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Making Connections: Learning and Teaching Chemistry in Context

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Abstract Even though several studies have reported positive attitudinal outcomes from context-based chemistry programs, methodological obstacles have prevented researchers from comparing satisfactorily the chemistry-learning outcomes between students who experience a context-based program with those who experience a content-driven program. In this narrative inquiry we are able to address the question: how do the recalled experiences of a student and her teacher in context-based and concept-based chemistry programs compare? From the student's unique perspective of experiencing both programs with the same teacher, we have constructed our collective account around four themes; namely, the extent to which the student makes connections between chemistry concepts and real-world contexts, developing research independence through engaging in extended experimental investigations related to contexts, learning chemistry concepts through contexts, and conceptual sequencing in a context-based program. The student reported real-world connections between chemistry concepts and contexts, found her engagement in the context-driven tasks interesting and productive, and identified connected sequences of concepts across the contexts studied. Despite difficulties for teachers who are required to shift pedagogies, the student's lived experiences and outcomes from a context-based program provide some encouragement in working through these issues.

Keywords Context-based approach · Chemistry curriculum · Teaching and learning · Narrative inquiry

> The chemistry this year… you can see the real-life aspect to it where this year we look at a particular thing and see the chemistry behind it where[as] last year we just looked at the chemistry without seeing the real-life application. Like this year with the *Pandora* (the name of a shipwreck off the North Queensland Coast) [unit] we looked at how gas laws affect scuba divers where last year we just looked at Boyle's Law as pressure and volume. (Amanda, October 18, 2006).

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In this comment Amanda (a pseudonym) recounts how her context-based chemistry curriculum – that focuses on the application of science in such a way as to develop students' capacities to function as responsible participants in their everyday lives[1] – enabled her to make connections between gas laws and real-life activities like scuba diving. A student report like this about one of the perceived strengths of a context-based chemistry program is not surprising. The literature is replete with similar anecdotal comments from engaged and interested students (e.g., Bennett and Lubben 2006; Gilbert 2006; Gutwill-Wise 2001; Ramsden 1997; Schwartz 2006). What is particularly unusual in this case is that Amanda's experience is quite unique. After completing a 2-year traditional (conceptually-based) chemistry program, Amanda repeated her final year of high school. However, the chemistry program at the school (as required by the State assessment board/authority) had changed from a concept- to a context-based approach. Amanda then experienced a different (i.e., context-based) chemistry program in her repeat year. Her comments are not simply anecdotal musings about what it was like to study chemistry in context. Rather, she was able to compare authoritatively, as we see in the leading comment, her experiences in both context- and concept-based chemistry programs. Amanda's "misfortune" of repeating her final year of school at a time when the program shifted from one approach to another provided us with a serendipitous opportunity to compare a student's lived experience across two very different approaches to learning chemistry.

Amanda's teacher, Alberto (i.e., the second listed author), brought Amanda's case to the attention of Donna (i.e., first listed author) and Steve (i.e., third listed author) during an informal conversation at a recent conference we attended together. During this conversation we recognised collectively the potential contribution to the research literature Amanda's insights could offer – she had experienced both approaches to similar chemistry topics that were taught by the same teacher. As we discussed the potential of documenting and interpreting Amanda's perspectives on both approaches we hurriedly mapped out a research plan before this opportunity was lost.

Our narrative account of what we have come to know about context-based approaches to chemistry teaching in this case was principally informed by Amanda's responses to two interviews conducted by Alberto towards the end of Amanda's formal high school commitments (see Appendix for sample interview questions). The two interviews were separated by a 1-week time frame. During this time, Donna transcribed the first interview, and both Steve and Donna posed additional questions that could be asked at the second interview. Alberto also prepared a set of statements about learning and teaching chemistry through contexts from his own experience. These statements were shared with Amanda at the end of the final interview to stimulate further discussion about her chemistry experiences. Of course, as we read the transcripts and listened to the tapes we each made connections to our own research programs and former experiences. We also have drawn on these connections as we individually and collectively interpret Amanda's responses. Before we discuss these interpretations, we establish Amanda's credibility as a reliable informant.

[1] While there are different ways of defining context-based learning, the trial pilot chemistry syllabus in Queensland defines context as "a group of learning experiences that encourages students to transfer their understanding of key concepts to situations that mirror real life" (Queensland Studies Authority 2004, p. 11). Generally, a context-based approach and related science-technology-society (STS) curricula adopt an alternative rationale for learning experiences for students than traditional or conceptually focused programs. The focus in a context-based approach is on the application of science as a means of developing scientific understanding in such a way as to develop students' capacities to function as responsible participants in their everyday lives (Aikenhead 2006; Bennett 2005).

Something about Amanda

Amanda was a confident young woman who had been a volunteer research "subject" in Alberto's research program on analogies in chemistry for 3 years. In this final (repeat) year at high school, Amanda turned 18. When the focus of Alberto's research shifted from analogies to context-based learning for the purposes of studying Amanda's experiences with the contrasting approaches she had encountered, he renegotiated Amanda's participation and informed consent. On this occasion, Amanda, now an adult, signed the required ethical clearance forms for herself.

