Incorporating digital technologies into science classes: Two case studies from the field

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As the rate of digital technology development accelerates, so too do the challenges for teachers to maintain their digital technology skills and to effectively apply these skills to benefit student learning (Phelps, Graham, & Watts, 2011). The impact of digital technologies on teaching and learning practices must be recognized and further understanding of their complex nature is required (Hennessy, Deaney, & Ruthven, 2005; Metiri Group, 2006). This paper reports on case studies from two larger studies with an aim to add to this understanding.

The first case study is of students' use of digital video production to record and represent their science learning. It reports on the adaptation of the writing-to-learn in science model (Prain & Hand, 1996) to video-to-learn in science. This adaptation of a mature learning model to a new setting, was noted by Wang and Hannifin (2005) and reflects the common classroom situation in which teachers must modify and adapt their practices to accommodate new technology (Hennessy et al., 2005; Hobbs, 2006).

The second case study focuses on students' learning about and with the specialised scientific representations commonly used in chemistry. It reports on the classroom strategies and resources used to help chemistry students learn about the meaning and application of multiple static and dynamic diagrammatic digital representations and describes some of the challenges and resulting outcomes for the teacher and students.

Background

These studies responded to calls from many authors to investigate the use of contemporary digital media as part of the learning process. Prain (2006), one of the authors of the writing-to-learn in science model, called for research into how the model might be applied to emerging technologies. Buckingham (2005) warned of a growing digital divide between students' out-of-school use of digital technologies and their classroom use, thus emphasising the need for educators to actively include and adapt digital technologies to the classroom.

With specific reference to student use of video production and resultant adaptation of teacher practices, an historical progression of enthusiasm is evident in the literature as digital video capabilities have become less expensive and more available to classrooms. At the turn of the 21st century, Jonassen, Peck, and Wilson (1999) predicted that student video production would lend itself to constructivist learning practices. Yerrick and Ross (2001) believed that digital video production had the greatest potential for classroom applications of any information and communication technology (ICT). Murphy (2003) called for further exploration of how student digital video production could be used to improve learner outcomes while John and Sutherland (2005) enthused that digital technologies had the potential for ‘extending and deepening classroom learning in ways hitherto unimagined’ (p. 406).

The development of such digital technologies in recent years has resulted in the availability to teachers of diverse multimedia resources, such as modelling tools (e.g., molecular modelling software) and dynamic learning tools (e.g., animations and simulations) (Chiu & Wu, 2009). These resources can assist students to develop a deeper understanding of abstract and complex concepts. Ardac and Akaygun (2005) argued that digital technologies have the capacity to allow science students to construct their own understanding through a recursive process, which involves making, using, and elaborating on scientific models. The challenge for teachers is to adapt their classroom practices to incorporate opportunities for students to use and learn through these powerful technologies.

In this paper, two case studies are presented to illustrate these applications of digital technologies. Case Study 1 is focused on the use of digital video in a middle school setting. Case Study 2 focuses on the use of molecular modelling and simulation software in secondary school chemistry classrooms. In both cases, the researchers obtained full ethical clearance and permission from all participants and stakeholders. In the case of the students, permission was also obtained from parents or caregivers.

Case Study 1. Video-to-learn

Background to the study

Often digital technologies become available in classrooms without specific understanding by teachers as to how to utilise their capabilities. As schools purchase digital cameras and computers, by default they acquire digital video and editing capability. Learning to use these digital tools can provide a powerful classroom teaching and learning opportunity but can also provide challenges to teachers’ technological and classroom practices.

As the writing-to-learn in science model (Prain & Hand, 1996) has been used extensively and successfully in science classes to guide student learning and production of written evidence of learning, this study was developed to determine its usefulness in guiding student science learning through video recording, editing, and presentation. The traditional schooling emphasis on text-based instruction (Yerrick & Ross, 2001) is challenged by the capabilities of digital technologies through changes to the teaching and learning dynamic to deliver, develop, represent, and assess knowledge. This case study reports on the teaching and learning practices as a teacher and class transition from writing-to-learn in science to video-to-learn.

Background to writing-to-learn in science

The idea of writing-to-learn (in any subject) emerged in the late 1960s and early 1970s (Bangert-Drowns, Hurley, & Wilkinson, 2004). It was believed that students improved their understanding and retention of a topic through the process of writing. Klein (2004) summarised the writing-to-learn research stating that the learning benefits were usually identified as recall and comprehension, but the theory was most effective when students transformed their information through writing.

Specific theories relating to writing-to-learn in science developed in the late 1980s and early 1990s. These early studies examined writing genres such as expository (essay) writing in science (Kirkpatrick & Pittendrigh, 1984; Van Orden, 1987) or expressive writing genres including narrative and journal writing (Ambron, 1987; Malachowski, 1988; Reynolds & Pickett, 1989).

Two main approaches to writing-to-learn in science were noted by Prain (2006) as epistemological, where student writing reflected traditional scientific report formats (Gee, 2005; Kelly & Chen, 1999; Unsworth, 1997), and a diversified approach allowing a focus on understanding science concepts, methods, and practices (Boscolo & Mason, 2001; Hand & Keys, 1999; Prain & Hand, 1996).

