International Journal of Science Education

ISSN: 0950-0693 (Print) 1464-5289 (Online) Journal homepage: http://www.tandfonline.com/loi/tsed20

Context-based assessment: creating opportunities for resonance between classroom fields and societal fields

Alberto Bellocchi, Donna T. King & Stephen M. Ritchie

To cite this article: Alberto Bellocchi, Donna T. King & Stephen M. Ritchie (2016): Context-based assessment: creating opportunities for resonance between classroom fields and societal fields, International Journal of Science Education, DOI: 10.1080/09500693.2016.1189107

To link to this article: http://dx.doi.org/10.1080/09500693.2016.1189107

Published online: 26 May 2016.

INTERNATIONAL JOURNAL OF SCIENCE EDUCATION, 2016
http://dx.doi.org/10.1080/09500693.2016.1189107

Routledge
Taylor & Francis Group

Context-based assessment: creating opportunities for resonance between classroom fields and societal fields

Alberto Bellocchi[a], Donna T. King[a] and Stephen M. Ritchie[b]

[a]Faculty of Education, Queensland University of Technology, Kelvin Grove, Queensland, Australia; [b]School of Education, Murdoch University, Murdoch, Western Australia, Australia

ABSTRACT
There is on-going international interest in the relationships between assessment instruments, students' understanding of science concepts and context-based curriculum approaches. This study extends earlier research showing that students can develop connections between contexts and concepts – called *fluid transitions* – when studying context-based courses. We provide an in-depth investigation of one student's experiences with multiple contextual assessment instruments that were associated with a context-based course. We analyzed the student's responses to context-based assessment instruments to determine the extent to which contextual tests, reports of field investigations, and extended experimental investigations afforded her opportunities to make connections between contexts and concepts. A system of categorizing student responses was developed that can inform other educators when analyzing student responses to contextual assessment. We also refine the theoretical construct of *fluid transitions* that informed the study initially. Implications for curriculum and assessment design are provided in light of the findings.

ARTICLE HISTORY
Received 4 December 2014
Accepted 9 May 2016

KEYWORDS
Context based; contextual assessment; chemistry education; assessment; fluid transitions; resonance

Context-based chemistry courses are designed to improve students' interest and understanding of chemistry by 'start[ing] with aspects of the students' lives, which they have experienced either personally or via the media' so that chemical concepts are developed on a need-to-know basis (Bennett & Lubben, 2006; pp. 1001–1002). In context-based curricula, a common distinction is made between *chemical concepts* (also *content knowledge*; cf. Broman & Parchman, 2014) and *contexts*, which represent realistic situations or scenarios to which the concepts are applied (Beasley & Butler, 2002; Gilbert, Bulte, & Pilot, 2011). Unlike traditional courses (i.e. concept based) whereby the curriculum was organized through a sequence of chemical concepts, in context-based courses situations and scenarios drawn from students' life-worlds structure the learning sequences and concepts are organized according to their utility for explaining issues that present within the context.

We have reported previously the highly unique experiences of a student known as Amanda (pseudonym) who repeated the 12th grade with the same teacher (i.e. Alberto)

CONTACT Alberto Bellocchi alberto.bellocchi@qut.edu.au Queensland University of Technology, Victoria Park Road, Kelvin Grove, Queensland 4059, Australia

when the curriculum changed from a concept based, or traditional course, to a context-based course (King, Bellocchi, & Ritchie, 2008). In that study, Amanda externalized during interviews the connections she had made between societal issues (i.e. contexts) and concepts, which she attributed to the new context-based course. Amanda also reported experiencing positive affect toward contextual inquiry tasks[1] called extended experimental investigations (EEIs) and extended response tasks (ERTs), which formed part of the new assessment instruments associated with the context-based curriculum. Interview data suggested that her experiences with the inquiry tasks contributed to her chemical understanding of her world through which she connected contexts, such as water quality and marine-artifact restoration, and chemical concepts including properties and structure of water and REDOX. Amanda's experiences were also compared with data from another school site where a context-based approach to chemistry was also being implemented. Donna (i.e. Author 2) was conducting a study in the school at that time. The students from the second school site corroborated many of the comments that Amanda made about her positive dispositions toward the context-based curriculum when compared to her original experiences with the traditional course. Collectively, the participants reported improved engagement, improved connections between chemistry topics and their life-worlds, and demonstrated conceptual understanding about chemical topics during interviews. Amanda also drew our attention to the role that the new inquiry-based approach to teaching and learning, and the key inquiry-based assessment tasks (i.e. EEI and ERT) had on her learning. She reported that the EEI provided students with greater autonomy than her experiences of practical-laboratory (i.e. cookbook) reports from the concept-based course. Amanda also experienced a second inquiry-based task called an ERT as well as traditional examinations as part of the assessment program related to the new course. These new assessment instruments were contextualized in that they required students to apply chemical concepts to resolve problems in realistic scenarios or situations. Whereas the EEI and ERT provided fully contextualized assessment experiences, tests were also used that included a combination of contextualized question items and traditional questions that were purely conceptual (i.e. no application of chemistry concepts to a realistic scenario was required).