Amanda was an average student in chemistry. Her exit level of achievement for chemistry in 2005 and 2006 remained the same despite repeating Year 12. Amanda knew her final results at the time of the interviews, due to the nature of the progressive school-based assessment program at the school (as required by the assessment system across the State for the last 30 years or so). In other words, Amanda knew that her participation and comments in the interviews could not influence her final results. We were satisfied that Amanda's comments were both honest and reliable. For example, Amanda's comments from the first interview (on October 18, 2006) that matched Alberto's perceptions of the implemented curricula included: "We have done more excursions this year"; and "[W]e did the EEI (Extended Experimental Investigation) [this year]. We had an experiment that we had to set up ourselves, and research behind it; that was really interesting, that was more independent. We could do what we wanted to do by doing the research ourselves, it helped us learn more too…." A comment that initially took Alberto by surprise, however, was: "I don't think we have done any pracs this year but last year we did." This comment could be taken as uncomplimentary because most students enjoy "pracs" or practical activities (Friedler and Tamir 1990; Gibson and Chase 2002; Hodson 1990; Hofstein 2004; Okebukola 1986). This demonstrates Amanda's capacity to offer honest opinions without fear or favour – calling it as she saw it. While we do not claim that Amanda's comments are impartial or in some way objective claims that could be verified by "outsiders," they are nevertheless truths of her experience. As noted by the Personal Narratives Group (1989):

> When talking about their lives, people lie sometimes, forget a lot, exaggerate, become confused, and get things wrong. Yet, they are revealing truths. These truths don't reveal the past "as it actually was," aspiring to a standard of objectivity. They give us instead the truths of our experiences. (p. 261)

Although Alberto did not challenge Amanda's comment in the context of the interview, it caused him sufficient concern to reflect on how Amanda could come to such a view when his perception was so different.

> *Alberto: At first I thought no, we did heaps of prac work with the Extended Experimental Investigation (EEI) taking perhaps two weeks of straight lab work. Looking back over the year though, I realise that there were fewer cookbook-style pracs and pracs in general. I can explain this now in retrospect in terms of the organisation of the units of work. As it was the first time that we were teaching these contexts, the other chem. teacher and myself were really doing things on the run most of the time. So in units that were not based around the EEI, such as the unit on the Chemistry of the Human Body at the end of semester 1, we did very little prac work. It was very theoretical. Also, the end of semester assessment was a traditional style test and this tended to focus the instruction more on theoretical rather than practical aspects of chemistry. However, in second semester we focussed on one unit for the two*

terms, The Chemistry of Pete Creek (a pseudonym). This involved a field trip where students collected water samples from a local creek and analysed them for various water quality parameters. Leading up to this unit, students had practised the various water quality tests and learnt to use the datalogging equipment for some time. Perhaps her impression is based on the fact that in the units after the Pandora (the name of an archeologically significant shipwreck off the coast of North Queensland) unit there were few structured, worksheet-based practical activities. In terms 3 and 4 students conducted 1–2 experiments dealing with solubilities of various materials in a range of solvents including water.

The shift to a context-based approach then, led to the substitution of weekly cookbook practicals by a single EEI for the designated *Pandora* unit, for which each student planned his or her project with Alberto before undertaking the procedures. Subsequent units involved analysis of water samples collected in the field, but again these were not scheduled as weekly cookbook practicals from which students could tell the expected outcomes by reading the stated aim for each prac. When asked for her preferred approach to lab work, Amanda replied: “I think the one we used this year is better. You find you are [covering] more the other way (i.e., concept-based approach) when you don’t have to do the research behind it it’s a lot faster. You can do things faster but you don’t learn as much in the process” (October 18, 2006). This view is consistent with research that demonstrates inquiry-based science activities promote interest in the study of science, enables students to ask better questions and gives them a greater sense of ownership over the scientific problem (e.g., Hofstein and Kesner 2006).

Other Methodological Matters

We start our interpretive procedures with Amanda’s comments. Alberto reflects on these comments, as above, in relation to his experience as Amanda’s teacher – both providing emic (or insider) perspectives of their lived experiences in the same classroom for 3 years. As Donna and Steve read these commentaries they made connections to their own experiences – each providing an etic (or outsider) perspective.

In Donna’s case, she was able to draw on her formal investigation into the implementation of a context-based approach to chemistry at a different school. In this study, Donna observed a Year 11 chemistry class for a term during a unit on water that she co-designed with the classroom teacher. She also interviewed the teacher and a selection of students on numerous occasions, and analysed the students’ formal culminating reports. In a separate but related study, Donna interviewed a sample of innovative chemistry teachers who had implemented context-based chemistry programs in their schools (King 2007). This gave her an opportunity to make connections between the experiences of a wider sample of chemistry teachers and those expressed by Alberto and Amanda.

In Steve’s case, he was able to reflect on the data from both Alberto’s classroom and that which was studied by Donna, by relating these to his previous studies of Year 11 and 12 high-school students, who were engaged in extracurricular-chemistry research projects in a university laboratory under the supervision of a practicing scientist (e.g., Ritchie and Rigano 1996).

As we explore the question, “how do the recalled experiences of a student (and her teacher) in context-based and concept-based chemistry programs compare?” we use both first-person and third-person methods in the genres of narrative inquiry and auto/biography, to a lesser extent, to establish intersubjectivity that escapes the false dichotomy of objectivism versus subjectivism (Roth 2005). As Roth argued, "Auto/biography and auto/ethnography… can… contribute tremendously to the study of cultural practices concretely realized in our patterned behaviours acquired in and through socially mediated participation in societal affairs" (p. 9). We exercise some caution with the claims we make, however, due to the limitation that Amanda's most recent experience with context-based teaching might have coloured her recollection of her experiences in the concept-based program.

While there is no universal agreement on the criteria for judging narrative inquiry (e.g., Clandinin and Connelly 2000), Elbaz-Luwisch (1997) commented, narrative researchers:

- Aspire to collaborate with participants to produce multi-voiced texts (see also Brockmeier and Harré 1997)
- Challenge the prevailing logistical view which underlies technical rationality of much educational research
- Accept that educational practice is changed from the inside, by practitioners working together, often with the help of researchers
- Do not aspire to generalization
- Do not promise immediate practical benefits
- Attempt to gain increased understanding of the multitude of meanings that are created by practitioners and by researchers working together. (pp. 76–78)

Unsurprisingly, the interpretations reported in articles authored by narrative researchers tend to be believable partial truths, requiring the text to be open to alternative interpretations that might lead to greater understanding of the issues but not certainty (Riessman 2002). We use narrative inquiry in this study with the intention of awakening readers' stories of related experiences that might reinforce practices they value or help transform those practices they identify needing change, and/or to gain insight into unfamiliar life experiences. Interestingly, Clandinin and Connelly (2000) noted "many narrative studies are judged to be important when they become literary texts to be read by others not so much for the knowledge they contain but for the vicarious testing of life possibilities by readers of the research that they permit" (p. 42).