The diversified writing-to-learn in science model (Prain & Hand, 1996) was chosen as the framework for teacher and students to follow in the case study reported here. This model has five key areas: topic, type, purpose, audience, and method of text production. Each of these key areas contains options from which the writer chooses. For example, *topic* choices involve key concepts, linking themes, and applying concepts. The *type* of writing assignments include narratives, journals, travelogues, and posters that can be written for varying *audiences* such as peers, parents, and younger students. The *purpose* of the writing is determined for the start of writing, during writing, and at the completion of writing. The *method* of text production involves choices of individual, pair, or group work using pen, computer, or other means.

If in the science context, as stated by Wallace, Hand, and Yang (2004), writing-to-learn involves reasoning skills to organise information, describe scientific phenomenon, create knowledge claims, and formulate an argument it was anticipated that, with some adaptation, student digital video production to record and represent science learning should achieve similar positive outcomes.

The Study

Participants, setting and knowledge background

This study was conducted in a state school in Queensland, Australia, with the researcher as teacher. The intervention involved an intact Year 7 (N=21) class consisting of 11-12 year olds, with a close balance of males and females. The classroom had enough video cameras and computers for the students to work simultaneously in groups of two or three.

The teacher/researcher (instructor) was familiar with the basic video production techniques using simple digital cameras with video capacity and the movie editing (Moviemaker) software that came as standard with the classroom computers. The students also had some experience with the digital media, having made simple videos and animation videos earlier in the year. The instructor was familiar with the writing-to-learn in science model having used it with previous grades; the students were not familiar with the model.

The intervention phases

In the initial phase (familiarisation) of the study, students working in groups of two or three, engaged in a science investigation over four lessons in a two-week period to develop familiarity with the writing-to-learn in science framework and the process of capturing and representing salient moments of an investigation of scientific *fair tests* with digital video and subsequently preparing a brief video presentation. At the conclusion of the investigation students shared their video productions on the class electronic white board. The class, with the instructor, engaged in guided critical analysis of the video presentations, in particular focussing on the scientific aspects and their alignment with the writing-to-learn model as well as discussions about what made a video more presentable, informative, or enjoyable.

The second phase (consolidation) of the study was a replication of the timeline of a two-week, four-lesson science investigation into the *functioning of a balance beam*, and again using the writing-to-learn in science model and digital video to record and represent learning. The five key elements of the writing-to-learn framework were selected as follows:

- *Topic:* understanding concepts of the functioning of a balance beam
- *Type of text production:* digital video
- *Purpose:* to explore, clarify and demonstrate
- *Audience:* classmates but also younger students (Year 5)
- *Method of text production:* working in groups of 2 or 3

Data Sources

Interviews

Structured interviews were conducted with six randomly selected students. The interviews were conducted the day after completion of the final video products. The interviews focussed on the student perceptions of the video making process, the writing-to-learn in science model, and their own learning.

Research reflection journal

A journal was kept by the researcher, articulating thoughts on the research phases, in particular the success of the adaptation and implementation of the writing-to-learn model to video-to-learn, as well as classroom logistics and management issues.

Video Products

The students' videos were viewed and analysed as a data source for the representations of knowledge gained through the science investigation.

Results

Video products

Understanding of the functions of a balance beam can be assigned complexity levels (see Klein, 2004) from Level 1 to Level 5 (Level 5 being the highest). Of the videos made by the eight groups, half demonstrated an understanding of the highest complexity level, two groups attained the fourth level, and two groups demonstrated understanding to the third level. Overall, this was a strong result for the class, showing the results of a robust investigation and subsequent representation of findings through video.

Structured interviews

Students were interviewed to determine their beliefs as to the benefits of video production in science, including their thoughts on learning, thinking, and remembering with video production in science.

Students reported positive responses to the video production process and working in a group. The responses included reference to students' diverse abilities with technology skills and science knowledge and how they could rely on each other for assistance.

When asked if they thought making a video helped their science learning all respondents agreed that it had. One student stated that knowing and understanding the topic was required before filming took place: “I go over the thoughts in my head about the science” (Student 2). Another student stated “Yes because we had to get information because we had to put it into a video to teach people” (Student 1). Another student reported, “You don’t really notice that you’re learning” (Student 4).

Students were asked if and how they thought making a video about a science topic helped them remember what they had discovered. All interviewees agreed that it had, with one student saying, “Yeah, it’s in your head like when you see an ad you kind of remember it” (Student 3); and another responding, “Yeah, you can always look back to it and see what you’ve done” (Student 1); and a third stating, “Yeah, yeah, because you’ve seen it more than once … so it sort of gets stuck in your head” (Student 2).

Students were asked to compare their science learning with video to other methods they had used. Five students said that video aided their learning more than other methods and one student (Student 5) was unsure. Some students articulated that video required them to learn or know the science before committing it to video recording, for example, “I guess because you’re actually talking about it and recording yourself, so you’ve got to already learn the stuff to be able to talk about it” (Student 2). Another student said, “You actually physically think more about what you’re doing because you know you’re going to be on camera, so you’ve got to think deeper and deeper into it …” (Student 1). The visual nature of video was noted: “It’s easier because you remember it with pictures and sound and who says what” (Student 6) and “With video you get every detail, and you might forget something writing it down, but you wouldn’t if you’d video taped it” (Student 4).