In our previous study, we did not investigate extensively Amanda's responses to the three different kinds of contextualized assessment instruments (i.e. EEI, ERT, and tests) to which she had been exposed. This led us to ask in the present study: (1) to what extent did Amanda make connections between contexts and concepts in her assessment responses? and (2) how do different types of assessment items (i.e. conceptual and contextual) afford opportunities for students like Amanda to connect contexts and concepts? The unique opportunity to explore Amanda's experience of two different curriculum and assessment approaches when taught by the same teacher allowed us to understand better the ways in which assessment supports the intent of context-based curriculum reform and the extent to which assessment instruments provide further opportunities for students to link contexts and concepts as intended by the curriculum.

Context-based assessment in science

Although various reports of the effects of context-based chemistry courses exist, there are few in-depth analyses about the role of assessment in supporting the intent of context-based curricula and the way in which students respond to context-based assessment instruments. As Fensham and Rennie (2013) have argued, if one wishes to engage students with contextualized courses, such initiatives need to be supported by well-aligned assessment instruments. 'Alignment' refers to the process of matching curriculum intentions with assessment items and instruments (Webb, 2007). Context-based assessment therefore should reinforce the intent of the curriculum which seeks to increase student interest and engagement, explore conceptual understanding relevant to specific contexts, enhance appreciation of the role played by science in society, encourage the transfer of learning to novel contexts, and broaden students' knowledge of science and technology (Fensham & Rennie, 2013). There is on-going international interest in science education about the development of context-based courses and assessment and understanding the impact these approaches have on teaching and learning (e.g. Avargil, Herscovitz, & Dori, 2012; Fensham & Rennie, 2013). Exploring the way in which students respond to contextual assessment instruments that are aligned with context-based courses has the potential to further our understandings about context-based curriculum and assessment practices.

Effects of context-based assessment

In the past, school-based assessment has tended to reflect the decontextualized nature of school learning rather than the work of practitioners in a field of study (e.g. scientists; Brown, Collins, & Duguid, 1989). Success in school tasks consequently bore little significance to the field of science. In contrast, authentic assessment instruments require students to engage in activities that are similar to those encountered by experts in the field. This notion of authenticity developed by Brown et al. (1989) is similar to Bulte, Westbroek, de Jong, and Pilot's (2006) approach to context-based curriculum that was developed around the practices of experts in a scientific field. As well as being more authentic, assessment instruments need to be aligned with a context-based course if they are to assess validly what students have been taught (Bennett & Lubben, 2006; Webb, 2007). In this study, we use the terms *context-based assessment* or *contextual assessment* when referring to instruments that specify the application of science concepts to situations or scenarios with which students may be familiar (Ahmed & Pollitt, 2007). It is important to note that scenarios that are unfamiliar to students also constitute contexts based on this definition because they may form part of their life-worlds more broadly. As an example of a context in our study, Amanda's class collected first-hand data about the water quality of a local creek. One aspect of the assessment required students to ascertain whether the creek was in good health by comparing the multiple water quality parameters they had measured and their qualitative observations to national standards of water quality for natural waterways. This contextual task was also authentic because it reflected the kind of work that environmental scientists conduct to determine the effects of land use on the health of waterways. Although students may not have been familiar with the context of 'water quality analysis,' they were familiar with the creek and some of the water and land usage in the area based on personal experiences of this local environment. Details of this assessment task are elaborated in our results section.

Four different lines of research were discerned from existing literature that has explored the effects of contextual assessment on student learning. One line of research involved early attempts to determine the impact of context-based courses on students' conceptual understanding (Barker & Millar, 2000; Bennett & Holman, 2002). Comparisons of the effects of conventional courses (i.e. concept based) and context-based courses on student achievement indicated that overall there were no negative effects in relation to conceptual understanding of chemical concepts as a result of studying context-based courses (Bennett & Holman, 2002). One study reviewed by Bennett and Holman (2002) involved 250 chemistry students studying the context-based Salter's Advanced Chemistry approach (Barker & Millar, 2000). Questionnaires targeting students' understanding of concepts related to thermodynamics and bonding were used over three different time intervals to investigate changes in student conceptions about chemistry topics. Significant improvements were reported on the effect of the Salter's curriculum on students' conceptual understanding of some chemical topics.

Although Barker and Millar's study reported positive learning outcomes with respect to students' conceptual understanding of some chemical topics, the questionnaires used to explore student conceptions were not aligned to the context-based curriculum. That is, the items in the questionnaire were traditional chemistry problems devoid of any societal issues or applications of chemistry. In contrast, a second line of subsequent research has involved the interpretation of results from international tests (i.e. PISA) to compare the achievement of students from different countries on *contextual* test questions (Nentwig, Roennebeck, Schoeps, Rumann, & Carstensen, 2009). Findings from this research showed that students in most countries performed equally well on items that assessed knowledge-recall and application. The *application* items required students to extract information from contextual scenarios. Student test results from the Netherlands were significantly higher on contextual items than other countries. This considerable difference in results was attributed to the Dutch curriculum that emphasized scientific processes (i.e. inquiry) and societal issues (i.e. contexts) that served to align the contextual questions in PISA with the curriculum. These results suggest that student achievement on contextual assessment may be affected by the extent to which the curriculum and assessment instruments are aligned.