While it is appropriate that we, as co-authors, attempt to make connections between Amanda and Alberto's experiences and our own research experiences, we inevitably will use language that already is connected to others who read the account, bringing together our collective subjectivities. Accordingly our narrative account of any observed or perceived similarities and differences between our shared experiences is crafted in a similar fashion to some fairly recent studies of science learning and teaching (e.g., Barton and Darkside 2005; Hart et al. 2000; Tobin 2000).

Comparing Experiences: Concept- versus Context-based Chemistry

The results from mostly quasi-experimental studies have shown that context-based/science-technology-society (STS)[2] approaches develop a level of scientific understanding

[2] We group context-based and STS approaches because Bennett (2005) found it too difficult to distinguish between implemented programs aligned with each approach. Both approaches adopt an alternative rationale to more conventional programs. The focus in context-based and STS programs is on the application of science to develop students' capacities to function as responsible participants in their everyday lives (Aikenhead 2006; Bennett 2005).

comparable to that of conventional courses (Barber 2000; Barker and Millar 2000; Eijkelhof and Lijnse 1988; Ramsden 1997; Smith and Bitner 1993; Wierstra 1984). However, there is limited evidence to suggest that understanding may be enhanced as a result of employing a context-based approach (Banks 1997; Bennett 2005; Tsai 2000; Winther and Volk 1994). Stronger evidence supports context-based/STS approaches fostering a more positive attitude to school science over conventional courses (Barber 2000; Key 1998; Smith and Matthews 2000; Wierstra 1984; Yager and Weld 1999; Zoller et al. 1990; Zoller et al. 1991). In Australia, studies of context-based physics and chemistry programs have shown that contexts help students make links to their experiences (Lye et al. 2001), and teachers see relevance and motivation as advantages of context-based approaches (Wilkinson 1999). Despite these positive outcomes, teachers have expressed concerns that their students experience difficulty transferring learning and applying concepts to situations outside the context (Vignouli et al. 2002; Wilkinson 1999). By comparing Amanda's experiences in both concept- and context-based chemistry programs through narrative inquiry, we are able to contribute additional insights into the growing body of evidenced-based literature on the outcomes of context-based approaches to chemistry.

There are four main issues of importance to both teachers and researchers in relation to context-based chemistry curricula that we have gleaned from Amanda's comments and the related literature. The first issue was identified in Amanda's opening remarks, namely, to what extent does a context-based approach help students make connections between chemistry and real-world applications or contexts? The second issue concerns what Amanda (and other chemistry students) perceives she learned from engaging in extended experimental investigations. The third issue addresses the enduring question: do students in a context-based program learn or can learn important chemistry concepts through contextually-focussed tasks? Finally, the fourth issue deals with curricular coherence; that is, how does a student like Amanda perceive the relative "delivery" of conceptual sequences between the contrasting programs (i.e., concept- v context-based)? Each issue is addressed separately. As we deal with each in turn we highlight Amanda's comments and relate these to the relevant literature and our own personal (auto/biographical) experiences.

Issue 1: Connections to the Real World

Ten units structured the concept-based chemistry program that Amanda experienced in 2005. They included established topics such as Oxidation-Reduction, Chemical Equilibrium, Electrochemistry and Electrolysis. In the repeat year in 2006, as Alberto indicated in his previous reflection on Amanda's opening comment, the context-based program featured three context-based topics or units. In each of these contexts, according to Amanda, students were afforded opportunities to make connections between chemistry concepts and real-life applications such as the restoration of archeologically significant metal artefacts (in the *Pandora* Unit), the water quality of the local creek (in the Water Unit), and the healthy functioning of the human body (in the Chemistry of the Human Body Unit).

Since chemistry concepts from the traditional program were taught in Amanda's first year of chemistry, it could be argued for Amanda, that the second year was merely an application of the previously learned concepts. For example, the topic of Redox was dealt with in both years. However, there were concepts that emerged through the context that were different from her previous year's experience. In particular, the chemistry of corrosion that featured in the Pandora unit in regard to the restoration of artefacts, was absent in the traditional course. Also, solubility and precipitation reactions in the second year required new conceptual links with water treatment. This is evident in the following quote where Amanda articulates the differences in the learning of solubility between the 2 years:

> Like this unit we are doing now with soluble and insoluble ions we are actually seeing how adding the calcium carbonate to water by adding the carbonate to water you can get the calcium out of it where we just knew last year okay calcium carbonate is insoluble. Now we are seeing how it can affect water treatment. We are actually seeing a use for it which we didn't get last year. (October 18, 2006)

In this topic, students learnt how the concentration of calcium ions affects the hardness of water. The concept of 'hard water' was introduced for the first time in the repeat year allowing students to explore how the 'hardness' could be removed. These real-life connections were not merely applications of previously learnt concepts; rather, they were concepts that emerged through the real-life context that were different from the previous year's experience.

Learning concepts like solubility through this context now enabled Amanda (and possibly other classmates) to make real-life connections to water treatment. This contrasted with Amanda's previous experience in the more traditional concept-based approach she encountered in 2005. In fact, Amanda identified real-life connections as a positive feature of the context-based approach over the concept-based approach on 16 occasions during the interviews in ways similar to the following representative comment: "You can see the real-life aspect to it…. [T]his year we look at a particular thing and see the chemistry behind it where[as] last year we just looked at the chemistry without seeing the real-life application" (October 18, 2006). Similar comments were made by the boys at St. Anthony's in Donna's study.

