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ACADEMIC SUCCESS IN CONTEXT-BASED CHEMISTRY: DEMONSTRATING FLUID TRANSITIONS BETWEEN CONCEPTS AND CONTEXT

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Abstract

Curriculum developers and researchers have promoted context-based programs to arrest waning student interest and participation in the enabling sciences at high school and university. Context-based programs aim for student connections between scientific discourse and real-world contexts to elevate curricular relevance without diminishing conceptual understanding. This interpretive study explored the learning transactions in one 11th grade context-based chemistry classroom where the context was the local creek. The dialectic of agency|structure was used as a lens to examine how the practices in classroom interactions afforded students the agency for learning. The results suggest that firstly, fluid transitions were evident in the student-student interactions involving successful students; and secondly, fluid transitions linking concepts to context were evident in the students' successful reports. The study reveals that the structures of writing and collaborating in groups enabled students' agential and fluent movement between the field of the real-world creek and the field of the formal chemistry classroom. Furthermore, characteristics of academically successful students in context-based chemistry are highlighted. Research, teaching and future directions for context-based science teaching are discussed.

Key words: Context-based, sociocultural, dialectics

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INTRODUCTION: ORIENTING THE CURRICULUM TO CONTEXTS

Throughout the last two decades, context-based courses in chemistry have been developed and implemented in schools internationally in an attempt to increase the relevance of the prescribed chemistry concepts to students' life-worlds (King & Ritchie, 2012). A context-based course is one in which the *context* or application of the chemistry to a real-world situation is central to the teaching of chemistry (Beasley & Butler, 2002). In this way, the chemistry is taught when the students require the knowledge for further understanding of the real-world application. In other words, context-based courses are underpinned by a "need-to-know" principle where the context legitimizes the learning of chemical concepts from the perspective of the students, and thus makes their learning both intrinsically and extrinsically meaningful (Beasley & Butler, 2002; Bulte, Westbroek, de Jong, & Pilot, 2006).

Context-based courses evolved after dissatisfaction with established chemistry programs that prioritized the rote learning of a prescribed body of knowledge, well-structured problems and mechanical and algorithmic laboratory work (Hobden, 1998; Tobin & McRobbie, 1995; Tytler, 2007). Such concept-based programs are still taught in chemistry classrooms today, arguably limiting opportunities for students to connect concepts and contexts or appreciate the relevance of chemistry to their real-worlds beyond school. Alarmingly, the number of students studying chemistry at high school and university is in decline internationally (Dekkers & de Laeter, 2001; Dobson, 2006). Unfortunately, fewer students see the sciences as a possible career path even though many aspects of modern life are dependent on the products of scientific and technological enterprises (Tytler, 2007). A context-based emphasis in the curriculum is one approach that has attempted to address the decline in student interest. Proponents of such courses have argued that a context-based approach is more likely to increase student interest and motivation in chemistry (Barber, 2000; Gutwill-Wise, 2001; Parchmann et al., 2006; Ramsden, 1997).

Contextual learning underpins courses like *Chemistry in Context* in the USA (American Chemical Society [ACS], 2001), *Salters* in the UK (University of York Science Education Group [UYSEG], 2000), *Industrial Science* in Israel (Hofstein, Kesner, & Ben-Zvi, 2000), *Chemie im Kontext* in Germany (Parchmann et al., 2006) and *Chemistry in Practice* in The Netherlands (Bulte et al., 2006). Research from these international projects provides valuable insights into the issues concerning context-based chemistry education (see King, 2012). The research suggests that students' conceptual understanding of chemistry in context-based courses compares favourably with the outcomes from conventional chemistry courses (Barber, 2000; Barker & Millar, 2000; Gutwill-Wise, 2001; Lange & Parchmann, 2003; Smith & Bitner, 1993). Also, students in context-based courses find the chemistry more relevant to their out-of-school lives demonstrating increased motivation and interest in learning chemistry (Barber, 2000; Gutwill-Wise, 2001; Parchmann et al., 2006; Ramsden, 1992, 1997). Furthermore, there is some recent evidence from Australia that students make connections between the designed context for study (e.g. a shipwreck) and related concepts (e.g., oxidation) through their participation in the course (King, Bellocchi, & Ritchie, 2008).

One reason that context-based approaches have not been implemented on a wide scale in high-school chemistry classrooms is the lack of shared understanding by teachers about what constitutes a context-based approach (e.g., King, 2007). Another reason is that how students learn in a context-based chemistry classroom is not understood fully (Bennett, 2003). Despite prior research that suggests students studying context-based courses learn chemistry at least as effectively as students studying traditional chemistry courses (Barber, 2000; Smith & Bitner, 1993), and more compellingly, that students in context-based courses demonstrate a deeper understanding of concepts than students following more conventional courses (Barker & Millar, 2000; Gutwill-Wise, 2001; Lange & Parchmann, 2003), traditional concept-based approaches are still privileged in mandated syllabus and curriculum documents. Perhaps this is because teachers and curriculum developers remain unconvinced of the benefits of context-based courses, and have limited understanding of the classroom structures that afford students opportunities to connect canonical science with real-world contexts. Research is needed to understand more fully the circumstances by which students connect concepts and contexts in context-based classrooms and the outcomes of a context-based approach for teachers and students. Our study is significant because it identifies pedagogical structures that afford students opportunities to connect chemistry concepts with contexts. Furthermore, research publications of the implementation of context-based courses in chemistry are devoid of studies from a sociocultural perspective. In this study, we explore a new way to view the learning in a context-based chemistry classroom through a dialectical sociocultural framework. In particular, we focus on the conditions necessary for students to achieve a successful academic outcome in one context-based chemistry class structured around an investigation.

Despite a plethora of criteria for success used by researchers, in this study we adopt the pragmatic position of success used by stakeholders in senior chemistry classes at the study site; that is, students were successful when they achieved a grade of sound (C grade) to very high achievement (A grade). While there are many cultural and linguistic aspects that may influence academic success for students in science (e.g., see Tobin & McRobbie, 1996) we defined “success” in this paper as occurring when the students applied accurately the chemistry concepts to the context in a final written report and culminating individual interview. The interview assessed students’ understanding of their written report by asking key questions about the water tests (see Appendix 1 for sample questions). Furthermore, we highlight the characteristics displayed by successful students.