The structured interviews showed that the Year 7 respondents viewed video production in science as an aid to their learning, memory, and thinking. They liked and appreciated the collaborative approach required to make the videos. The nature of video as a visual medium was seen as a strong means of representing ideas. The student interviews showed that certain learning behaviours could be naturally elicited through the video production process. These behaviours included a natural desire and need to collaborate; a concern for the audience of the video instilling a need to ‘get it right’; and a regular re-engagement with the key science knowledge gained in the investigation through the reviewing, editing, and sharing of the videos.

Research journal

The research journal showed that the phased intervention – familiarisation phase followed by consolidation phase – allowed the instructor’s focus to shift as student skills with the writing-to-learn model and video production improved.

The initial phase journal entries showed daily concern about the means for facilitating the student learning of the required skills as well as continuing the guidance and monitoring of the *fair tests* science investigation. Instructor confidence for teaching each aspect was strong but when all aspects of the teaching and learning process combined, requiring attention to science processes, technological aspects, and classroom management, some stresses were noted. Just as the students were learning new skills, the instructor learned many skills to incorporate in future classroom practices, for example, monitoring distance between groups and volume levels to prevent sound pollution on videos and developing clearer protocols for file naming on computers.

The consolidation phase of the intervention showed that more attention was focussed on the teaching and learning processes, such as guiding and assisting groups with their science investigations in the context of the writing-to-learn framework and less on the logistics and management issues.

General observations about student engagement, time on task, enthusiasm, collaboration, and science learning behaviours were all very positive.

Discussion

The purpose of case studies such as this blending of a digital technology with an existing model for learning science is to give broad guidance for implementation in classrooms. The study responded to calls by researchers such as Prain (2006) to determine how the role of writing-to-learn in science may change as science teaching and learning incorporates technologies with multi-modal capabilities. Expanding the writing-to-learn in science model to include video production as a text was pre-empted by Buckingham (2007), who stated that the "logic for separating verbal and visual media or electronic technologies and non-electronic technologies will come under increasing pressure" (p. 117). This case study has validated the use of video production as a legitimate text in the writing-to-learn in science model.

This study also gives credence to Prain's (2006) belief that opportunities for science learning afforded by new technologies and their multi-modality imply "new roles for student writing as only one tool among many for supporting conceptualisation in science learning" (p. 194). Student learning of the science concepts through their investigation was very sound. The students themselves reported many positive aspects to using the writing-to-learn model in conjunction with video production.

From an instructor's point of view, video production fitted seamlessly into the science class with the learning benefits it afforded, such as student collaboration, concern for target audience, and regular visual and oral re-engagement with the science concepts. For video production in science to be viewed as a beneficial classroom practice, it must provide educational advantages to students and the teacher and be time efficient. Efficiency of practice is important for teachers, as Keiler (2007) noted, "instruction must be as efficient and effective as possible" (p. 151). As recorded in the instructor's research journal, this efficiency sometimes takes time to develop, with teething problems in classroom logistics and management of digital technologies mostly overcome by the second research phase. Kimber and Wyatt-Smith (2006) noted three prerequisites for teachers to implement new learning activities involving ICT, all of which were evident in this case study: The teacher needs knowledge of the learning theories, the technology and its applications, and a positive attitude facilitating experimentation and risk taking.

In this study, the students used video to capture salient points of their scientific investigative processes (e.g., videoing the beam being manipulated to balance it), explain these processes through commentary (e.g., reporting the need to consider mass and distance from fulcrum when balancing), and then to edit the resulting clips into a short video. The results of this study show that through the process of video production in science, using the five key elements of the writing-to-learn framework (as outlined earlier), students were able to effectively conduct and report a scientific investigation using video-to-learn.

Case Study 2. Using multimedia to support students' learning in chemistry

Background to the study

In chemistry, students encounter many abstract and complex concepts. At times, the phenomena about which they are learning are unobservable. As a result, teachers find it challenging to provide explanations that assist students in developing a deep understanding of the molecular-level processes that are occurring. Much research has been conducted into the reasons for the difficulties experienced by chemistry students in learning about such concepts (e.g., Coll & Taylor, 2002; Gabel, 1999; Johnstone, 2000; Treagust, Duit, & Nieswandt, 2000). The central finding of this research is that students experience difficulties for two main reasons. Firstly, they cannot observe the underlying causes of the phenomena at the molecular level. Secondly, because of the need to explain what is occurring at this unobservable level, multiple symbolic and diagrammatic representations must be used and integrated. Students do not always understand the inherent meaning of individual representations or how these representations relate to one another or to the phenomena that they represent.

The use of multiple representations to assist students to understand chemistry concepts is not new, however, because of the range of digital technologies now available in school classrooms, teachers and students have expanded access to resources with which to teach and learn. For example, the use of animations and simulations can assist students to visualise otherwise unobservable phenomena and processes. In addition, through the use of molecular modelling software, students can create their own models to assist them in building their understanding and in communicating their explanations. The availability of these technologies has required that teachers develop or adapt their teaching practices to ensure that students are able to use them effectively in their learning (Ainsworth, 2008).