> *Donna: Amanda's comments about the real-life application of the chemistry reminded me of my observations of the Year 11 chemistry class in my study (e.g., King and Ritchie 2007) at the boys school to which I have given the pseudonym: St Anthony's College. The assessment for the water unit was embedded in the completion of an Extended Response Task (ERT) or a report on the water quality of the local creek. Like Amanda, they preferred chemistry when they had to "do it yourself" like real-world chemists. This was expressed most clearly by one of the boys in the study as follows: "It's like a real-life situation where you do it yourself....It gets into your head a lot more and you understand the concept rather than just going through it and remembering the notes and stuff." This is similar to comments Amanda made about how she prefers to see how the chemistry is applied through visualisation. "You can see how it's applied more when you see more applications you get a better understanding. I like visualisation as well and a lot of other people do too. You can see what's happening it helps you" (October 24, 2006).*

Many studies have shown that if students are able to see how the laboratory work relates to their "real life" and have a greater sense of ownership of the investigation they are likely to be more motivated and successful in the area of science they are investigating (Hofstein and Kesner 2006; Hofstein and Lunetta 2004; Key 1998; Rigano and Ritchie 1994; Skinner 1994). Making real-life connections between chemistry concepts and the contexts in which they were realised have been shown to have positive affective outcomes for many students who have studied senior science through a context-based approach in overseas studies (Ramsden 1997; Sutman and Bruce 1992), as well as research conducted in Australia and New Zealand (Lye et al. 2001; Rodrigues 1993). Amanda and the Year 11 students in Donna's study generally expressed a preference for a chemistry approach that makes connections to the real world. This provides some evidence for Linn's (2000) reasoning that "if students connect ideas from science class to personally-relevant contexts then they will be poised to revisit these ideas outside of class" (p. 783). In contrast, "[w]hen students cannot connect school and home understanding, they follow a path of isolating, fragmenting and, ignoring the science instruction they encounter in school" (Linn 2000, p. 783).

While we return to the issue of conceptual understanding later, Amanda commented that the context-based approach helped her make real-life connections to chemistry content, and that this increase in relevance enhanced her interest and engagement in chemistry. In relation to the *Pandora* Unit, Amanda said, "we went to the *Pandora* and saw how they are trying to salvage artefacts for shipwrecks and that, that's really interesting" (October 18, 2006). When asked to compare her experiences between the two approaches across 2005 and 2006, Amanda made some interesting observations about the relative engagement of the different cohorts of students. In the second interview, Amanda noted:

> Last year a lot of the kids just didn't pay attention in class because they thought it was boring where if they thought it was interesting they would have paid attention…. [This year] it is more of a discussion and the kids are asking questions. They are obviously paying attention like they know what they have got to learn. (October 24, 2006)

From Amanda's emic perspective, she equated her perceived increase in student-initiated questions to greater student engagement and interest in chemistry and a sense of purpose for learning chemistry. We acknowledge that Amanda's observations and inferences, by themselves, do not prove that a context-based approach to chemistry engages students in more relevant and interesting activities from which students can more readily identify connections to real-world phenomena that give purpose to their learning. Alberto, as Amanda's chemistry teacher held a different view of student engagement in the context-based chemistry class.

> *Alberto: I found Amanda's comments interesting once again both as her interviewer and teacher. I would agree with Amanda in saying that students seem interested in the contexts they studied. However, I am not sure that I see a larger number of interested students than in previous years. From my perspective, I would probably rate student engagement in class activities the same as in the concept-based courses from previous years. Amanda is correct in saying that there was plenty of discussion in her class this year but this might have more to do with the dynamics of that class rather than the contextual course.*

Notwithstanding Alberto's cautionary note above, Amanda's views along with our collective observations elsewhere align well with other studies of implemented context-based approaches to chemistry. For example, a study (Ramsden 1997) that compared the Salters' suite of context-based programs (e.g., University of York Science Education Group [UYSEG] 2000) developed in the UK, with the more traditional General Certificate of Secondary Education (GCSE) course, reported that one of the benefits of the approach was stimulating students' interest in science. A typical comment made by students in the Salters' course was: "I have enjoyed the things that actively interest me as a person and help me understand things outside school" (Ramsden 1997, p. 709). In contrast, no non-Salters' students made statements specifically about the relevance to their lives of what they had studied. Similarly, a comparative evaluation between ChemConnections (American Chemical Society [ACS] 2001), a context-based course in the USA, and more traditional approaches, showed that context-based courses improve attitudes towards chemistry beyond the level currently seen in traditional courses (Gutwill-Wise 2001). Students reported that they "understood the material better, enjoyed the course more and would be more likely to recommend the course than the non-Modular (traditional) section students" (Gutwill-Wise 2001, p. 688).

Issue 2: Connections from Extended Experimental Investigations

The main task Alberto's students completed during the *Pandora* unit was an EEI. In this task students were required to design an investigation to determine the optimum conditions for the electrolytic reduction (restoration by electrolysis) of a series of rusted nails. Students had seen *Pandora* artefacts during an excursion to the Museum of Tropical North Queensland. They had also been lectured on the methods used to restore and conserve metal artefacts by the Museum's conservator. Students remarked at the extensive information the conservator shared with them and the extent to which he related chemical concepts to everyday situations, even outside his own field of work. These experiences and material objects set up the context for the EEI; that is, the rusted iron nails represented marine artefacts and the students' task was to identify suitable conditions for the restoration of metal objects from a mythical shipwreck using the nails to test the conditions for electrolysis required to produce rust-free nails.

Through the context students had encountered a range of chemical concepts. Since marine artefacts must first be salvaged and then restored, students learnt how the gas laws related to diving in the context of salvage missions. Subsequent to this, students learnt how REDOX chemistry applies to reversing the process of corrosion of metal objects. Instruction ranged from teacher lectures and demonstrations to student independent research during the unit.