The principal research question that guided the study was: How do successful students demonstrate links between concepts and context in a context-based chemistry course structured around a water quality investigation? To answer this overarching question, two sub-questions were addressed: (1) How do student-student interactions contribute to links between concepts and context? (2) How do students link the chemistry of water quality to the real-world context through a written task? Data from participant observations, interviews and artefacts produced were interpreted from a sociocultural perspective that featured the dialectic of agency | structure. Before detailing these interpretive processes, we discuss the theoretical background that guided the development of our research design.

THEORETICAL FRAMEWORK

A Dialectical Sociocultural Perspective

Our sociocultural perspective originates in the work of Vygotsky (1978) who viewed the development of students' higher cognitive skills as occurring through their participation in social practices. Vygotsky (1978) attributed the origins of a child's intellectual functioning to be found in his or her surroundings and through interactions with others before it appears internally:

> Any function in the child's cultural development appears on the stage twice, or on two planes. First it appears on the social plane and then on the psychological plane. First it appears between people as an interpsychological category, and then within the child as an intrapsychological category. (p. 57)

Applying this to the classroom setting, students construct knowledge with others that allows them to organise and relate self to circumstance. Lave and Wenger (1991) describe this process of change from individual participation to increased participation in socially organised practices as becoming a full participant or a member of a community of practice. At some stage, through the conversations that occur in group activities in the community of practice, the learner may transform knowledge from cultural knowledge to individual knowledge. Vygotsky (1978) defined the translation from a cultural plane to an internal plane as "the zone of proximal development" (p. 84).

One interpretation of the zone of proximal development is the distance between understood knowledge as provided by instruction and active knowledge as owned by the students (Hedegaard, 1988). This interpretation is based on Vygotsky's distinction between scientific (understood knowledge) and everyday concepts (active knowledge); that is, a mature concept is achieved when the scientific and everyday versions merge (Vygotsky, 1978). Accordingly, new approaches to teaching science such as the context-based approach may afford opportunities for the understood knowledge provided in the classroom, through teacher-facilitated interactions, and the active knowledge such as the real-world contexts, to come together. In such a classroom environment, students may learn through the real-world context and through interactions with others before the concepts appear internally. A broader view of the zone of proximal development incorporates this societal dimension where learning is collaborative and occurs in the social world of classroom interactions. Adopting this sociocultural perspective, allowed us to view teaching and learning as a form of cultural enactment where the classroom interactions between students and between the teacher and students contributed to students' understanding of canonical chemistry leading to academic success. In particular, a dialectical sociocultural perspective provided a specific lens to view these important interactions.

Influenced by the work of Sewell (1999) and Giddens (1981), the use of a dialectical sociocultural framework enabled analysis of the cultural practices associated with the teaching and learning within the context-based chemistry classroom. Sewell (1999) describes culture as a dialectic of system and practice. Applying this to the classroom, the rules and symbols of the class may shape their practice but also the practices of the teacher and students are shaped by the rules and symbols of the school system. A dialectic is a pair of opposite entities or concepts that are dependent on each other, or presuppose each other, in order to exist, such as, structure and agency (Sewell, 1992). If people use their agency or "power to act" in creative ways, their actions may change the structures that initially gave them the power to act. Conversely, modified structures may afford people more agency.

Structures can both enable and constrain human agency (Giddens, 1976). Structures in the chemistry classroom (such as teacher-led instruction) may shape students' practices and simultaneously, students' practices (listening to the teacher and answering questions) may constitute (and reproduce) structures (Sewell, 1992). However, students can use their agency by initiating discussions in the chemistry class thus changing the structure to student-led conversations that afford opportunities for the whole class to learn. Therefore agency and structure are two mutually codependent constructs (represented as agency | structure, Roth, 2005) that can be used to explain the interrelationships between the agency of the students and teacher and the structures in the chemistry classroom that were crucial for learning to occur.

Fields

Our theoretical framework also draws on social constructs articulated by Bourdieu (e.g., 1977). The notion of a *field* is used in this study to help us theorize the practices that occurred in a context-based chemistry classroom. Bourdieu (1977) originally used the term "field" to represent both the physical location and the structure and resources that constitute that location. For example, the chemistry classroom is a field and the teacher-led instruction may structure the learning that occurs in the classroom.

As classroom conversations transpire, structures from other fields may be introduced by participants to be used as resources for continuing activities in the classroom field. In this way, fields do not have fixed boundaries or absolute barriers to cultural exchange (see Sennett, 2008). Rather, the border of a field is an "active edge" (Sennett, 2008, p. 227), much like a cell membrane that is porous to some resources and impervious to others, allowing selected cultural resources and practices produced in other fields to be enacted in the classroom field and elsewhere (cf. Tobin, 2006). For example, the real-world application of a concept in chemistry may occur in a field outside the chemistry classroom (e.g., the local community who are interested in the pollution of their local creek) but can be brought into the field of the classroom for analysis (e.g., water testing) and further understanding. Each of these fields is structured by the rules (e.g., listening to the teacher), and non-human resources (e.g., water testing equipment) and human resources (e.g., prior knowledge of water chemistry) that the teacher and students access and appropriate to meet their goal of establishing the health of the local creek (Tobin, 2006).

Fields can be understood in terms of networks of value or capital where *capital* refers to a person's accumulated resources at their disposal during transactions in social and cultural contexts. There are various forms of capital that relate to a person's agency including cultural, social, and symbolic (Bourdieu, 1992). *Cultural capital* is the information, expertise and personal qualities one gains from life experiences. In this study we anticipate a student who brings the human resources such as considerable prior experience with chemistry and academic achievement in science into the context-based chemistry class is likely to have more cultural capital than a student who brings less knowledge or previous experience.

RESEARCH DESIGN AND PROCEDURES

The purpose of this study was to describe and interpret the learning that occurred in one 11th grade chemistry classroom in Australia in which the intended curriculum emphasized a context-based approach. The context-based unit occurred in the second term of the students' first year of chemistry (year 11) so they were developing an understanding of basic chemistry concepts. A culminating assessment task that required students to write an Extended Response Task (ERT) or written report on an assessment of the water quality of the local creek, structured the context-based unit. An ERT is a written report that usually involves the analysis of both primary and secondary data from a case study, industrial visit or field trip. Following a logical argument based on detailed analysis, a final decision is reached in the report (Queensland Studies Authority, 2004). We used an interpretive methodology using ethnographic techniques for this study

(Erickson, 1998; Merriam, 1988; Stake, 1994). The study was conducted during one three-month term (i.e., March to May) in an 11th grade chemistry class at an independent boys' high school in Australia. At the start of the term, the average age of the students was 15 years and 9 months. St. Anthony's (a pseudonym) is situated in a suburb of Brisbane with a total of 1,200 students from years 5 to 12. Students are predominantly from middle to upper-class families.