The case study reported here is part of a larger study that investigated the effects of teaching with digital technologies on Year 11 chemistry students' learning outcomes. The study also investigated the teaching strategies that were used in order to facilitate students' learning through the use of digital technologies. In this paper, the focus is on the use of multimedia and visualisation software and the associated teaching strategies.

Learning with and about multiple representations

In order for students to effectively communicate their understanding in chemistry, they must understand and be able to integrate representations on three levels: the macroscopic level (representations of phenomena that are observable); the sub-microscopic level (representations of molecular-level structure and behaviours); and symbolic (representations of particles, either individually or in groups, for example, a chemical equation (Vermaat, Terlouw, & Dijkstra, 2003; Wu & Shah, 2004). The predominance of abstract symbolic representations as a means of explaining chemistry concepts to students has been identified as a key factor in the challenges faced by students in understanding chemistry (Davidowitz & Chittleborough, 2009; Gabel, 1999). According to Wu et al. (2001), students' learning and thinking rely on sensory information. Unfortunately, it is often difficult for them to make links between what they observe and the diverse range of representations used by teachers in their explanations. Teachers tend to move between levels of representation without being aware that they have done so, while at the same time, many students cannot do this (Gabel, 1999). This results in an imperative for teachers: Because molecular-level behaviour is invisible and symbolic representations are abstract, teachers must emphasise the links between the three representational levels explicitly (Davidowitz & Chittleborough, 2009). In addition, students must be familiar with multiple representations, to understand the inherent meaning in them, and to understand how they relate to one another. Even when students are able to use a range of symbolic representations, the realities that they symbolise may not be clear to them (Keig & Rubba, 1993). It is for these reasons that if students are to be able learn effectively *with* representations, students need first to learn *about* representations (Ainsworth, 2008; Chittleborough & Treagust, 2008; Taber, 2009).

To assist students in understanding complex concepts and the ways in which multiple representations can be used to understand and explain them, the use of models and other visualisation tools has been widely advocated (Gabel, 1999; Gilbert, 2005; Johnstone, 2000). Özmen (2008) argued that the use of ICT supports students' learning because of the capacity of ICT to facilitate knowledge construction and to develop other skills including problem solving and communicating. Ainsworth (2006) suggested that digital learning environments are advantageous for helping students to learn with multiple representations because they make the relationships between representations more explicit, they provide active support for students to relate representations to one another, and they facilitate translation of representations from one form to another.

While digital resources can be valuable tools for learning, the learning experiences into which they are integrated need to be carefully structured so that students are able to capitalise on the affordances of digital technologies. The challenge for chemistry teachers is to merge new teaching strategies and resources (such as those associated with digital technologies) with more traditional learning experiences (such as laboratory investigations). In the case study described here, a 10-week chemistry unit was adapted to incorporate a range of multimedia tools, including molecular modelling software, animations and simulations, as a means of promoting students' understanding of chemical bonding.

The Study

Participants and setting

This study was conducted in a state secondary school in Queensland, Australia, again with the researcher as teacher. The intervention involved two intact Year 11 classes (N=22, N=27) consisting of 15-16 year olds, with equal numbers of males and females. Students were taught for three 70-minute periods per week over a 10-week term at the beginning of the year. Due to timetabling constraints, the classes were conducted in a range of settings including traditional classrooms with a desktop computer and electronic whiteboard, a computer laboratory with sufficient computers for each student to work individually, and a chemistry laboratory with a laptop and data projector. The study had two phases: an initial six-week phase and a second four-week phase. Each phase was designed to focus on aspects of using digital technologies for developing students' understanding of chemistry and their competence at using and interpreting a range of chemistry representations. This case study reports on findings from the first phase.

Teaching resources

The study was conducted at the beginning of Year 11 when students were studying an introductory unit about chemical bonding. Chemical bonding is a central concept in chemistry (Fensham, 1975), without an understanding of which students cannot make sense of other aspects, such as the nature and properties of materials, the processes that occur in reactions, or more complex relationships such as those in thermodynamics and equilibrium. It is well documented that students find the topic of chemical bonding challenging, firstly because of the diverse models used to understand the nature of different bonds and secondly because students already hold a number of misconceptions (Taber & Coll, 2002). Early in the first phase of the study, the students were introduced to several digital technologies such as molecular modelling software to allow them to explore and create a range of representations to assist them in understanding the use and inherent meaning of the individual representations used to explain different chemical bonds. This approach responded to research findings that student need first to learn *about* representations (Ainsworth, 2008; Chittleborough & Treagust, 2008; Taber, 2009). The students also used simulations and animations to learn about bonding, atomic and molecular structure, and intermolecular bonding and interaction *with* multiple representations.