Previous studies of assessment pertaining to context-based education have used traditional concept-based assessment instruments to investigate the effects of context-based courses on students' understanding of chemical concepts (cf. Bennett & Holman, 2002). More recently, the reverse has been reported whereby Swedish upper secondary students (i.e. years 10–12) who studied a traditional chemistry course presented in the national syllabus were assessed through the use of contextualized assessment instruments (Broman & Parchman, 2014). The syllabus, called the Natural Science Program (NSP), is designed to develop future scientists and students could self-elect to study the program. Fifteen contextualized problems related to organic chemistry problems were designed to investigate students' abilities to apply the chemical concepts they had learned through the NSP. Problem-solving techniques of 20 students aged 18–19 from three different schools were explored using semi-structured interviews and think-aloud protocols. Student participants had completed the two years of the NSP program before the interviews were conducted, and their teachers identified them as medium to high achieving students in Chemistry.

Broman and Parchman (2014) structured the problems so that chemical formulae were provided before the context was presented. They found that in doing so, students provided narrow responses focused on the given chemical formulae. When answering questions, students drew upon two related chemistry content areas by recalling memorized facts from their NSP studies. In contrast, when the chemical formulae were removed from subsequent interview questions, this had the effect of eliciting a wider variety of responses. Students referred to various features of the context that would be salient for a reasoned response and identified chemical concepts they perceived to be relevant for answering the question that went beyond material recalled from their NSP studies. For example, in responding to a question about medicinal drugs, one student drew on factors such as drug solubility in water and pH of stomach acid as important for explaining drug absorption. This kind of response was different from those offered in the first line of interviews whereby students focused on the functional groups represented in the structural formulae given in the questions.

Broman and Parchman's (2014) study provided understandings about the way in which students who are unfamiliar with the contexts presented in chemistry problems attempt to solve them. Although it provided the reverse perspective to the approaches reported previously by Bennett and Holman (2002), which applied traditional assessments to students studying context-based courses, neither set of studies presents an example of students' solving contextualized problems that are related to a context-based course. This limits what we currently know about the ways in which high school students solve problems in context-based courses. We attend to this in the present study because the assessment instruments to which Amanda responded were aligned to the context-based course that was used for instruction.

In a third line of research, students' activation of suitable scientific concepts in response to contextual test questions was examined (Ahmed & Pollitt, 2007). This research investigated the ways in which junior science students (14-year olds) responded to contextual science items in the TIMSS test. Ahmed and Pollitt manipulated contextual test questions from a TIMSS test to generate what they called more *focused* questions and *less focused* questions. 'Focus' refers to the extent to which a context in a question provokes the appropriate scientific concepts in students' minds for answering the question. In every case in which contextual questions were modified to be more focused, there was an improvement in students' retrieval of the correct scientific concepts that pertained to the context presented by the question. These researchers concluded that 14-year-old students can become distracted by contextual information in questions and fail to identify the relevant science concepts required to answer the question if the items are not carefully constructed.

The fourth line of research on contextual assessment identified ways in which students made connections between contexts and concepts when responding to inquiry tasks associated with a societal issue (i.e. *contextual inquiry tasks*) or during interviews about the tasks (King et al., 2008; King & Ritchie, 2013). These studies have shown that when students experience context-based courses and contextualized inquiry tasks, they make statements during interviews and in written reports that explain phenomena related to the context presented in the assessment instrument by applying the relevant chemical concepts. Further elaboration of these studies is provided because they informed directly our research and theoretical framework.

Students in one 11th grade Chemistry class who studied a context-based course connected chemical concepts related to water quality (e.g. pH, turbidity, fecal coliform) and the possible land use surrounding a local creek near their school (King & Ritchie, 2013).

During classroom interactions and interviews, high achieving students talked about the health of the local creek by oscillating between chemical concepts, such as the pH level recorded at different sites along the course of the creek, and the potential cause of different pH levels due to different forms of land use. The same students provided similar links in their written reports (i.e. ERT reports) about the empirical creek water data. King and Ritchie (2013) concluded that the way in which the ERT report was structured required students to articulate the connections. This was enhanced through the use of classroom and group-work as part of the teacher's pedagogy, which afforded opportunities for students to link contexts and concepts in what the researchers referred to as *fluid transitions*. In contrast, low-achieving students were not successful at externalizing fluid transitions and this was attributed to low levels of conceptual understanding of the chemistry as well as weak literacy skills. One issue that was raised in their study, was the extent to which a visit to the local creek could have enhanced the quality of fluid transitions made by the students because that class had used second-hand data for their report analyses. We attend to this issue in the present study in which Amanda's class conducted a similar investigation of the water quality of a local creek that incorporated a field excursion to gather first-hand data.

Although King and Ritchie (2013) have reported on student responses to interviews about contexts and contextual inquiry tasks, no comparisons were made between students' responses to different types of contextual assessment instruments (e.g. the EEI vs. the ERT vs. paper and pencil tests). The EEI and ERT are different tasks because EEIs involve a controlled experimental methodology whereas ERTs involve a non-experimental methodology such as correlational designs. These differences could affect the ways in which students make connections between contexts and concepts. Tests are commonly used assessment instruments in schools that provide different affordances to teachers and students when compared to investigation reports. In the present study, we focus in-depth on the different affordances for making connections between contexts and concepts provided by three types of assessment instruments. This is likely to extend current understandings about the role that assessment instruments have to play in supporting the intent of context-based courses identified through King and Ritchie's study.