Teaching chemistry contextually in Queensland, Australia began with an initial 25 schools trialling the context-based syllabus in 2002. St Anthony's was one of the original 25 schools chosen for the initial trial. Caren (the teacher – a pseudonym) was leading the transition to the new syllabus in her school. We invited Caren to identify two groups of students for the purposes of detailed classroom observations and interviews about their activities. She determined the groups predominantly based on their academic results from the previous term. These groups represented the full range of achievement standards.

Major data sources were video and audio recordings of the student-student discussions and teacher-student discussions in whole-class interactions, and within-group interactions. Other data sources included classroom documents, student journals, interviews with students and teacher, and field notes. Our analytic process began with the transcription of the 17 video-recorded lessons, 32 MP3 recordings from in-class interactions of students, 13 interviews with Caren and 15 interviews with the students. The audio and video recordings, final interviews with students and the written reports and field notes from the two focus groups were the salient data for this article.

During our observations of students' interactions we tentatively proposed that students were metaphorically moving back and forth between the context and concepts. For example, the students discussed the canonical chemistry of the water quality data and then referred to the map of Yabbie Creek, shifting between the data and map as they applied the concepts to the context. This led us to undertake a wider search of the literature from which we generated the metaphor of fluid transitions or *toing and froing* from Beach (2003). The metaphor of *transitions* was first used by Beach (2003) to mean “a developmental change in the relation between an individual and one or more social activities” (p. 42). He used the term “collateral transition” to refer to an individual’s relatively simultaneous participation in two or more historically-related activities (Beach, 2003). In other words, collateral transitions are multi-directional and involve back and forth movement between activities. Even though the students may not physically move between two or more fields, their discussions and written work may move back and forth between the chemistry of water quality and the context of the local creek. Following this literature search, we interrogated the data and discovered this back and forth movement between concepts and context occurred in the students’ conversations and written work in the context-based chemistry classroom. The term “fluid transitions” seems to represent approximately how the students’ conversations and written work smoothly transitioned back and forth between the concepts and context. Just as tides ebb and flow, the back and forth movement or *toing and froing* between concepts and context, evident in student conversations and written work, resembles this property of fluids. Once fluid transitions were determined as an important indication of student learning, transcripts and written reports were coded for evidence of the *toing and froing* between concepts and context; that is, data were searched for evidence of canonical science concepts applied to the context of the water quality of the local creek.

The Water Unit

The chemistry unit was designed around an inquiry task on water quality of the local creek as the application of science to students’ real-lives. Therefore, the canonical chemistry concepts in the study relate to water quality tests such as the dissolution of ions (nitrates and phosphates), Dissolved Oxygen, pH, turbidity, Biochemical Oxygen Demand, salinity and faecal coliforms. These are established chemistry concepts that are applied to the context. For example, understanding that nitrates and phosphates found in fertilizers may cause increased concentrations in water promoting the growth of phytoplankton which affects the population of filter-feeding organisms that compete with coral for space (Smith, Monteath, Gould, & Smith, 2006), incorporates knowledge about the established science concepts of acceptable concentrations of anions in solution as well as ecological knowledge about impacts on populations.

Prior to implementation, Caren (the teacher) and Donna (the first listed author) met on four occasions to design the water unit. One of the main goals during the design process was to maintain the centrality of the context (i.e., the water pollution of the local creek) to the classroom processes. The teaching sequence designed by Caren and Donna was informed by State mandated requirements and supplementary material gleaned from a review of international developments in context-based approaches (e.g., Beasley & Butler, 2002). This teaching sequence was planned to elicit key questions from the students through an introductory activity. Following this, the questions were answered through investigative laboratory work and analysis of the results, and content was taught as the students required the knowledge. Finally, the students applied the knowledge to write a report and make decisions about the water quality of the local creek. The written report or Extended Response Task (ERT) had been previously determined by the school work program as the assessment task for the unit; that is, no “test” was administered.

The water unit required the students to conduct water analysis tests on three samples taken from three different locations (i.e., The Yacht Club, Sewage Treatment Plant and Mouth of Yabbie Creek) in the school’s local creek, Yabbie Creek (a pseudonym). While the students did not go to the creek to collect the water samples, they were required to complete the water tests in small groups utilising laboratory skills developed in previous classes to analyse the results. Maps of the creek were provided to assist students with locating the samples in the geographically correct position where they were collected. The ERT required students to complete three components: firstly, background research on each water test; secondly, to carry out the tests; and thirdly, to report on the water quality. The higher-order thinking required in the task occurred when students synthesised the data to make generalizations about the water quality of the creek. Since this task occurred early in year 11, these higher-order thinking skills were developing for most students. Information about the chemistry of water and an explanation about the characteristics of water that made it a good solvent were to be included in an Appendix at the end of the report. The teacher explained the requirements of the ERT at the beginning of the unit and it was marked separately by both the teacher and Donna. Oral interview data were also used by Donna to determine students' understanding of the tests and their results.

The water unit was taught for one full term (i.e., 10 weeks) where there were 19 chemistry lessons. Author 1 attended every lesson as a participant-observer and gradually became accepted as one of the group (Burns, 2000). Ethnographic work demands lengthy immersion in the research site, which reduces any novelty impact due to the presence of the researcher on student outcomes. Moreover, Erickson (1986) asserts that "The conduct of interpretive research on teaching involves intense and ideally long-term participant observation in an educational setting, followed by deliberate and long-term reflection on what was seen there" (p. 156).

Within the 19 lessons that structured the water unit, five lessons were categorized as teacher-led, three lessons were laboratory activities in groups, three lessons were computer-based research, one lesson was a video lesson followed by laboratory work, and four lessons were a combination of teacher instruction with a group activity other than laboratory work. The lessons were divided into two phases based on the pedagogical approach used by the teacher. Phase 1 was marked by the first 12 lessons where the lesson sequence emphasised the real-life application of water quality to the context of the local creek. In this phase, content was primarily taught in response to the students' "need-to-know." In contrast, in Phase 2, Caren changed her teaching approach to teacher-led coverage of content in lessons 13-19 due to time constraints and her perceived need to cover set content that was prescribed by syllabus documents. Furthermore, the set content was necessary for students to complete the requirements of the Appendix component of the assessment task. Paradoxically, the concepts taught in Phase 2 were not needed to address the requirements of the report component of the ERT. The 19 lessons that structured the water unit are outlined in Appendix 2.