There are many challenges for teachers when using digital technologies in the classroom. Some of these relate to mismatches between the software used and learners' needs and experience or mismatches with the curriculum, while others relate to cost, availability, or lack of professional development to assist teachers in learning how to use the software (Baggott La Velle, McFarlane, & Brawn, 2003). To overcome these problems, the criteria used to select the digital resources used in the study included:

- Availability for download to students and teachers free of charge or at minimal cost
- Applicability to a range of topics, year levels, and student needs
- Ability to be used by teachers with little or no access to professional development and
- Ability to be used by students with minimal instruction on their use (to retain a student-centred rather than technology-centred learning environment).

A number of programs were identified that aligned with these criteria. Of these, *ChemSketch* was chosen for use in molecular modelling because it allows students to create models in a range of modes and to transform them; the models are easily rotated and manipulated on screen; and models can be copied and embedded into student work as pictures, which allows students to integrate their molecular representations into explanations and to create multimodal texts. Many simulation tools are available online, however *Molecular Workbench* was selected because its simulations are research-based; the activities are editable by teachers so that they can be tailored to student and curriculum needs and teaching goals; and the activities are self-paced, allow students to monitor their understanding, and to save and print their answers to questions.

Teaching strategies

At the beginning of Phase 1, the students' conceptions of chemical bonding were tested using a two-tier diagnostic instrument designed to identify students' misconceptions (Tan & Treagust, 1999). The results of the test were used to design and sequence learning experiences that would place emphasis on and scaffold students' learning in appropriate areas. The sequencing and teaching strategies were also informed by research about ways to minimise the development of misconceptions in chemistry students (e.g., Coll & Taylor, 2002; Tan & Treagust, 1999). Strategies focused on developing students' understanding of key concepts through the use of multiple visual and symbolic representations. Students were introduced to the software with which they completed a range of structured activities to create and interpret molecular representations. The activities were guided through the use of task sheets that asked questions to which the students responded by creating, manipulating, and integrating molecular models. An example is shown in Appendix 1. The students also used simulations to investigate chemical bonding and structure as well as intermolecular interactions. The teaching strategies used provided students with opportunities to integrate the use of digital technologies with other learning experiences, such as laboratory investigations. For example, if students conducted an experiment about physical properties of materials, they also had opportunities to use modelling software to construct molecular-level models to help them understand and explain the underlying causes of their laboratory observations.

Data collection

Test items

The 9-item two-tier Chemical Bonding Diagnostic Instrument published by Tan and Treagust (1999) was used in the study. Students were pre- and post- tested using this instrument at the beginning and end of the six-week phase. An additional three open-response items were used to assess students' representational competence (i.e. their ability to use appropriate and accurate representations to justify their explanations). These latter three items, shown in Appendix 2, were scored using a modified version of Kozma's and Russell's (2005) representational competence levels (see Hilton & Nichols, 2011). This is a five-level scale where 1 indicates representational use based only on physical attributes or surface level features of a phenomenon or representation and 5 represents the ability to use multiple representations to make multi-level explanations of phenomena.

Semi-structured interviews

Twelve students from each class participated in individual semi-structured interviews. The question prompts focused on students' perceptions of their learning experiences. The questions were informed by the teacher's research journal, maintained throughout the study. The students' responses were analysed followed the processes of thematic analysis suggested by Leech and Onwuegbuzie (2008) and Gay, Mills, and Airasian (2006). This involved transcription of the interviews, reading to identify separate idea units, coding of individual idea units, identification of themes, and further coding of idea units within themes to identify subthemes.

Results

Pretest – posttest comparison

The results of the tests for the students in both classes were pooled, resulting in a total of 49 students. The results of the posttest were compared with those of the pretest using a paired sample *t* test. The difference between the results of the two tests was significant, which indicated that there was a significant improvement in the students' understanding of concepts associated with chemical bonding ($t = 8.45$, $df = 48$, $p < .0005$, two-tailed). The effect size was large ($d = 1.23$). The items that were designed to assess students' representational competence were compared using the Wilcoxin Signed Ranks test. This non-parametric test was used since the data were ordinal in nature (Knapp, 1990). Again the posttest scores were significantly higher than the pretest scores for each of these three items ($p < .0005$, $N = 49$, two-tailed). These results suggest that the use of digital resources within scaffolded student-focused activities were effective for enhancing students' understanding and representation of chemical bonding relationships and concepts.

Student interviews

The thematic analysis of students' responses to the interview questions revealed five themes within which there were 12 sub-themes. The themes (subthemes shown in brackets) focused on (1) Learning with and creating multimodal communication (Shaping texts, Using and transforming modes of representation); (2) Student engagement (Motivational factors, Promotion of higher order thinking); (3) Pedagogical approaches (Making connections beyond school, Student-centred activities, Teaching with digital technologies); (4) Scaffolding learning with digital technologies (Visualisation, Text production, Research and information selection); and (5) Multimodal text production strategies (Planning and drafting, Seeking information and clarification). An elaboration of each of these 12 sub-themes is beyond the scope of this paper. In addition, some sub-themes within Themes 4 and 5 relate to the students' experiences in a phase of the study not presented in this paper. A summary with some illustrative examples of relevant student comments relating to Themes 1 to 4 are provided here.

