTs, provided they supported student learning.
they [students] came up and did it [simulation of gel electrophoresis on SmartBoard] ...they did it interactively ... I found that really cool and so I got different kids to come up and drag the different things and they found it really good and then they went home and actually had a look at it at home as well. So I thought that [simulation of gel electrophoresis] was great to consolidate the work. (Teacher S)

Despite a lack of ICT for Teachers A and L, they willingly used what was available, ever mindful of student engagement.

... it’s extremely difficult here to get into the computer labs ... but what I did do, I gave them URLs so that they could do it at home. (Teacher A)

I look at what is on offer in the particular type of technology resources ...I pick a selection what I consider easy, medium and hard and the way it’s presented ... I don’t want it [digital resource] so simple that it’s providing misconceptions for students ... so moving into higher order thinking type ideas and [so] try to cater for the students that are here. (Teacher L)

These findings are consistent with work done by Dawson (2008). It is not only early-career teachers who display confidence with the use of ICT and hold positive beliefs about their value quality pedagogy but also experienced mid-career teachers. Moreover, the classroom practice of Teachers S, L and A aligns with similar findings by Deaney and Hennessy (2007, 88), who report that ‘teacher confidence, skill and enthusiasm for using ICT, their strong beliefs and affinity for particular approaches’ will become ‘significant motivational factors underlying sustainability of practice’.

**Students’ use of digital content to think about how they learn**

This was shown clearly with Teacher L’s very able students. Requiring students to engage in meta-cognition was an integral part of her teaching repertoire and evident in most lessons. In the lesson about DNA structure, for example, students were required to critique various representations of DNA, and simultaneously verbalise their thinking to peers. The following transcript is typical of the way in which Teacher L invites them to explain how they learn:

T: Alright. Now, what I’d like to get is a little bit of feedback in relation to how our learning was today.

S1: I thought it was good. We were in small groups and I think it’s the first time we’ve done it so we were more attentive. And and the work is all bulk, it’s all ... there’s – like all those pictures and diagrams and a bit of everything.

S2: It’s got a different perspective, like that one has a more text than the other video did. So it was sorta-like we consolidated what you’ve learned in one thing, because interactive so ...

ICT-rich environments support student learning because they bring about conceptual change, enable student to engage in demanding cognitive tasks and allow teachers time to focus on questioning and meaning-making with students (Webb 2005). Findings from this study support the work of Webb (2005) in the identification of affordances shown to benefit student learning, in particular, that increasing students’ self-management enables them to track their own progress, thereby
allowing teachers more time to support student learning. Moreover, findings from this study demonstrate that student engagement with their own meta-cognition can be done successfully despite limited access to ICT.

**Interchange of language (informal and formal) between teachers and students about the purpose and meaning of representations**

This was illustrated in Teacher S’s lesson, where two students were asked to draw a diagram and flowchart of their understanding of DNA transcription and translation after viewing the DNA Learning Centre website. The lesson segment showed Teacher S interacting with students as they navigated the task. Language interchange was evident also in Teacher A’s lesson on cloning, in particular, her use of Dolly and KopyCat as examples of successfully cloned animals. These were then used to support the content of an animation for cloning a mouse (Genetic Science Learning Center 2011c).

Important for this study is Wellington’s (2005) view that multimedia in science learning can provide ‘… motivation in learning science via improved visualisation and understanding of abstract concepts (32). Findings from this study suggest that the use of multimedia to enhance understanding of abstract concepts can be supported with the use of both formal science language and informal talk by teachers and students.

**Students’ use of digital technologies with ease to deconstruct and reconstruct content**

Digital technologies were used by students to explain their understanding of genetic concepts. For example, students from Teacher S’s class were observed to engage in a whole-class discussion of mutations using the graphics provided. Teacher A’s students worked in small groups using an animation on cloning mice. Teacher L’s students began with small group discussions and then met for whole-class discussion. Once students had an understanding of the content, they were able to apply that knowledge to other contexts.

The view of this writer is that students’ use of digital technologies, for the purpose of demonstrating conceptual understanding by deconstructing and reconstructing content, lies in the increasing availability of mobile devices. For example, there is a wealth of available science apps available online; the challenge will be for schools to make use of existing apps but increasingly for students to create their own apps using Web 2.0 capacities. Some of this work has been undertaken by Hoban, Loughran, and Nielsen (2011), whose work using Slomation (a narrated stop-motion slow animation at two frames/second) consistently demonstrates the level of science content knowledge of students when given the opportunity to showcase their understanding using animation or when used by teachers as an authentic assessment task. As Hoban and colleagues (2011, 1005) contend, these ‘instructional resources may be a new way for them [students] to learn science content or at least provide a motivation to learn it [science concept’].

**Conclusion**

This paper illustrates how experienced biology teachers incorporate digital technologies into classroom practice and so improve the quality of student learning via discourse, engagement and meta-cognition. This paper responds to the call of Tyler
and Prain (2010) for further research on the way in which science teachers use language and their choice of representations of concepts to enable students to learn. The three teachers in this study were innovative in the way that they made use of what technologies were available while acknowledging the many problems with access that currently existed. They were confident in their content knowledge, including its language. Each had a strong sense of professional identity as a highly accomplished biology teacher. They were able to make ICT accessible to students. Students were provided with websites that they could use at home for study purposes and digital resources were placed on the school server. The study demonstrates how teachers respond in creative ways to the limits of available technology and how they adapt and optimise ICT to foster student understanding of molecular genetics. Within a climate of significant investment in technological resources, teacher training and support, contextual factors can militate against the development and dissemination of ICT-supported practice (Deaney and Hennessy 2008). For Teachers S, L and A, interrogating the potentiality of ICT to assist student learning underlined their practice. For sustained incorporation of ICT (including new and emerging technologies), professional development must be ongoing, dynamic, supported by the school and involve sustained communication among teachers (Hubber et al. 2010). Teachers S, L and A report their professional development throughout the conversations sustained within Phase 2 of this research.

Even though the students found molecular genetics interesting, their in-depth intellectual engagement with the content was supported by digital technologies. For the teachers, learning support of difficult content occurred when digital technologies were seamless and purposefully integrated with content. This is in contrast to earlier work by Vrasidas and Glass (2005), who reported a number of obstacles to technology integration in classrooms. Students’ personal mobile devices allow them to produce their own interactive representation of genetics concepts, created by them and available to others at any time. The study has provided further evidence to show that students who are interested in both ICT and genetics can collaborate in ways that do not compromise the teaching of biology.

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