We categorized the students' work into three rankings (i.e., high achievement, sound achievement and low achievement) based on the quality of their written reports submitted at the end of the unit and conceptual understanding demonstrated in a final interview. Grades were allocated to the written reports on the basis of canonical accuracy. For example, a student who received a high achievement grade accurately explained nine or more water tests from the eleven tests in his written report and explained seven or more of the eleven tests accurately in a follow-up interview. In the sound achievement category, students explained six or more water test results in the written report but generally were unable to explain the tests with the same level of canonical accuracy in the interview. Finally, the low achieving students gave consistently inaccurate canonical responses across both written and spoken forms. The classification of all students' rankings was checked for reliability with two chemistry educators.

A summary of the final results of the 26 students in the class are provided in Table 1. The two focus groups of students, who were representative of the successful and unsuccessful students in the class as demonstrated in Table 1, were the subject of detailed analysis.

Table 1

Class Achievement of all Students

Student's Name (Pseudonym)	**Final Grade**	**Student's Name (Pseudonym)**	**Final Grade**

*Mark	Sound Achievement	Roger	Sound Achievement
*Shane	Sound Achievement	Adam	Sound Achievement
*Ryan	Sound Achievement	Tom	High Achievement
*Richard	High Achievement	*Peter	Low Achievement
*Ned	Sound Achievement	Steven	Low Achievement
*Charles	Sound Achievement	Max	Sound Achievement
*George	High Achievement	John	Sound Achievement
*Aaron	High Achievement	Simon	Low Achievement
David	Sound Achievement	Tony	Sound Achievement
Joseph	Sound Achievement	Abraham	Sound Achievement
Jim	Sound Achievement	Nigel	Low Achievement
Coby	High Achievement	Conor	Sound Achievement
Corey	Sound Achievement	*Dave	Low Achievement

*Focus Group students

LEARNING IN CONTEXT-BASED CHEMISTRY

Two assertions supported by the evidence presented focus on the students' learning of chemistry. Each assertion addresses a specific research question. Firstly, we establish the existence of fluid transitions in the group activities where the students discussed the test results and applied them to make scientifically acceptable inferences about the water quality of Yabbie Creek. Secondly, fluid transitions occurred in the written activities; namely the ERTs. In both assertions, the work of focus group students are discussed to show how the interactions and written work of the successful and unsuccessful students in the whole class differed.

Fluid Transitions in the group interactions

Assertion 1: Fluid transitions were evident in the student-student interactions involving successful students

Group work was a large component of the lessons that structured this context-based unit. Throughout the study we observed students in the whole class and the focus groups (Groups 1 and 2) interacting frequently in class, predominantly in Phase 1 as they shared ideas and used the discourse of science to make inferences about the water quality in Yabbie Creek. In the student-student exchanges there was evidence of *toing and froing* between concepts and context or fluid transitions. Excerpt 1 was typical of the exchanges observed between the students in Groups 1 and 2. Mark was leading Group 1 in the explanation for the high faecal coliform results at the Yacht Club site in Lesson 10 when it occurred. At this point in the lesson, the students had analysed their data and were inferring what could have caused the high faecal coliform count at the Yacht Club. The students referred to a map of the three collection sites for the water samples as they discussed causes of the pollution.

Excerpt 1: An example of fluid transitions in Group 1 interactions

> Ryan: There is still a high faecal coliform count [in the area of the Yacht Club.]
> Shane: The main thing we are judging its [pollution] by is the faecal coliform count well it drops down by 10 000 as Mark said there's another creek running through it and that would dilute it a lot.
> Mark: With the Sewage Treatment Works there *(points to map)* the run off is going to be pretty dirty and it's going to flow out into Yabbie Creek and then when it gets to the Yacht Club it's merged with this one and it's also spreading out and it's going from smaller to large and so when you get out to the ocean it is even diluted more and so it's probably going to be highly concentrated [at the Yacht Club] so the Yacht Club must be doing something to the water.
> Author 1: I'm with you something is happening at the Yacht Club why is it cleaner at the Sewage Treatment Plant?
> Mark: I think they would be doing a fair bit of treatment actually; they wouldn't want to dump it straight into the ocean
> Shane: What about all the boats.
> Mark: We don't know but it might be coming from the other side of the Sewage Treatment Plant where they are actually dumping bad stuff. (Lesson 10)

In this excerpt the students were surprised by the abnormally high faecal coliform readings for the Yacht Club site compared to the sample from the Sewage Treatment Plant since this was not what they had expected. They had anticipated that the readings would be higher at the Sewage Treatment Plant. Following this conversation in Excerpt 1, they had a 15 minute discussion about the possible causes for the readings, and decided that there were "two possible suspects either the creek that leads into Yabbie Creek is polluted or boats are contributing to the pollution." In this exchange we observed the students speak fluently and animatedly as they moved backwards and forwards between the chemistry test results and the real-world. They were focussed on the task and collaborating through the structure of group work, as they made transitions between the canonical chemistry (in this case the faecal coliform results) and the real-world context (Sewage Treatment Plant and Yacht Club as represented on the map). As in many other interactions, Excerpt 1 illustrates how the group structure elicited conversations that empowered members to share ideas through their expression of agency.

Another example that is representative of the whole-class group conversations where the students applied water quality chemistry to the context of the local creek, occurred in Lesson 12. In this particular lesson, students were practising their written skills required for the ERT by presenting to the class the analysis of one water quality test (e.g., pH). Fifteen minutes after the activity began, Author 1 went over to Group 1 to check their progress:

Excerpt 2: An example of fluid transitions in Group interactions

> Author 1: What water quality parameter were you given?
> Richard: We were pH
> Author 1: Tell me about your results so far
> Aaron: We found out the results from upper Yabbie Creek. The pH is 7.1
> Richard: This is average which is very good
> Aaron: The mouth of Yabbie Creek was also 7
> Richard: Bream Bay was 7.75 still pretty good
> Aaron: For marine life to survive the pH needs to be between 6.5 and 8
> Richard: So the pH values tell us Yabbie Creek is within the acceptable range (Lesson 12)

In Excerpt 2, the students were making fluid transitions between the water test results (pH) and the water quality of Yabbie Creek. This occurred when they applied the experimentally determined pH value to conclude Yabbie Creek was within the acceptable range. This excerpt was typical of the exchanges between successful students where the structure of group work afforded them the opportunity to demonstrate fluid transitions between concepts and context through student-student interactions. Consequently, for the sound and high achieving students, fluid transitions were realized in the student-student interactions. The in-depth data analysis from multiple sources coupled with the researcher's observations revealed the interactions within group work, a strategy used frequently with the whole class, provided information for the sound and high achieving students that became a resource for the ERT.