Undertaking the EEI involved students researching related concepts in texts and relevant websites, selecting variables relevant to accelerating or reversing corrosion, planning investigations, and testing a series of selected variables related to electrolysis that might help to reverse corrosion. Some conditions that students chose to investigate included the temperature of the electrolyte, type of electrolyte, concentration of electrolyte, running temperature of electrolyte, potential difference across the electrodes, type of electrode, arrangement of electrodes, and running time. The task was demanding in a number of ways. While all students were familiar with the process of electrolysis from their Year 11 studies (although Amanda was unfamiliar with the EEI process) they were not familiar with the more complex process of electrolytic reduction. Thus, while they had the skills required to set up their equipment, the variables that would provide ideal results were unknown. This was also true for Alberto and the other Year 12 chemistry teacher. In fact, while suitable conditions for the electrolysis of iron artefacts are available, the dependence of the outcomes on the size of the object being restored meant that no known process was available to students or teachers alike, even with thorough research on the internet. Amanda's group chose to investigate the optimum time and type of electrolyte for reducing the rusted nails.

Undertaking an EEI in chemistry in her repeat year was a new experience for Amanda. When Alberto asked Amanda to compare the lab work between the two approaches, she commented:

> Prac reports I find really easy because you do your first prac write up in primary school. You do little experiments, but now the EEI there was a lot of research we had to understand the background behind what the report was going to be on. We had to set up everything ourselves it was completely independent. All the research and notes we had to do ourselves. (Amanda, October 24, 2006)

Amanda used the word *independent* on six occasions during the interviews when describing how her experience with the EEI compared with previous years of doing chemistry practicals. As we can see from this comment and her previous response in Interview 1 (on October 18), as noted earlier, Amanda not only felt more independent as she researched a particular problem in depth, but also she felt she developed a deeper understanding of the related chemistry in the process.

> *Steve: Amanda's comment instantly reminded me of a study I did with Year 11 and 12 chemistry students who worked on an authentic extracurricular research project in a university laboratory more than a decade earlier (Ritchie and Rigano 1996). Over the three-month project, both students in my study, like Amanda in many respects, developed skills in advanced laboratory techniques to become independent researchers – similar to other researchers working in the laboratory.*
>
> *At that time, well ahead of the implementation of context-based approaches in chemistry in Australian schools, I was uncertain whether students with less capacity and perseverance for chemistry research in typical school settings could attain the same sense of independent research. I hesitated to recommend similar open-ended laboratory projects for all, identifying problems associated with the possibility of reinforcing negative attitudes to science for less committed students, and the difficulties for typical chemistry teachers to supervise these projects. I think from what we have heard from practising teachers, they too share concerns with the extra responsibilities and conceptual difficulties associated with such supervision (e.g., Beasley and Butler 2002; King 2007). That Amanda, an average student in chemistry, completed an extended project independently with such positive attitudinal outcomes is encouraging for other teachers. Notwithstanding Alberto's superior academic background in both chemistry (i.e., Alberto completed one-year of a doctorate in biochemistry before entering a teacher education program) and chemistry education, it might be possible for typical chemistry teachers to develop confidence in managing EEIs with experience, especially as more resources become widely available to schools.*

For the second half of the second interview, Alberto shared four points – he had printed out on a single sheet of paper – with Amanda. These summarized his (teacher) perceptions of the differences between the traditional and context-based chemistry programs he had implemented. In relation to how he perceived EEIs impacted on students, Alberto declared:

> I think that the EEI provides students with an opportunity to investigate a topic and carry out experiments on the topic, and the research allows students to look in greater depth at specific topics and content. Students do a lot of independent research and learn a lot of concepts along the way that are not all necessarily taught in class.

In response to Alberto's documented perceptions, Amanda took up the issue of independent study for comment:

> With the EEIs I think it teaches us to be independent which is good for students who go to uni and that they already have the skills in school to do an assignment independently so they can carry on with uni. And because we have to do the research ourselves we have to do the hard work for it we haven't been handed everything and so I think students appreciate it more. (October 24, 2006)

As well as promoting independent learning in chemistry, the EEI was a positive experience for Amanda. She felt it helped her to develop an appreciation of the depth and breadth of the work required to understand the related chemistry in the investigation. Furthermore, it gives additional weight to the study of Hart et al. (2000) that established how important it was for teachers to make the purpose of lab work explicit for students, in both cookbook labs and more open-ended investigations. “In so doing it might better help them to make the links between tasks in such a way as to build a more holistic view of their science learning experience” (p. 672).

Issue 3: Connecting Contexts and Concepts

The principle behind context-based approaches to curriculum design is that they provide relevance of the course of study to students’ lives (Bennett and Holman 2002). These approaches supposedly create opportunities for students to make connections between chemical concepts and real-world applications (or contexts) of these concepts. The question arises then, do context-based curricula help students make desired connections? Bennett and Holman’s (2002) review reported few differences between students’ understandings of chemical concepts when taught through concept- or context-based approaches. One study by Gutwill-Wise (2001), for example, found that students who had followed a context-based approach in an introductory chemistry course at university emerged with a better understanding of chemistry than their peers who had followed a traditional approach. So, what connections did Amanda make?

As shown in the previous section, Amanda was able to link particular chemistry topics (e.g., gas laws) studied in the context-based program with real-world issues (e.g., scuba diving) during the interviews, suggesting the program provided relevant topics of interest to her. While Amanda identified several real-world connections, statements in which she made connections between chemistry concepts associated with the contexts would provide evidence of conceptual understanding as defined by Cavalcante et al. (1997); that is, “conceptual understanding...is the product of mental processes which establish relationships between what would otherwise be isolated facts and ideas” (p. 185). In the following excerpt, we see evidence of such understanding. Amanda begins by answering Alberto’s request for her to give an example of how she learnt a topic on “Water as a solvent: Aqueous solutions” in more depth during the context-based program versus the concept-based program.