Limited research has focused on the role of tests in supporting or hindering the implementation of context-based curriculum approaches. One study by Bellocchi, King, and Ritchie (2011) categorized the contextual test questions used in chemistry tests, also experienced by Amanda, into two types: (1) *contrived questions* in which the students did not need to refer to the context to answer the questions and (2) *focused questions* in which students were required to connect the context with concepts in answering the questions. The first category contained a clear separation of contexts and concepts that inhibited any need for connections between these two constructs to be made by students when answering the questions. An example of this type of question is as follows: *Calculate the pOH of a sample of saliva where the hydrogen ion concentration is 1M* (Bellocchi et al., 2011). In this example, reference to saliva has no bearing on the calculation that students are being asked to perform. Its inclusion provides a contrived attempt at presenting a context related to saliva in an otherwise conceptual question (see Ahmed & Pollitt, 2007).

The second category of *contextual questions* required students to use information related to the context in the question in combination with chemical concepts in order to arrive at an answer. An example of a well-contextualized question is the following:

> The first location visited on a field study along Pete Creek was near a shipping port. The table below [not included here] presents a range of water quality parameters for the site. Systematically analyze the data in the table and provide a justification for the observed patterns in water quality parameters. (Bellocchi et al., 2011)

This question required students to make connections between their visual observations of the land use surrounding the creek and the water quality parameters provided to them. The inclusion of the context of the creek is relevant to answering the question in this example because physical features of the surrounding land use can help to explain the quality of the water. A limitation of Bellocchi et al.'s study was that it focused only on the nature of contextual test questions and did not report students' responses to the two different categories (i.e. contrived and focused) of questions that were developed. This limits the extent to which we can understand any potential relationships between context-based curriculum and assessment with respect to the way in which students may connect societal issues and chemistry topics in their responses to such questions. In the present paper, we report the analysis of Amanda's responses to the test questions reported in that earlier study.

The studies by Ahmed and Pollitt (2007) and Nentwig et al. (2009) focused on TIMSS and PISA tests aimed at junior science students and not senior chemistry students who face more complex science concepts. The available knowledge on the effects of contextual assessment on learning is based on the experiences of younger children and predominantly in cases where the intent of the curriculum was not supported by the assessment instruments. We address these issues in this study by focusing on the way in which Amanda responded to different types of contextual assessment instruments that were aligned with a context-based course through multiple theoretical tools.

Conceptual tools for investigating context-based assessment

The multiple goals of context-based education articulated by Fensham and Rennie (2013) focus mostly on the way in which students experience societal issues or applications of science (i.e. contexts) with respect to the science content in curriculum and assessment. To explore these dimensions, a framework is needed that is sensitive to the dialectic that exists between contexts and concepts (i.e. the two constructs depend on each other). A necessary feature of such a framework is the ability to identify when contexts and concepts are being represented as disconnected constructs or as binary constructs (i.e. when assessment and curriculum are not aligned, or when assessment is contrived). For this reason, a multi-theoretic framework was adopted in this study that was informed by the following constructs: *fluid transitions*, *fields*, and *division* and *fragmentation*. The *fluid transitions* construct (King & Ritchie, 2012) is related to Beach's (2003) metaphorical use of the term *transition*. In this usage, transition refers to the developmental change of an individual that corresponds to one or more social activities (Beach, 2003). When individuals move back and forth between one or more activities, their movements are referred to as 'collateral transitions.' The back and forth movement – or *toing* and *froing* – across activities is called fluid transitions (King & Ritchie, 2013). Fluid transitions occur when students make connections between contexts and concepts while working in context-based courses. For example, high school chemistry students connected chemical concepts to the context of a creek system when writing about the results from a series of water quality tests during a contextualized chemistry unit (King & Ritchie, 2013). There was a *toing* and *froing* between context and concepts evident in students' written reports. One student in the study remarked that the values of a series of water quality parameters (e.g. dissolved Oxygen levels) near a Yacht club were an indication of the poor health of the water system at that location. He then extended this by suggesting that high fecal coliform levels (i.e. bacteria) were the probable cause. In his written response, he moved back and forth seamlessly between the context of the creek and the concepts (e.g. Oxygen levels) relating to water quality; for example, the Yacht club potentially polluting the creek.

Associated with fluid transitions we identify that students experience different *fields* by studying context-based courses (Bourdieu, 1977; King & Ritchie, 2013). Originally the term 'field' was used by Bourdieu (1977) to represent both a physical location and the structure and resources that constitute that location. Another way of explaining a field is as a social space; that is, the social space of the chemistry classroom provides one field in which certain actions are possible or permissible due to the physical structures as well as the power structures (e.g. teacher/student) that constitute that social space. In our study, the power structures that existed in different fields were less salient to the analyses than the structures that afforded Amanda opportunities for making connections between societal issues (or contexts) and her classroom chemistry field. The structure of the context-based course and contextual assessment instruments was the focus of the study because structures afford or constrain students' agency for connecting the field of classroom chemistry and a societal field such as the Yacht club in the example presented earlier. Fields such as the Yacht club could provide students and teachers with different possibilities for action due to the different structures that may operate there (e.g. open space vs. desks and walls of classrooms; different objects present in different locations).