Fluid Transitions in the ERT

Assertion 2: Fluid transitions linking concepts to context were evident in the successful students' reports

We begin the discussion for Assertion 2 with representative students George and Richard who were ranked as high achievers.

Prior to beginning this context-based chemistry unit, George had considerable experience with the topic through his involvement in an extension science course in Grade 10 on water analysis. This prior experience meant he was more familiar with the topic that gave him greater access to relevant resources compared with most of the other students in the class. George's interest in chemistry was evident in class when he would volunteer information and ask thought-provoking questions. Unsurprisingly, he wrote a final written report that was ranked as a high achievement.

George demonstrated strong written skills in the ERT, outlining causes of pollution at the creek through connections with canonical science concepts. This was evident in the following excerpt illustrating fluid transitions between concepts and context:

Excerpt 3: A section of George's written report

> All the above indicators ultimately make the overall water quality of the Yacht Club poor. Another piece of information to consider is the fact that not far up Yabbie Creek there are sewage outlets which may cause the faecal coliform counts to be high. According to these test results, high algal photosynthetic activity seems to be in progress in the water. I say this because scores over 110% in saturation in the Dissolved Oxygen test indicate algal photosynthetic activity. I suggest the water only be used for boating and nothing else. (Written Report, p. 2)

In the opening sentence, George connected the water test results with the context of the local creek by writing "all the above indicators ultimately make the overall water quality of the Yacht Club poor." The data from laboratory tests that had been summarized in the written report substantiated this claim. Following this, George demonstrated fluid transitions with the real-world context when he connected the cause of the pollution to the high faecal coliform count in the sewage outlets, and linked the saturation results to algal photosynthetic activity in Yabbie Creek. The numerical reference to "scores over 110%" was canonically accurate since results greater than 110% saturation indicates that algal photosynthetic activity is producing a super saturation of Dissolved Oxygen (Smith, Monteath, Gould, & Smith, 2006). In comparison to the other students in the class, George's ERT achieved a high level of canonical accuracy. Furthermore, George summarised comprehensively the 10 water test results and their comparison to standards. Not surprisingly, the data for George were replete with examples of fluid transitions which were found on 20 occasions in his ERT and 8 occasions in the follow-up interview. In the follow-up interview he accurately explained the purpose of 8 of the 11 tests and connected them with his test results. In one of these instances for example he described pH as "the potential of Hydrogen how acidic or alkaline the water is." He further explained that his test result for pH was "within the acceptable range for healthy water."

George appropriated the discourse of science to write about the water pollution in the local creek as he drew on his strong content knowledge and good literacy skills. Excerpt 3 showed how the written task afforded George the opportunity to make connections between the chemistry and the context. In other words, when the chemistry was relevant to George's life-world, fluid transitions occurred (i.e., chemical test results from the water analysis were applied to the context of the creek to account for the algal growth and unsuitable conditions for humans to be wading or swimming in the creek). George's writing transitioned from the chemistry analysis of data on the percentage of Dissolved Oxygen to what this means for the creek environment. In such a way, he has demonstrated higher order thinking by synthesising scientific test results, comparing them to standards and drawing a conclusion about one parameter contributing to the pollution at Yabbie Creek. For George, learning chemistry in this way was important because, "The thing that I like is that we actually did real-life testing that we based our assignment and our work on real test conductors and we wrote a report on the tests that was a good thing we were actually putting chemistry to use in the real-life." Making chemistry relevant to George's life-world was "a good thing." The structure of the ERT afforded George the agency for making connections between chemistry and the real-world.

In comparison, the molecular theory of water taught in Phase 2 was included in an Appendix at the end of the report, revealing that George saw it as something separate. For George, fluid transitions between the concepts and context did not occur with the theory taught in Phase 2 of the lesson sequence. Author 1 became aware of the separation between the molecular theory of water and the context while she was a participant observer in the study, causing her to explore the students' understanding of the concepts taught in Phase 2 in the final interviews. George not only gave a canonically accurate answer explaining the solubility of water, he also reflected on how to integrate this concept:

> Author 1: Why is water a good solvent?
> George: Because it is such a polar molecule - one end is delta negative and one end is delta positive and if an ionic compound is most soluble the negative end of the water molecule will attract the positive ion and the positive end of the water molecule will attract the negative ion and it will pull them apart. (Final Interview)

Author 1 then asked “how does that link to what we have done with the water quality in Yabbie Creek?” and George replied “I had trouble finding a link there as well.” He paused for five seconds before saying “basically it is just the study of water, you have to know how the water is made, the atomic structure of water and the chemistry behind it, you have to know it if you want to study water quality that’s the first step to understanding and then build up from that.” George articulated a reason for learning the concept of water solubility, so Author 1 probed further: “Have you learnt about the chemistry of water doing this unit?” he replied: “Yeh I think I did because we had to find out what all the factors *(water quality parameters)* meant and we found out about the water and also about the chemistry of water I think it could have been taught a bit sooner *(referring to the solvency of water)* because it was at the end.” George’s insightful comments showed that he was unsure about how the concept of water solubility was to be integrated into the report. His comments demonstrated an understanding of the importance of studying the atomic structure of water for this unit on water quality. However, due to a lack of time, this concept was not taught until Week 7 when the students had been working for seven weeks on their reports. Rather than trying to integrate it into the main body of the report, George tacked it on as an Appendix as required by the task. The structure of teacher-led lessons on the molecular theory of water did not afford George the agency to demonstrate connections with the theory taught in Phase 2. Implications for the separation of the molecular theory of water from the water quality study and suggestions for improvements in subsequent context-based chemistry units are addressed later.