> **Amanda**: um…like this solubility unit last year we were just shown okay these ions aren’t soluble where[as] this year we see how certain ions are soluble in water and this is why and we’re taking it one step further. Okay you can use that for purification of water like you get certain ions in water and you can add substances to it to get those ions out of water. Like you understand the theory behind it and you see a practical use. You learn more about it. It gives you a better understanding.
>
> **Alberto**: So what do you mean it gives you a better understanding?
>
> **Amanda**: Well, like we’re told all nitrate ions are soluble in water so when we do the tests for nitrates we know the sediment in the water won’t be nitrates. (October 24, 2006)

Here Amanda clearly identified the decontextualised nature of the previous chemistry course in her opening line “okay these ions aren’t soluble.” Under the concept-based program studied in 2005, students were given a set of solubility rules that were used to solve problems such as determining whether a particular combination of ions produced an insoluble compound or not, and to determine a separating scheme for a mixture of metal ions from a solution. In the context-based program in 2006 students learnt about the effects of excess calcium and magnesium ions on the properties of water. Excess concentration of these ions leads to the condition known as hard water that reduces the ability of soaps and detergents to lather. A key point in the study of this condition was that calcium ions could be removed from water by precipitation with carbonate ions. In this instance, students required an understanding of solubility rules and application of solubility tables to choose appropriate ions for such a separation. This deliberate abstraction and a search for connections is an example of what Perkins and Salomon (1991) call high road transfer. More specifically, high road transfer “depends on deliberate, mindful abstraction of skill or knowledge from one context for application in another,” while low road transfer “reflects the automatic triggering of well-practised routines in circumstances where there is considerable perceptual similarity to the original context” (p. 218).

While Amanda was familiar with nitrates as nutrients for plant growth through the requisite reading for the water unit, she explicitly abstracted principles from the solubility rule “all nitrates are soluble” to the presence of insoluble materials in water. Also, Amanda made a connection between the concept of nitrate solubility and the context “presence of solids in water.” This indicates that Amanda had established a purposeful connection between a chemical concept and the context of water quality, demonstrating high road transfer. Amanda’s comments were consistent with the definition of Cavalcante et al. (1997) on conceptual understanding presented earlier; she demonstrated in this excerpt that her knowledge of solubility of ionic compounds was not limited to rote recall of a set of rules (cf. low road transfer, Perkins and Salomon 1991) but rather, she could integrate the factors that affect water quality in her response. Amanda’s reference to the nitrates test did not fit with the rest of her explanation in this instance, however. Nitrate tests are designed to indicate presence of nutrients. Tests for suspended solids indicate the amounts of insoluble materials in a water sample. This could indicate that Amanda developed some confusion over the purpose of the two tests.

This demonstration of a contextualised conceptual understanding raises the question of whether assessment should also be contextualised or not. Bennett and Holman (2002) claimed that if the scope of a context-based program was to develop conceptual understanding, then students could be assessed in decontextualised ways on their understanding of chemical ideas. On the other hand, if the course aims to develop scientific literacy and ideas about science, assessment should be contextualised (Bennett and Holman 2002). While we do have access to Amanda’s assessment scripts across both programs, a detailed analysis of these is beyond the scope of this article.

The context-based program introduced two new assessment tasks for Amanda. One item was the EEI, as previously discussed, and the second was the Extended Response Task (ERT) on water quality. In 2005 practical reports were dominated by cookbook-style practical activities followed by short reports that included presentation and discussion of results and observations. Amanda’s practical reports typically ended with a conclusion stating something like “the prac was successful and this is how it can be improved next time it is done.” In 2006, both the EEI and ERT explicitly required students to establish links between chemical concepts and observations or other results obtained in any experimental work that related to the tasks. These reports were structured so that students presented a brief conceptual review section at the start of the report where relevant chemical concepts (obtained through class-work and independent reading) were explained. This structure was designed to provide students with opportunities to establish links between concepts and results as well as to create a need for students to engage with important chemical concepts. As such, these reports began to take on the genre of a formal scientific paper rather than a cookbook style of report.

Amanda's EEI involved three experiments that were presented separately in her report and then summed up with an overall analysis and conclusion, thus providing four opportunities for her to connect her results with her understanding of the related concepts. Amanda made one link between results and concepts, and this was presented in the final section, as follows:

> Another thing that I noticed was that more bubbles came from the nail which was expected because of the reaction $2H_2O \rightleftarrows 2H_2 + O_2$. That means that there is twice as much hydrogen gas produced from the nail as oxygen gas produced from the stainless steel cathode. (Amanda, January, 2006)

In this excerpt from Amanda's report, she established a relationship between her observations of more bubbles being formed on one electrode compared to the other, and the chemical concept that twice as much hydrogen gas is produced compared to oxygen gas when water is electrolysed.

The ERT was the assessment task linked to the unit on "The Chemistry of Pete Creek." Students had collected a range of water quality data on a fieldtrip to the creek and subsequently analysed these data in the classroom. Students were required to write a conceptual overview section at the start of their reports where they established connections between chemical concepts of solubility with the water quality tests of the local creek. The analysis section of the reports provided further opportunities for students to establish connections between their observations from the test results of the water from the local creek and chemical concepts. While some connections to chemical concepts pertaining to solubility were made in the introductory section, the findings from Amanda's study were not linked to chemical concepts in the analysis or conclusion sections of the report.

It is impossible to account for these responses definitively. We know from Amanda's interviews that she was capable of establishing connections between chemical concepts and contexts. Perhaps the instructions and the nature of these assessment tasks did not prompt Amanda sufficiently to articulate her understanding of chemical concepts. Alternatively, verbal rather than written approaches to assessment might have provided Amanda with cues to respond differently. When these two tasks, the EEI and ERT, were compared with Amanda's responses to test items in 2006, a different view emerged.