The conceptual tools of *division* and *fragmentation* (Bohm, 1994) complemented the fluid transitions construct for informing our understandings of context-based curriculum in this study. *Division* is the process by which we create categories or by which we distinguish things from one another. An example of this is the categories *context* and *concept* in educational research and curriculum and assessment design discussed in this study. Social constructs such as *contexts* and *concepts* are examples of the products of division in science education. In science curriculum and assessment design, *concepts* are abstractions developed by science (e.g. atomic theory) and take the form of facts that are often reported in textbooks (Latour & Woolgar, 1986). Abstractions such as science concepts are some of the divisions of reality constructed by scientific endeavor as one thing, or phenomenon, is distinguished from another. *Contexts* represent divisions of reality that are used to distinguish between science curricula that attempt to make connections to students' lives from more conventional concept-based courses, which focus on chemical concepts rather than their applications in different contexts. For example, a context-based course may foreground a societal issue to frame the course of study before the chemical concepts relevant to understanding that issue are presented to students. In this way, a division emerges initially between the societal issue and the chemical concepts as a means for organizing the curriculum.

Division of curriculum and assessment into contexts and concepts can be problematic if, by forgetting the process of categorization, we start thinking of contexts and concepts as new and discrete entities (i.e. *fragmenting* them; Bohm, 1994); that is, if we reify the categories. Accepting the categories as real (i.e. creating fragments) is problematic because it can lead to *false unification*. That is, putting the fragments back together in ways that are inauthentic. For example, if a student responded to a contextual question by providing only a science concept, they may be fragmenting the concept from necessary contextual information for arriving at a complete response to the question. Another example would be tacking on contexts or applications of science at the end of concept-based courses (see Gilbert et al., 2011) rather than structuring the course with the context as the main organizer for the curriculum and the concepts being addressed on a need-to-know basis. If contexts are tacked on to the end of a concept-based course, students may experience a traditional chemistry course for the bulk of their learning and contexts would appear at the end of the course as examples of the applications of science to a social issue. This would result in a fragmented experience of the contexts and concepts.

Although Bohm (1994) warned against fragmentation, he recognized the convenience of creating categories:

> We may *distinguish* [emphasis added] certain things for the sake of convenience. The word "distinguish" means "to mark apart." A distinction is merely a mark which is made for convenience; it doesn't mean that the thing is broken [or fragmented]. It's like a dotted line … So in our minds we should draw dotted lines between thinking and feeling and chemistry and so on not solid lines. (Bohm, 1994, p. 72)

Organizing curriculum and assessment by using categories such as *contexts* and *concepts* is useful because it allows us to challenge and change hegemonic practices like traditional concept-based chemistry courses that may disengage students. Dividing science into contexts and concepts may be useful because it allows a flow of ideas through a process of *fluid transitions* between these two constructs. This would not be possible if a course was focused narrowly on concepts. In the construction and implementation of assessment, contexts and concepts are useful ways to think about how questions may be structured (e.g. is there some context in which problems arise that can be investigated through chemical concepts?). Dividing science curriculum into contexts and concepts guides teachers and curriculum or assessment developers to select appropriate social issues for curriculum and assessment design.

Based on the theoretical tools presented in this section, we can expect that *fluid transitions* are likely to be observed when students perceive contexts and concepts as related entities and do not treat them as *fragments*. When fluid transitions are observed, we infer that the overlaps between *fields* associated with the context (e.g. societal issues like water quality) and the classroom field have become externalized at some point in a student's experience.

Investigating context-based assessment through Amanda's experiences

City School, the study site, was a large suburban state high school in Queensland, Australia. The 12th grade chemistry teachers were responsible for the development of contextual assessment instruments at the time of this study as part of the normal practice in Queensland schools. Contextual assessment instruments used throughout the year were aligned with the context-based units of study as shown through examples in Appendix 1. We conducted a comparative analysis (Stake, 2010) of concept-based and context-based assessment instrument responses *post hoc* due to the unique opportunity that Amanda's circumstances presented. This was an authentic comparison of two different treatments (the two courses and associated assessment instruments), as other conditions remained the same (i.e. the student, the subject of chemistry, the teacher, and the school). In this way, the study approached a within-subjects research design (Kim, 2010). By comparing Amanda's responses to different assessment instruments that were administered throughout the two academic years, this also provided a *repeated measure* dimension to the research through which we could compare the development of her responses to context-based and conceptual instruments through the repeated exposure to multiple assessment instruments. Whereas within-subject research designs often require contrived experimental conditions, the authentic circumstances of Amanda's unique experiences provided a level of ecological validity to our study that is not possible in traditional experimental research design. That is, we did not impose the curriculum, instruction and assessment as researchers because all of these elements were part of the state-mandated requirements for the school curriculum and assessment.

Background: curriculum, assessment, and instruction

Students at City School were free to choose their Year 11–12 subjects from a range of options provided by the school. There were no restrictions on entry to Senior Chemistry although advice was provided that students should attain a passing grade in Year 10 science if they were considering chemistry in the senior years. Chemistry at high school is a gateway subject for all science courses in most Australian universities so it typically attracted students who were interested in a range of science options at university and few students who had not achieved a passing grade in year 10 elected to study the subject. Despite this pattern in school-based enrolment into chemistry at City School, the subject was not designed to be exclusively for students wanting to study science at university and a number of students chose the subject based on interest in chemistry or to keep options open for their future.

During Amanda's repeat year, the state curriculum authority in Queensland had revised the senior chemistry curriculum requiring schools to teach chemistry content through contexts. A state-developed syllabus (i.e. curriculum) was designed to assist teachers in developing contextualized school-based *work programs.* The syllabus provided an outline of what context-based education *is* and specified the chemistry content, assessment and reporting procedures required of all state schools in Queensland (QSA, 2007; https://www.qcaa.qld.edu.au/1952-assessment.html). Within this system, work programs are school-level curriculum documents developed according to the principles outlined in the state-mandated syllabus, and approved by the state curriculum authority. School work programs include details of each 10-week unit, or course of work, that students study across years 11 and 12 (typically 8 units), along with the school-based assessment instruments developed by the teachers.