Richard was a high achieving student from Group 2 who demonstrated fluid transitions in his written report and conceptual understanding in the follow-up interview. The example of the water quality results chosen for Richard focuses on the faecal coliform test. Richard demonstrated an understanding of the faecal coliform test results as applied to the context, in both the written report and interview. In the following example, Richard links the faecal coliform test results with the pollution for each of the three sites tested and confirms his understanding in a follow-up interview:

Excerpt 4: A section of Richard's written report

> Faecal coliforms are micro-organisms that live in the intestinal tract of an animal, if it is found in water then it is an indication that the water is contaminated with the faeces of an animal, sewage etc.....Faecal coliforms are measured in colony forming units per 100mL (CFU/100mL). A CFU of one or less is healthy enough for drinking. If it is higher than 200CFU/100mL then the water is unsafe for swimming in. Sample 1 had a CFU of 14 252 CFU/100mL which is incredibly high. *Ms Ellen the lab assistant recorded that there were too many to count, this just confirms the previous findings. Sample 2 was 1,299 CFU/100mL or 2100 CFU/100mL by Ms Ellen. Sample 3 was 5594 CFU/100mL or 4500 CFU/100mL by Ms Ellen. These numbers are all appalling and show that the water quality is terrible, and extremely unhealthy to drink. (Written Report, p. 2)
>
> (*The laboratory assistant Ms Ellen helped students with the counting)

While Richard began the paragraph with a definition of faecal coliforms that could have been obtained from a textbook or internet source, he later explicitly connected the high faecal coliform readings with the context of the creek when he explained whether the water was safe to swim in or safe to drink. He wrote "these numbers are all appalling and show that the water quality is terrible, and extremely unhealthy to drink" concluding that the quality of the water was poor based on the high faecal coliform values. In this instance, Richard demonstrates fluid transitions between the faecal coliform test result and the context. His understanding of the faecal coliform test was confirmed in the follow-up interview when he was asked "Could you tell me what faecal coliforms are?" and Richard replied "Faecal coliforms are bacteria in the water that are found in the intestinal tracks of animals and you measure it by taking some water and putting it into a test bed and into an incubator and it is measured on colony forming units per 100 mL." After further probing he then went on to explain that the reading his group obtained was very high about 14 000 units which indicated very poor water quality. Not only could Richard explain the test with canonical accuracy, but he also translated the information into general conclusions about the water quality of the creek. Later in the interview he referred back to the faecal coliform count again when asked "What did you conclude overall about the water quality?" he replied "Although most of the tests indicated that the water quality was Okay the faecal coliform count was so high that I wouldn't consider swimming in it." Richard articulated his understanding of the faecal coliform test in both his oral and written responses by *toing and froing* between the test results and the water quality of the creek. Interestingly, the fluid transitions in this instance drew predominantly on biological concepts rather than chemistry concepts. A discussion about the integration of science discipline areas for context-based education and inquiry-based assessment tasks such as ERTs follows in the conclusion.

In this class, academically successful students like George and Richard demonstrated learning through the *toing and froing* evident in their written reports and interviews where they demonstrated how to populate both the real-world field and classroom field simultaneously (cf. Bourdieu, 1977). Also, there was evidence of higher-order thinking through "the manipulation of information and ideas in ways that transform their meaning and implications" as defined by the Productive Pedagogies framework (Queensland Government Department of Education and Training, 2004). The Productive Pedagogies were designed for the New Basics project in Queensland from years one to nine, however, their suite of pedagogies could be equally used as a referent for senior chemistry teachers (see, http://education.qld.gov.au/corporate/newbasics/index.html). This transformation occurs when students "combine facts and ideas in order to synthesise, generalise, explain, hypothesise or arrive at some conclusion or interpretation." The students combined water quality data and scientific facts with the context of the creek to arrive at a conclusion about the health of Yabbie Creek. By applying the chemistry or biology concepts that were part of the water quality analysis the students were engaging in higher-order thinking. After all, the study occurred early in year 11 when discipline specific knowledge was new and just developing.

Similarly, the representative middle range students, Shane, Ned, Mark and Ryan demonstrated fluid transitions between concepts and context in their written responses, however, no consistent and coherent pattern emerged in the oral data where they showed self-initiated links between the canonical science and the context. Unlike the high achieving students, the sound achieving students did not always connect the chemistry concepts with the context especially when the chemistry was inaccurate. Also, on occasions, the sound achieving students did not report accurately on all of the required water test results. These varied results will be discussed with representative examples from Ned (Group 2) and Mark (Group 1).

Ned's written report contained detailed written explanations for the test readings. On one occasion as demonstrated in Excerpt 5, he accurately interpreted a high nitrate reading supported with feasible explanations:

Excerpt 5: A section of Ned's written report

> Sample 3 had an average reading of 11ppm, this is also a very high level and is disturbing as this sample is from the middle of Bream Bay rather than in the creek, run off from the sewage plant and residences may be a cause when that is washed from the creek into the bay affecting the water quality for marine life in the bay. (Written Report, p. 4)

Ned connected the high level of nitrates (11ppm) with runoff from the sewage plant and near-by residences. Since nitrate is formed from the oxidation of organic wastes such as manure, by the action of nitrogen-fixing bacteria in soils, it is a reasonable inference to suggest that the high nitrate level is from the sewerage plant or the soil of surrounding residences. Water runoff from farming lands, intensive agriculture, effluent disposal to inland waterways, and percolation of water into groundwater have, in many areas, led to increased levels of nitrate in water bodies. However, when questioned in the interview about the origin of nitrates, Ned's answer was more limited than in the ERT. When he was asked: "Where do nitrates come from?" he replied "Fertilisers, that's the main source" (Final Interview). The greater detail in Ned's written report may be due to access to the internet and other references that can be resources for the written report when writing in the field of his own home. This may be a factor that contributed to more comprehensive written answers compared to the interview for the sound achieving students. Ned's written report contained fluid transitions on 21 occasions in the ERT compared to seven occasions in the interview. Also, the interview occurred one week after the reports had been handed in so the students may not have recalled the detail of the water tests and their comparison to standards accurately. For these academically successful students, their written tasks were replete with examples of fluid transitions; however, the oral data were not as convincing.