> *Donna: I also found contradictory results in my analysis of the written and spoken forms of data on the water quality of Yabbie Creek, by the students at St. Anthony's. In my analysis I found that connections had been made between the chemical concepts related to the water testing and the real-world applications of the concepts. In particular, analysis of the students' water reports showed the above-average students were able to make the connections between the chemical concepts that explain their test results from their laboratory work and then apply the results to interpret the pollution of the local creek. However, chemical theory on the atomic structure of water and intermolecular forces of attraction that had been taught in isolation from the context of the local creek was added on in an appendix in 16 out of 23 reports, rather than being contextualised by the students. I have reflected with colleagues on the possibility that such an "atomic" level explanation is not pertinent to the contextual task in hand. This is an unresolved dilemma for teachers who have been educated themselves in conceptually focussed programs. Their background, that emphasised rigorous chemistry content, might impede a complete shift to a contextual program where only required content is taught.*
>
> *In this example at St. Anthony's, the teacher did not explain to the students how this theory on intermolecular forces could be integrated into the report and did not give*

> *them any examples. Modelling the integration of the theory may have helped the students use the chemical concepts to add depth to their explanations. In particular, intermolecular forces of attraction could be used to explain the solubility of ions such as nitrates and phosphates and would help students (like Amanda) clarify the differences between the dissolution of nutrients in water and sediments which are suspended in water. The above average students at St. Anthony's were able to see how the water test results were interrelated to draw conclusions about the water quality at the local creek but were unable to do so for concepts that were not taught as connected to the Extended Response Task. In this case study, the context-based program appears to afford students the opportunity to experience the curriculum as an interrelated set of important concepts, provided the concepts clearly link to the students' laboratory work and the teacher makes these links explicit.*

Issue 4: Curricular Coherence

Several well-known national and international studies (e.g., Goodrum et al. 2001) report student disengagement in science as a major problem for schools, and society in the long term. Lack of relevance of the curriculum to students' everyday lives is often regarded as one of the main causes for such disengagement, a problem that context-based approaches attempt to address. School students who are alienated from the formal curriculum find it difficult to make connections between a smorgasbord of topics required to be covered in syllabi or standards' documents (e.g., Barton and Darkside 2005). Small-scale curriculum projects to bring the formal curriculum closer to students' life-worlds (or even professional practices in university settings) are emerging in the literature (e.g., Tobin 2000). An appropriate question to ask in the present study was, does a context-based program afford students opportunities to perceive and experience the curriculum as an interrelated or integrated set of important concepts? In other words, how does a student like Amanda perceive the relative "delivery" of conceptual sequences between the contrasting programs (i.e., concept- v context-based) she experienced?

> *Steve: Before we begin to address this question we should note that university curricula are not immune from the criticism of the curriculum as a set of unconnected concepts either. Numerous education students I have taught have complained that their degree structures simply glue together otherwise unrelated courses that leave them to make whatever connections they can with the conglomerate of experiences.*

Amanda answered the question without prompting in the first interview, as shown below:

> **Amanda**: If you learn like say equilibrium and gas laws together it doesn't really matter if you learn acids and bases and gas laws together whatever, as long as it flows.

> **Alberto**: And what do you mean by "as it flows"?

> **Amanda**: Oh, you learn this and you see how the next topic… sort of match[es] up. [This year] you can see this relate[s] to this and that relates where[as] last year it was this topic and then that topic and the next topic. Last year there was no connection between the two, like we learnt topic one and topic two and there wouldn't be a connection there. Where this year, we learn topic one, and then topic two just flows into it – you can't really see the distinct line between the different units. (October 18, 2006)

From this excerpt, Amanda acknowledges that the concepts or topics in her concept-based program did not appear to be linked. In contrast, during the next year, the contexts (in the context-based program) became organising frameworks for the development of related concepts. She could more easily perceive the connection between the concepts when the curriculum appeared to flow from one topic into the next. Amanda's perception here adds weight to the growing claims that context-based curricula help students make connections to both real-world phenomena and those concepts identified within the contexts treated in the curriculum.

Donna: This reminds me of an interview I had with the teacher (Karen) at St. Anthony's. She had taught a unit called "Quality Control" which introduced the concept of moles after the water unit. She had taught this unit with a direct-teaching approach which contrasted with the student-centred approach of the water unit. I interviewed her towards the end of the moles unit and asked her to compare the two approaches and she said "[in the traditional approach] there's a lot more teacher input...there's a lot more times when the teacher has to explain things... there's a lot more content... and whilst you did a number of experiments to build up an understanding there's not a continuous flow." Like Amanda, Karen also perceived there was more of a flow in the contextual unit. Further comments about the context-based approach confirm these perceptions. "I think it's [the context-based approach] good because it gives a more coherent approach for the whole term. I think it gives a focus for the learners to know where they are going and why they're learning something and rather than just learning it so they can do an exam they're learning it so they can come to a better understanding, in this case of water quality, and so I think that that will be better." In a student-centred classroom where the learning occurs in groups, like the context-based water unit, it is possible for the connections between the concepts to be more easily perceived. This is because all of the laboratory work and analysis is leading to the same end point, the final written report about the pollution of the local creek.

Implications for Teaching and Research

As with many innovative-science curricula, a context-based approach to chemistry embeds classroom learning within rich tasks or contexts that students, on balance, appear to find interesting, relevant and effective for conceptual learning (Bennett and Holman 2002; Sherin et al. 2004). This was borne out in Amanda's unique case, discussed here, of experiencing both concept- and context-based programs at the Year 12 level in chemistry. Specifically, in relation to her lived experiences in contrasting chemistry programs at the same level in which some concepts were repeated and others emerged for the first time, Amanda reported greater personal interest in chemistry through the contexts studied, and she demonstrated she could link her classroom work to real-world phenomena. As well, Amanda suggested that the contexts and tasks provided a structure that connected the related concepts in meaningful ways, and these connections were less apparent to her in the previous concept-based program. These "truths" for Amanda, along with our collective supporting experiences as teachers and researchers, could have wider implications for teachers and researchers.