At City School, the teachers[2] embraced the new context-based approach and developed a two-year course of study (i.e. years 11–12) that was fully contextualized and incorporated assessment instruments that were also context based. Appendix 1 presents the Year 12 contextual units of work, associated chemical topics, and assessment instruments experienced by Amanda. The contextual units called *The Chemistry of the Pandora Shipwreck* and *The Chemistry of Pete Creek* were locally relevant to students because the renowned Pandora shipwreck was a local dive site and artifacts from the wreck were contained in the local museum. Pete Creek was one of the main tributaries of the river that traversed the city. It supported a range of local recreational activities, and was significant because various forms of land use surrounded the creek including housing, industrial, recreational, natural, and commercial. In this way, the contexts were societally relevant for students. The other context, *The Chemistry of the Body* was personally relevant for students as it pertained to the human body and dealt with personal issues such as health and dental chemistry. Embedded within each context were professional aspects such as careers like dentistry, museum conservation, and exercise science. In this way, the contexts could not be classed into simplistic systems that present personal, societal, and professional contexts as discrete entities (cf. de Jong, 2006). The focus on multiple dimensions within each contextual unit was designed by the teachers to have a broad appeal to the diverse range of students in the subject as recommended by Beasley and Butler (2002). An important aspect of the instruction, assessment and curriculum in this school was that students were expected to view these contexts through the lens of chemistry. That is, when learning about the tasks completed by a water quality analyst or museum conservator, students investigated the chemistry that was relevant to this work. From this perspective, the assessment required students to identify the chemistry that is relevant to aspects of the various contexts they had studied. Units or work were sequenced so that the chemical concepts studied in Year 11 were revisited in greater depth in Year 12 in line with the mandated curriculum requirements.

Classroom instruction proceeded from the context to identifying specific chemical content relevant to understanding the context. For example, in the *Shipwreck* unit, Alberto (i.e. Amanda's teacher at that time) began instruction with videos of divers (i.e. the museum conservator) investigating the *Pandora* site. This video served as a stimulus for classroom discussions focused on the needs of museum conservators who have to dive to retrieve artifacts. Ensuing instruction and learning experiences were focused on the Gas Laws to explain the immediate needs of the divers. Subsequent instruction was related to the retrieval and conservation of artifacts. The class investigated different methods of marine-artifact conservation through Internet and library research and scaffolded classroom activities using print-based resources. These learning experiences created the need for students to learn about the different materials found in shipwrecks, their properties and chemical structures, and processes of oxidation. Once they had learnt about the different forms of corrosion affecting metals, glass and ceramics, their inquiry-based assessment task (i.e. the EEI) required them to form groups and investigate how they could conserve metal artifacts (represented by rusted nails). This inquiry simulated the work of the museum conservators, to which the students had been exposed during a visit to the local museum with a tour provided by a conservator. During the *Creek* unit, students conducted a field-based study of the water quality of a local creek in addition to classroom-based instruction about the health of waterways more generally that led to discussion about solubility, the measurement of a wide-range of water quality parameters, and the principles of physical chemistry that underlie the functioning of water quality testing instruments. The *Human Body* unit (see Appendix 1) did not involve an excursion and was entirely based on classroom work.

Teachers used two textbooks as resources for supporting instruction. The classroom textbook, *Elements of Chemistry: Earth, air, fire, and water* (Bucat, 1983), which had been in use before the context-based curriculum was introduced, was heavily contextualized by drawing on examples of Australian settings for explaining chemical content. In the year that the curriculum changed to the context-based approach, the school required students to purchase the text *Chemistry* (Wilbraham, Stanley, Matta, & Waterman, 2007). This text contained some contextual references, but presented chemical content in a more traditional fashion. Neither text was used to drive the instruction and both served as resources for classroom activities, student reading and homework exercises. Classroom work was often provided through a wide-range of other print resources drawn from other texts and the Internet.

More about Amanda

We have detailed Amanda's unique situation in our previous research (King et al., 2008), so we provide some additional information here to extend her case as it relates to the focus of the present study. Amanda chose senior Chemistry because she aspired to study science at University. She had achieved above-average grades in junior school science, and demonstrated a keen interest in the sciences. In addition to Chemistry in Years 11 and 12, she also studied two higher level Mathematics subjects and Physics. Although Amanda was enthusiastic about Chemistry before the context-based approach was introduced (i.e. in her first attempt at Year 12), she reported in our previous research an enhanced enthusiasm during the repeat year when the curriculum and assessment became context based (King et al., 2008). The reason that Amanda had repeated Year 12 was so that she could attempt to improve her Year 12 results in a range of subjects before applying for entry into University. In contrast to her success with junior school science, Amanda found her senior mathematics and science subjects more challenging and she did not obtain the results she desired during her first attempt at senior school.