Mark connected the water test results with the context of the creek on 25 occasions in the ERT compared to eight occasions in the oral interview data. Connections were made between the test results and the context of the creek through instances similar to the example below:

Excerpt 6: A Section of Mark's written report

> Dissolved Oxygen (DO) is the amount of Oxygen dissolved in a water body. This is essential to living creatures in all aquatic systems to live. Plants and other organisms create DO during photosynthesis and this keeps the system circulating. The acceptable range of DO for "clean water" is 7-9 ppm. If the DO levels drop below 5 ppm, then the water is considered polluted and many of the aquatic organisms will die or fail to reproduce, which will give the water an unhealthy smell, increased populations of undesirable species, develop an unpleasant appearance and become unfit for human consumption.
>
> In Sample 1 an average measure of 5.8 ppm was recorded which is 17.14% below the accepted limit. Whilst not considered highly polluted, the water is on the verge of becoming polluted and drastic measures should be taken to increase the levels of DO in the water. (Written Report, p. 1)

Fluid transitions between concepts and context were evident in the above excerpt when Mark applied his knowledge of Dissolved Oxygen to the real-world context of the creek. When he wrote "if the Dissolved Oxygen levels drop below 5 ppm, then the water is considered polluted" he accurately interpreted the test results through comparison to standards. Also, he demonstrated the use of the discourse of science to connect his scientific understanding of Dissolved Oxygen and the laboratory results, to explain the effect on Yabbie Creek when he wrote "many of the aquatic organisms will die or fail to reproduce, which will give the water an unhealthy smell, increased populations of undesirable species, develop an unpleasant appearance and become unfit for human consumption.” Furthermore, Mark explained the Dissolved Oxygen test accurately in the interview and interpreted the test results to provide information about the water quality in the local creek:

> Mark: Dissolved Oxygen tells us how much Dissolved Oxygen there is in the water so plants in the water give off Dissolved Oxygen and most organisms in the water need Dissolved Oxygen so it balances itself out. When you get increases of sewerage or things like that the water is below quality (referring to Sample 1) but it’s not in the danger zone yet which is below 5 but it is very close so immediate attention should be taken...... either increasing it or looking into the source of why they are dropping the rate. (Final Interview)

Both the written and oral data showed Mark’s skill for connecting the test results with the context of the creek when he occupied both the real-world field and classroom field concurrently (cf. Bourdieu, 1977). The structure of the written task and final interview afforded Mark the agency for fluid transitions that also were found in both the written and oral data for the other six tests. Unfortunately for Mark, he became fatigued while writing the written report and omitted four important tests which contributed to the sound achievement ranking even though on occasions his written work displayed a higher standard. Academic success was achieved for the sound and high achieving students in the class who linked the chemistry of water quality to the real-world context by demonstrating fluid transitions in their ERTs. .

To achieve a successful mark in the written task students were required to demonstrate canonically accurate connections between the chemistry concepts and the context of Yabbie Creek. Peter and Dave, the two low achieving students in the focus groups, were unable to do this in the written work, interviews and in-class discussions. The study found that the low achieving students lacked the requisite skills such as competence with individual research, accurate analysis of test results as applied to the context and strong literacy skills to be successful in this water unit. An example of an excerpt of Peter’s unsatisfactory report is illustrated here:

Excerpt 7: A Section of Peter's written report

> As you can see the results that we have found for the three samples are polluted. Sample 1 results show that Upper Yabbie Creek was polluted in general. Sample 2 results Mouth of Yabbie Creek is also pullulated (sic). Finally Sample 3 results in the bay is polluted as well. It appears that the Sewerage treatment Works are effective because tests at the mouth of the creek and the bay show even more pollution than upper Yabbie Creek. If the turbidity was over 100 green substance will form which we called alge (sic) (Written Report, p. 2).

In this excerpt, Peter discussed the test results generally rather than referring to individual water quality results to support his conclusions. Furthermore, he did not demonstrate fluid transitions between the water quality test results such as pH, turbidity, faecal coliforms and the site at Yabbie Creek. His lack of understanding is evident when he confused turbidity with a measure of algal growth in the last sentence. Peter's inability to comprehend the water quality parameters was replicated in the follow-up interviews. For example, when Author 1 asked Peter to explain the origin of phosphates and nitrates in the water, he was unable to do so:

> Author 1: Phosphates and nitrates…can you tell me where they are from why they are in the water?
>
> Peter: Phosphates I am not sure where they come from (Final Interview)

Unfortunately, Peter and Dave did not have access to the necessary resources to fulfil the requirements of the task and hence rarely influenced structures or exercised their agency in whole-class or group settings. Despite Caren and Author 1 using out-of-class time to help Dave and Peter frequently, they did not develop the higher order thinking skills necessary for success in this unit. Structures in the class that support students with weak literacy skills are required to help them understand the requirements of the ERT, and how to apply the chemistry concepts to the context. Strategies for teachers to support students like Dave and Peter are included in the discussion.

The structure of a teacher-guided inquiry approach in Phase 1 that sought to prioritize student-student interactions afforded students the opportunity to demonstrate fluid transitions between concepts and context in the group discussions, ERT and interviews. Through fluid transitions students linked the chemistry of water quality to the real-world context. The study found that academically successful students in this class (i.e., sound and high rankings) made the necessary fluid transitions in both the written task and student-student interactions demonstrating connections between the context of the local creek and the water chemistry (or biology) concepts. Access to the appropriate resources enabled these academically successful students the agency to make the fluid transitions required for achieving the goals of the unit. Unfortunately, academic success was not experienced by all of the students in the two focus groups in the study. We found contradictions to our results for the two low achieving students; that is, fluid transitions between concepts and context were not realised in the written activities or student-student interactions. Their weak literacy skills impeded their understanding of the written task limiting their contributions to in-class discussions and student-student exchanges.

ACADEMIC SUCCESS IN CONTEXT-BASED CHEMISTRY

This article presents two assertions from an in-depth study on context-based chemistry education highlighting the chemistry achievement for selected students in one 11th grade context-based chemistry classroom. The circumstances by which students connected concepts and context were analyzed through a sociocultural lens using the dialectical relationship between structure and agency. We found that structures in the classroom that afforded students the agency to make connections between concepts and context enabled the students to be successful academically in this chemistry unit. For example, the structure of the ERT and the structure of group work afforded successful students opportunities to co-operate and collate results to complete the written assessment task. Furthermore, we found that students demonstrated links between concepts and context through fluid transitions. These fluid transitions were evident in conversations and written work.