The positive outcomes of implementing a context-based approach from this study suggest: context-based approaches help students to make connections between chemistry concepts and real-world applications; the Extended Experimental Investigations provide opportunities for independent study and for a deeper understanding of the related chemistry in the process; chemical concepts can be understood through applications to real-world concepts; and the links between the concepts are clearer in a context-based program compared to a concept-based program. Notwithstanding the extra design work in re-orienting the curriculum from concepts to contexts, there is little evidence here and elsewhere to dissuade teachers from changing approaches. In fact, a context-based program appears more likely to engage students in meaningful tasks with real-world connections than more traditional programs.

Another challenge for teachers is to create opportunities in the classroom for connections between chemistry concepts and the real world. Since the context-based approach is a recent initiative and is still in the trial stage in Queensland, it is worth cautioning that teachers can interpret quite differently what it means to "teach contextually" (e.g., see King 2007). Some teachers have interpreted it to mean they can sequentially build up concepts under the chosen context in a logical, systematic way not unlike the concept approach. This is not what appears to be intended in the syllabus. In the Queensland syllabus, to teach contextually involves using context rather than content (or concepts) to drive program design and implementation. This requires starting with a real-life context and developing scientific concepts from the context. In this way, the planned programs should lead to a different organisation of the chemistry content since concepts should be taught on a "need-to-know" basis. For example, the *Pandora* unit could begin with the real-life application of electrolysis for the preservation of artefacts. To understand this process more fully, students would need to learn about ions and how they are represented by chemical formulas, progressing to the use of symbolism for reactions in electrolysis. The syllabus objectives such as conceptual understanding, investigative skills and complex reasoning, still remain target outcomes to be developed systematically as a consequence of a student's activities in what are "need-to-know" stimuli. This change in pedagogical approach from a teacher-centred direct teaching to a more student-centred approach requires for many teachers a "complete paradigm shift in teachers' thinking, content knowledge and praxis" (Beasley and Butler 2002, p. 7). Amanda's lived experiences can provide encouragement for teachers to attempt these pedagogical changes. With professional development to support teachers there is the possibility that innovative classroom practices, like context-based teaching, will become more widespread.

A shift to a context-based approach in school science curricula is supported by a recent report released by the Australian Council for Educational Research (ACER) called *Re-imagining Science Education: Engaging students in science for Australia's future* (Tytler 2007) which calls for a 're-imagined' science education that is focused not only on preparing future scientists, but also on engaging all young people in science. The review argues that school science too often ignores the realities of students' own lives and interests. It supports the rationale for contextual learning as a means to motivate and encourage a more positive attitude to science through transferring knowledge to situations in the real-world (Bennett et al. 2007).

An important challenge for many teachers in implementing a context-based program will be to find new ways for students to demonstrate their conceptual understanding and whether or not they tie this understanding to a specific context as Amanda did. One solution for encouraging the transferability of concepts between contexts that has been tried in the past (e.g., PLON: Physics Curriculum Development Program) is to design a number of contexts that explicitly incorporate the same key concepts. This allows for teachers and students to revisit key concepts within different contexts, reinforcing the conceptual links (Kortland 2005). The Queensland syllabus stipulates that key ideas must be dealt with in at least two contexts providing teachers with the opportunity to design units that allow for the revisiting of key concepts between contexts. This should provide opportunities for a more thorough focus on fewer key concepts except that the excessive number of key concepts and key ideas in the syllabus continues to be a constraint for pedagogical change in Queensland.

What is necessary then is to investigate ways in which students create connections between concepts and contexts. It could be pre-empted that in traditional programs, students would rarely create connections between a concept they have studied and practical applications of it in some context. Perhaps contextual approaches to curricula provide for greater opportunities for students to do this. If this were true then one could expect students to make references to concepts in the same way Amanda has here; that is, by linking the concepts of nitrate solubility and water quality parameters as a result of a study of the former in the latter. Perhaps both researchers and teachers alike need to test student conceptual understanding in a contextual manner. This appears to be the approach taken by test designers for PISA (see OECD 2006).

Another constraint to the effective implementation of context-based approaches to senior chemistry and physics curricula is the non-alignment of pedagogies (and assessment practices) across the secondary-tertiary interface. If undergraduate university teaching of chemistry, for example, continues to privilege de-contextualised conceptual learning, there will be greater pressure on school teachers to prepare their best students for university as they themselves were taught chemistry. So, when Australia's chief scientist, Dr. Jim Peacock called "for a paradigm shift in science education across Australia" (Tytler 2007, p. vi), we would add that a unified change across sectors is needed for there to be widespread engagement of students in learning chemistry in real-world contexts.

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Appendix

Sample Questions from Interview One

1. Tell me what you did in chemistry last year.
2. Tell me if there were any similarities or differences between what you did last year and this year?
3. How did the pracs compare across each year?
4. What do you think of the two different approaches there are for doing experiments?
5. In what ways was the content linked to real life in both years?
6. What were the similarities and differences between the way content was taught between last year and this year?
7. What do you think of the two different approaches you have seen between last year and this year?
8. Imagine you were starting year 11 again and you actually had the choice of one of the two approaches, which one would you choose and why?

Sample Questions from Interview Two

1. Compared with last year, in what ways were the writing requirements similar and different this year?
2. How do you think the writing that you had to do for last year's tasks and this year's tasks compares in terms of understanding the concepts behind it?
3. How do you think that affects your understanding of the concepts that you're doing in those two different tasks?
4. I just remind you that in the last interview you said that you learnt things in more depth. Can you explain to me what you meant by you learnt it in more depth?
5. So when you say you have learnt things in more depth can you give me an example of differences between this year and last year? How did you learn something in more depth this year?
6. And also in the last interview you made a comment about how you personally like to see how the chemistry is applied to real situations. You said you like to see the purpose of the chemistry. Can you explain what you meant by this?

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