Data sources

Data sources for this study consisted of Amanda's responses to two types of contextual inquiry activities (i.e. the EEI and ERT reports), her responses to two contextual tests that also contained conceptual questions (i.e. Test 1 and Test 2[3]), her responses to traditional cookbook practical exercises (from the traditional course), as well as two interviews which were conducted after Amanda's final results had been determined at the end of the school year (see King et al., 2008). All of the assessment instruments were high-stakes assessments used to determine student levels of achievement (i.e. final grades) for calculation of tertiary entry options; student results were also documented on report cards. Amanda achieved a passing grade[4] (i.e. a 'C' level of achievement) based on the school-based assessment when she completed high school.

We classified the EEI and ERT as authentic assessment instruments because they were both based on the work of scientists working in realistic scenarios. The EEI was based on marine conservation through consultation with the local museum conservator whose background was in Chemistry. As part of the ERT assessment, students attended a field excursion during which they collected water samples from the local creek. This task replicated the work conducted by water analysts. The task was designed in consultation with experts in water quality analysis who worked with the local council and by drawing on Alberto's previous experience working for three months as a water analyst in a private company before becoming a high school teacher. Alberto's employment in the private company was based on his background in physical and analytical chemistry. As a teacher, Alberto provided two related learning experiences for his students. One experience involved learning about water quality testing *techniques* (e.g. water sampling, accurately measuring pH with a meter) from the local council staff during the field study, and in the classroom with the teacher. In the second experience, Alberto drew upon his chemistry background and work experience to extend his students' learning by focusing on the underlying analytical and physical chemistry concepts involved with each measurement technique. Students also supplemented their classroom and field-based learning experiences through their own library or Internet research as required through the assessment task. This example illustrates how the teachers helped students to move from macroscopic phenomena toward (sub-)microscopic and representational aspects of chemistry. In contrast to the more authentic ERT/EEI tasks, the two tests contained a combination of question items that are classed as routine exercises, or algebraic tasks, and problems requiring higher order thinking skills to achieve a solution (cf. Broman & Parchman, 2014). The alignment between these different assessment tasks and the curriculum used at the school are represented in Appendix 1.

The contextual assessment instruments were based on a criterion-referenced system that consists of State-mandated criteria and standards (https://www.qcaa.qld.edu.au/1952-assessment.html). The criteria and standards informed the design of all assessment instruments used in Queensland schools (QSA, 2007). These mandated criteria prescribed the characteristics that needed to be observed in student responses to assessment instruments in order to attain specific levels of achievement (i.e. an A–E level of achievement). Standards of achievement labeled 'A and B' were representative of higher order thinking processes, whereas those represented by a 'C' level were representative of lower order thinking and routine exercises (see also Bellocchi et al., 2011; Fensham & Bellocchi, 2013). In the present study, the EEI and ERT tasks contained complex problems with no pre-specified solutions due to the inquiry-based design of these instruments. In contrast, tests contained a combination of routine exercises, which would demonstrate a passing or 'C' standard of achievement if completed correctly, and more complex problems that would allow students to achieve 'A or B' standards if solved with clearly specified reasoning or correct answers. Examples and analyses of these test instruments and the question items contained within them are detailed in Bellocchi et al. (2011) (see also Fensham & Bellocchi, 2013).

The following extract from our previous study of context-based test questions (see Bellocchi et al., 2011) illustrates the difference between the C, B, and A criteria standards expected by the curriculum authority:

C [The student] … Consistently recalls, defines and explains a range of ideas and concepts … or, The student who applies knowledge and understanding in societal and scientific situations … applies algorithms concepts, principles and schema to problems solving and predicting outcomes … .

B The student who develops knowledge and understanding: Adapts and translates understanding of concepts, theories and principles.
A [The student] … Consistently adapts, translates and reconstructs understandings of … [concepts] … to … [answer the question] …

As these standards suggest, a greater level of depth in relation to the chemical concepts was important for the higher levels of achievement (i.e. A and B) when compared to the satisfactory level (i.e. C). These requirements informed the teachers' design of the assessment instruments, context-based units, and classroom instruction. For example, the *Creek* unit discussed earlier focused on analytical and physical chemistry concepts so that students could demonstrate the level of depth required for achieving the highest (A) standard in their assessment responses. If the unit had focused solely on water quality measurement techniques, it would not have afforded students the opportunity to achieve these higher standards. We discussed in our literature review how questions in tests targeted at the C level that contained contexts were more often poorly contextualized when compared to the greater number of high quality questions in A and B ranges. Because we have discussed the nature and quality of the test questions that were experienced by Amanda in depth in our previous study (Bellocchi et al., 2011), the focus of our present study was on the way in which Amanda responded to different types of questions (i.e. well contextualized and poorly contextualized), and more importantly how she drew together concepts and contexts in her responses to tests and assignments. Alberto's earlier role as Amanda's teacher also allowed us to gain access to the teachers' expectations of students' responses in these assessments. This knowledge informed our analyses of Amanda's responses allowing us to report the level of chemical explanations expected by teachers for students to achieve at the different standards (i.e. A and C). The teachers drew on available literature, existing resources such as texts and webpages containing contextual assessment questions or tasks, and also developed original questions as was expected in their jurisdiction. At the time of implementation, the teachers could not apply more recent ideas about context-based education (e.g. Gilbert et al., 2011) because these had not yet been developed.