In Phase 2, the students were not afforded the agency to interact in group work and the opportunity for student-student interactions decreased. Changing the structure constrained the agency of the students that limited the fluid transitions between the molecular theory of water and the test results. This was reflected in the example of George where the theory taught in Phase 2 was not integrated into the main body of his report but tacked on at the end as required by the task. Teaching the molecular theory of water unrelated to the context constrained opportunities for fluid transitions. One recommendation for subsequent context-based units structured around a water quality investigation is to change the ERT so that students are required to include the molecular theory of water in the analysis and written report. One such possibility is through solubility. The concentration of the anions, phosphate and nitrate, are important for the health of the creek and form attractive bonds with the positive end of the water dipole. By teaching the integration of such concepts in Phase 1 of the unit on a "need-to-know" basis, fluid transitions between the higher level chemistry concepts and context may have been realised. This may alleviate the time constraints to cover mandated syllabus concepts that contributed to the separation of the molecular theory of water in Phase 2.

Unfortunately, the structures that afforded the sound and high achieving students opportunities to make connections between concepts and context and contributed to their academic success did not do so for the low achieving students. High achieving students like George may have developed higher order thinking skills during their former years of science education. In comparison, the low achieving students did not have the resources of sound content knowledge or strong literacy skills as part of their cultural capital. If teachers acknowledge the differences in cultural capital that students bring to the chemistry classroom, they can create opportunities for developing these skills. For example, teachers could identify particular higher order thinking skills such as synthesising information, hypothesising, solving problems and drawing conclusions and teach these skills explicitly. Despite attempts by Author 1 and Caren to help Dave and Peter continuously throughout the water unit, the low achieving students did not develop the higher order thinking skills or literacy skills necessary for academic success in chemistry.

The classroom and the community of the local creek have been referred to as fields without boundaries in this study. While the students did not physically go to the field of the local community, their in-class conversations demonstrated fluid transitions between the two fields. When the canonical chemistry was applied to the pollution of the local creek through a discourse that moved backwards and forwards between the two fields, fluid transitions occurred. The existence of fluid transitions as students' conversations were *toing and froing* between the two fields is a new theoretical way of viewing how students make connections between concepts and context in chemistry education. The study found that evidence of fluid transitions is an important outcome for learning chemistry contextually and for academic success in chemistry.

There needs to be opportunities for students in chemistry classrooms to connect the real-world field with the field of chemistry knowledge or other science disciplines (e.g., biology). A study by Calabrese Barton, Furman, Muir, Barnes and Monaco (2007) showed that connections between science and students' out-of-school worlds can be created successfully by taking the students into the field of their local community. A similar approach could be adopted in context-based science teaching. Gilbert (2006) suggests such an approach in one of his four models for context-based teaching. The fourth model called "context as the social circumstances" situates the context in a cultural entity in society where students experience some aspect of their community (e.g., global climate, healthy food, the hydrogen economy) (Gilbert, 2006, p. 970). Through such a sustained inquiry in a genuine setting (rather than contrived) and through the communal engagement of teacher and students, there is the opportunity for students to learn chemistry (and other science disciplines) through the social activity (see Author 1, 2011 for similar study in a middle years classroom). In such a way, Gilbert's fourth model could be applied to the study of the water quality of the local creek if further opportunities for enhancing fluid transitions between concepts and context for all students were realized by visiting the sites from which the water samples were taken. Community immersion could include visits to the local Yacht Club, the Sewage Treatment Plant, as well as observing the community use of the creek over a period of time, talking to local residents and visiting the local council office to discuss water treatment practices and storm water drainage systems. Through community engagement, students may gain the necessary cultural resources to enable connections between the real-world field and the classroom field, particularly if structures in the classroom afford students the agency to apply scientific knowledge to their out-of-school communities. Research by Calabrese Barton et al. (2007) showed that all students, including those on the margin, were more likely to use a discourse that connected science with their real-lives when their lived experiences in the neighbourhood were foregrounded in the science classroom. Such opportunities may lead to greater academic success for all students in science especially those who cannot make the necessary connections in the field of the classroom.

Further Research - From Fluid Transitions to Resonance

This leads to the next exciting area of research that investigates how two fields can be brought more closely together after the students have physically spent time in the field of the local community. A subsequent study that analyzes students' conversations or written work for the merging of the sociocultural knowledge of the local community with their conceptual science knowledge would be timely. The water unit in this study could be a more socially aligned project where students are afforded the opportunity to talk to local residents, interview staff at the Yacht Club, visit the local council office and visit the Sewage Treatment Plant, increasing opportunities for the conceptual science and social knowledge to merge (Author 1 & Author 2, 2012). After the students have been immersed fully in the real-world field, it is possible that the *toing and froing* may be replaced with a blending of the canonical science and the real-world context where the distinction between the two is blurred. We define this blending of discourse as "resonance."

We propose that resonance needs to occur for students if the context-based teaching approach is to reach its full potential. Consequently, the next area of research for context-based education is to refine further the metaphor of “resonance” and the characteristics by which it can be measured to determine its achievement in a chemistry curriculum. Subsequent context-based units need to have a strong social orientation where students are immersed fully in the real-world field for resonance to be realized. In such future studies, students’ demonstration of resonance could be a measure of their academic success.

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Appendix 1- Sample of Final Interview Questions for Students

1. Explain what you have been doing in Chemistry this term.
2. Elaborate on the purpose of each of the water tests you have reported in your ERT.
3. How did you conduct the test and what did you find?
4. Explain the overall conclusion you reached about the health of Yabbie Creek

Appendix 2

Outline of Lesson Sequence for Water Unit

Lesson Number and Content	Type
PHASE 1	*PHASE 1*
1. Bottled water activity	Laboratory activity
2. Mind map	Teacher-led
3. Video and water tests	Video/Laboratory activity
4. Water tests	Laboratory activity
5. Water tests	Laboratory activity
6. Water tests	Teacher-led/Laboratory activity
7. Water tests	Laboratory activity
8. Library/computer research	Assignment research
9. Explanation of water tests	Teacher-led
10. Group activity	Teacher-led/group work
11. Group activity	Teacher-led/group work
12. Poster design and presentation	Teacher-led/group work
PHASE 2	*PHASE 2*
13. Theory: structure of water	Teacher-led
14. Concept map activity	Teacher-led/group work

15. Library/computer research	Research on assignment
16. Theory: H-bonding; dipoles	Teacher-led
17. Theory: water solubility	Teacher-led
18. No recordings	No recordings
19. Library/computer research	Research on assignment