Theme 1 centred on the students' perceptions that the process of creating and communicating using multimodal texts and representations strengthened their understanding of the content as well as helping them develop a better understanding of the representations used: "Using pictures makes it easier to express ideas and to explain than using words. When I can use diagrams and pictures … they really help you to explain. Sometimes you get stuck on words and structural diagrams really help you to show things" (Student 39). Other comments reflected the students' perceptions that using the molecular modelling software helped them to make links between the structure and properties of substances: "ChemSketch was good because it helped you to get used to the different types of diagrams and how to interpret the different diagrams. We could understand how this could be polar, and how this wasn't and why. So it made more sense" (Student 30). This comment suggests that the process of creating digital models also helped students to develop a clearer understanding of the representations themselves.

The second theme centred on the students' engagement in learning. Twenty-three of the 24 students mentioned fun or interest, making a total of 45 references to these factors. The students suggested that using computers in their learning was a motivating factor: "I liked the technology … it wasn't just 'copy this down off the board' and we got to see visualisations and to interact with them, I went home and downloaded ChemSketch the first day we used it and have used it since at home – I really liked that" (Student 12). Some students commented that they enjoyed the learning because they felt their understanding was enhanced: "I've enjoyed understanding everything – I liked doing things and understanding how the chemicals worked" (Student 35); "I didn't get anything last year – I didn't understand anything and this year was fun because I understood" (Student 38).

Theme 3 focused on the pedagogical approaches used. The students were able to make connections between the practical and theoretical lessons and activities. They felt that they were in charge of their learning. The following comment illustrates these ideas: "Biopolymers – because we made them in the lab and then reading about the making of them – we understood it because we actually did it – like turning from a solution to a plastic and drying out and then having all the properties. … I liked doing things and understanding how the chemicals worked, not just writing and information transfer because I knew what everything meant. This year it wasn't just information but the learning came from me as well and I really liked that" (Student 35).

The fourth theme focused on the students' perceptions of the ways in which using digital technologies scaffolded their learning, particularly in terms of their ability to visualise the sub-molecular processes: "ChemSketch helped me to understand the molecular structure and the shapes of molecules" (Student 3); "When I talk about concepts, I can picture the molecules in my head" (Student 36). A similar theme was reflected in comments about the simulations: "Molecular Workbench … I liked the simulations – that was one thing I got straight away because it was so visually there – I didn't have to shrink myself down. I got it because the molecules were moving – I got it first go" (Student 1).

Discussion

The findings from this phase of the study revealed a number of positive outcomes associated with providing learning opportunities for chemistry students to learn through the use of a range of digital technologies. The results of the pre-post test comparison show that using digital technologies to teach and learn chemistry can enhance conceptual understanding and promote the development of students' representational competence and their ability to create, select and use various representations to help them understand and to communicate. In particular, the representational competence items illustrated the importance of allowing students to learn about and with individual representations if they are to be able to effectively use such representations in their explanations of chemical phenomena.

The students felt that the computer-based activities helped them to develop a deeper understanding of the concepts involved. Their responses also suggested that engaging in such activities developed their understanding of multiple representations and their ability to use them for problem solving and for communicating their understanding and explanations. The use of such representations, in particular the simulations, promoted the students' ability to visualise chemical phenomena and processes. These outcomes suggest that digital technologies can assist students to address the problems identified in the literature (e.g., Davidowitz & Chittleborough, 2009; Gabel, 1999; Treagust et al., 2000) such as the difficulties experienced by chemistry students in understanding underlying causes of chemical phenomena observed and making links between their observations and the symbols and diagrams used to explain and represent them.

The students' interview responses showed that they found learning with digital technologies motivating. This is an important outcome since so much research suggests that many students do not enjoy studying science subjects, that they disengage from them because they are not interesting or exciting or because they are perceived as being either too difficult or insufficiently challenging (Goodrum, Hackling, & Rennie, 2000; Osborne & Collins, 2001).

Other benefits are related to the affordances of digital technologies to promote students' interactions with one another. For example, while students were seated at individual computers, the layout of the room allowed them to collaborate and discuss their ideas either in pairs or groups of four. This often occurred naturally as the students worked through assigned activities. The ability to create models on screen provided students with a visual representation to support their discussion. Students often used the models they had constructed to explain an idea to a peer or to justify or defend an answer to a question. Without the visual representations, it would not have been possible for the students to engage in this type of discussion. This suggests that an important implication of using with digital technologies is the need for teachers to include opportunities for both independent and collaborative learning with digital technologies in their lessons. This aligns with Ainsworth's (2008) suggestion that teachers need to develop or adapt strategies to maximise the benefits gained by students through the use of such technologies.

A key pedagogical consideration for teachers in using digital technologies in the ways that have been described here is the need for learning to be student-centred. The activities will, by their nature, be student-directed and in many cases, self-paced. Teachers need to be mindful of the fact that often, learning activities will take more time than one might expect of a direct instruction lesson about the same concepts, however, the findings from this study suggest that the benefits for the students are both positive and diverse, ranging from deeper understanding and promotion of higher order thinking to enhanced motivation and enjoyment. While beyond the scope of this paper, other findings from this study were used to develop a model for designing learning sequences utilising digital technologies in chemistry (see Hilton, Nichols, & Gitsaki, 2010).

Conclusion and implications of the case studies

With the introduction of digital technologies in recent decades, scientific forms of communication have expanded (Cairo, Karchmer Klein, & Walpole, 2006). The challenge for educators is to ensure that the ways students 'do' science and communicate in science parallel the ways in which professional scientists communicate (Kress, Jewitt, Ogborn, & Tsatsarelis, 2001; Prain, 2006).

The digital technologies used in the two case studies reported here have unique affordances with the power to enhance students' learning experiences in a variety of ways. For instance, in the use of video production in science, Ramadas (2009) stated that it has the capacity to capture much of the visual and spatial thinking that is the core of science learning. In calling for knowledge transformations to cross different modes of representation, Knain (2006) stated that digital technologies were able to facilitate the transformation across the modalities of scientific texts. Recently, Prain (2006) referred to a "growing recognition of the insufficiency of written language on its own to represent processes of reasoning, measuring, and explanation in science activity" (p. 180). Further, as noted by Unsworth (2001) and Gee (2005), science has complex literacy demands because of the diversity of symbols, representational systems, and practices used, a statement that is especially true of abstract concepts in subjects such as chemistry. Multimedia, modelling, and learning tools, such as simulations, have the capacity to support both teachers and students in the development of complex subject-specific literacies.

Kimber and Wyatt-Smith (2006) highlighted the need to find ways of maximising student learning in the school context by utilising digital media to enhance their cognitive, sociocultural, and technological capabilities. The development of pedagogies that can efficiently utilise video technology and multimedia tools is crucial. The case studies have provided evidence of the effectiveness of such technologies to enhance students' learning outcomes and to promote motivation and engagement.

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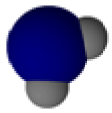
Appendix 1 Sample Task Sheet for ChemSketch Activity

CO_2  O=C=O

REPRESENTING MOLECULES

 O–H | H H_2O

Background

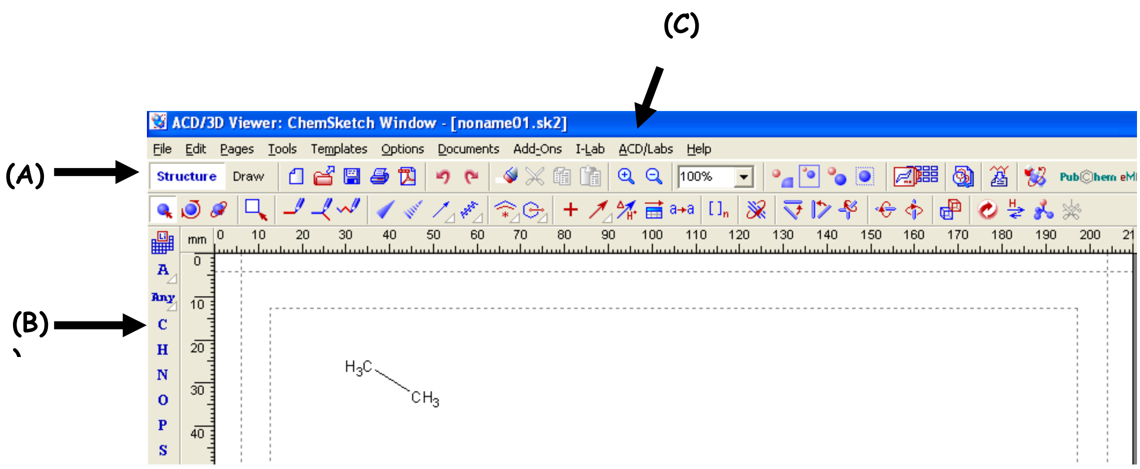
There are many different ways that chemists use to represent molecules visually and chemical reactions symbolically. Some of the representations they use provide different information from others.

Aim of this activity

In this activity, you will learn to use a program called *ChemSketch* and use it to create different representations of molecular compounds and elements.

Using *ChemSketch*

1. Open the *ChemSketch* program.
   - Choose Start, Programs, Science, ACDLabs 12.0 (C).
   - Open both ChemSketch and 3D Viewer
2. Click on Structure (A), select carbon (B) and draw ethane, $CH_3 - CH_3$ by clicking and dragging on the screen. Your screen should look like this one:

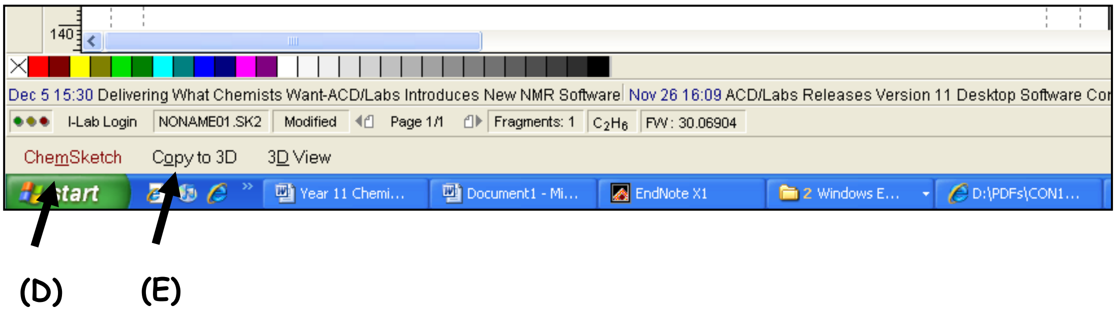


**You can choose a different element for your drawing by clicking its symbol on the side toolbar

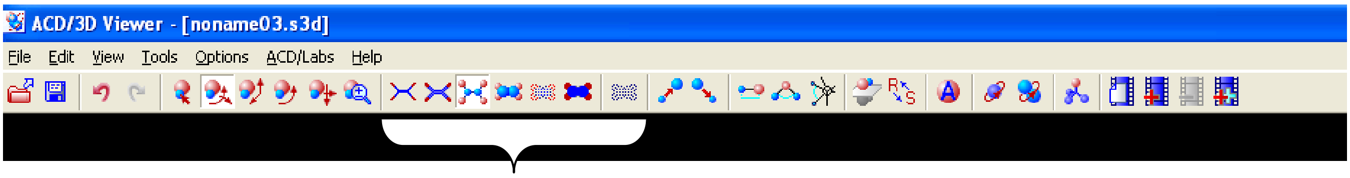
The diagram you have just created is called the condensed structural formula of ethane. The molecular formula of ethane is C_2H_6.

3. Click on ACD/Labs (C) and select 3D Viewer. This will open a new screen in the 3D Viewer.

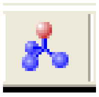
4. Return to ChemSketch by clicking the tab on the bottom toolbar (D) and select "Copy to 3D" on the bottom toolbar (E).



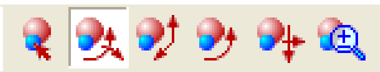
5. Explore the different options to view a range of representations using the toolbar at the top of the 3D Viewer screen.



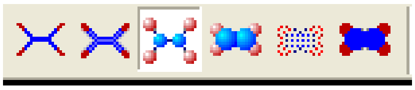
These tools let you create different types of representations. Hover over them to learn their names.



This tool optimises the model – it adjusts your structure to give it the right bond angles etc.



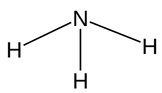
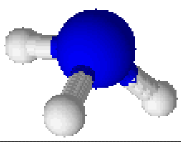
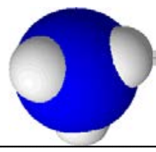
These tools allow you to rotate and examine your model in a variety of ways.



These tools allow you to select a number of different visual representations.

Activity 1: Investigating Molecular Geometry

1. Return to *ChemSketch* (using the bottom toolbar).
2. Create a model of ammonia, NH_3.
3. Use *3D Viewer* to create the representations with an asterisk (*) in the following list and copy and paste them into a table in *Word.* Use these headings:

Name & Molecular formula	Structural formula	Ball and stick model (*)	Space filling model (*)	Molecular Shape
Ammonia, NH_3				Pyramidal

4. To copy, press "Control C" or choose Edit, Copy.

5. To paste into *Word*, choose Edit, Paste special, Picture. You can then format, resize, etc. as you like.
6. If the formula has hydrogen atoms attached, you can remove them from the diagram by creating a double or triple bond. Create double or triple bonds by clicking on a single bond.
7. Repeat Steps 2 and 3 for the following and add them to your table.

a) Bromine (Br_2)
b) Oxygen (O_2)
c) Nitrogen (N_2)
d) Water (H_2O)
e) Sulphur dioxide (SO_2)
f) Carbon dioxide (CO_2)
g) Phosphorus trichloride (PCl_3)
h) Methane (CH_4)
i) Silane (SiH_4)

Don't forget…

- Optimise in *3D Viewer* to get the right shape for your molecules or to add hydrogen atoms if they're missing
- You might need to create double bonds to get the right structure and remove hydrogen atoms.

Appendix 2 Pretest and Posttest Representational Competence Items

QUESTION 1

Complete the following table using the representations indicated

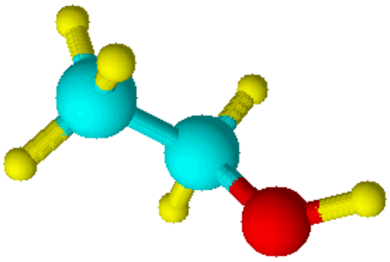
	Before sodium chloride is placed in water in a beaker	Sodium chloride is placed in water	15 seconds after sodium chloride was added to water	1 hour after sodium chloride was added to water
Drawing/diagram				
Explanation				

QUESTION 2

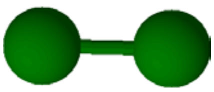
A group of students tested the electrical conductivity of pure water and salt water. They found that salt water conducts electricity whereas pure water does not. Use appropriate representations to explain their observations.

QUESTION 3

This diagram shows two different substances. Which do you think has the lowest boiling point?



Ethanol, CH_3CH_2OH



Bromine, Br_2

I Ethanol II Bromine

Explain using appropriate representations