Students in this class were taught about the level of chemical explanation required for responding to assessment tasks rated at different standards ranging from A to C. Classroom instruction included examples of the types of question that required more complex chemical responses in order to achieve the A and B grades, as well as the more routine exercises that represented the C standard. Although questions requiring a higher level of complexity in student responses used in the assessment instruments were novel, the students had experienced exercises of the same level of difficulty during classroom instruction. During instruction, students had also practiced the use of criterion-referenced marking rubrics for planning their responses. In this way, the teachers ensured that students knew the depth of chemical concepts required in responding to questions or tasks with different difficulty ratings (i.e. rated A, B, or C).

Data analysis

In our analyses, we drew on accounts provided by Alberto and Amanda about the assessment and teaching practices at City School during interviews. We began our interpretive efforts by analyzing interview data in which Amanda made claims about her learning experiences within the concept-based assessment and the contextual approach. We then analyzed her assessment artifacts to search for evidence that could exemplify her claims about her learning experiences. This involved a two-stage process beginning with each of us independently reading the assessment responses and identifying which ones contained references to the context presented in the question, and which ones made no reference to the context. This first stage was informed by our previous work in which we have used the typology developed by Ahmed and Pollitt (2007) to classify assessment questions as focused or contrived (Bellocchi et al., 2011). Similarly, we coded Amanda's responses to each assessment instrument as either focused or contrived based on the extent to which she connected pertinent chemistry concepts with contextual information in the test questions or assignment tasks to solve problems. It became clear after we met to discuss our initial coding that these two categories alone could not account for the different types of responses given by Amanda.

Based on the outcomes of our initial analysis, we developed new coding categories designated by the labels *conceptual responses* (*type 1*), *contextual responses* (*type 2*) and *fluid transitions responses* (*type 3*) for the second stage of analysis. Consistent with the emergent nature of our study, these new categories were informed by iterative cycles of data analysis and our reading of the theoretical frames and literature that informed the study. The categories are represented in Appendix 2 with cross-references to the examples reported in our results section. In Appendices 3 and 4, we provide coding data for the two tests with the test questions categorized according to whether they were *focused contextual questions* or *contrived questions* respectively based on previous research (Bellocchi et al., 2011).

Contextual responses referred to cases where Amanda did not provide any chemical concepts when answering a question or when providing an explanation in her EEI or ERT tasks. Her responses focused on macroscopic features of the phenomena represented in the question (cf. Davidowitz & Chittleborough, 2009). *Conceptual responses*, in contrast, were those whereby Amanda provided chemical concepts but did not show any connection to the context posed by the questions in tests or the scenarios in the EEI and ERT tasks. In these responses, her focus was (sub-) microscopic or symbolic chemical representations. The *fluid transitions* category represented those responses in which Amanda connected elements of the contextual information in the assessment items with relevant chemical concepts. Amanda made explicit connections between macroscopic factors, (sub-) microscopic and representational aspects of the relevant chemistry in these responses. Further sub-categories of the fluid transitions responses included *descriptive* and *explanatory* responses. In the descriptive fluid transitions responses, the connections made by Amanda between concepts and contexts remained superficial. Typically, she mentioned contextual features in the questions and concepts without explicating the connections between the two. We offer the following hypothetical example to illustrate this category. Descriptive responses may refer to land use surrounding a creek (*there is an old railway station at this site where chemicals were used*) followed by reference to chemical concepts (*the water has a lower pH at this site*). The contextual information about land use is not linked to the pH concept in any way; the statements offer a description of the state of affairs at some creek site. In contrast, her explanatory fluid transitions responses provided seamless connections between the chemical concepts and aspects of the context as Amanda applied her chemistry knowledge to explain issues or solve problems with reference to relevant contextual information. If we modify the previous land use example, this means that the response would attempt to explain *how* the nearby railway might have led to lower pH levels. This could be achieved by outlining the kinds of chemicals used at the railway site that were likely to leach into the creek and lower the pH. Such a response uses both chemical concepts and contextual information to explain the phenomenon of *low pH at a specific creek site*.

In the second stage of data analysis, we began by independently coding Amanda's responses by using the new categories. Upon completion, we then met and discussed our analyses to arrive at a final consensus on the codings. To resolve differences in our individual codings, we considered the three coding categories with reference to our theoretical framework and our previous studies investigating context-based assessment (Bellocchi et al., 2011; King & Ritchie, 2013). We then revisited the assessment response items in dispute and re-coded them until we reached full agreement on all codings.

Based on our theoretical framework, responses in which Amanda provided concepts-only or contexts-only were classed as *fragmented* (cf. Bohm, 1994). Fluid transition responses that were *explanatory* involved deeper connections between contexts and concepts than fluid transitions that were *descriptive*: the latter simply gave an account of the context with reference to a related concept. The results of the study that we report next represent our final consensus for the categorization of Amanda's responses. Extended examples of each coding category are presented in our results highlighting how each different assessment instrument provided opportunities for each response type. In our results section, we present selected questions and Amanda's responses that exemplify our categories (see also summary tables in Appendices 2–4).

Analyzing both the interview responses and Amanda's assessment responses allowed us to compare what opportunities were afforded to Amanda for connecting contexts and concepts by the assessment instruments and how she had responded to these opportunities. As we analyzed Amanda's responses to the assessment through our theoretical frames, we were also conscious of emergent themes that developed or challenged our frames. This allowed us to consider making refinements to the theoretical framework that we present at the end of the article.

Connecting contexts and concepts in contextual assessment: results of the study

As we show in the sections that follow, Amanda claimed during interviews that the contextual assessment instruments helped her to establish links between her world and chemical concepts taught through the context-based course. Her claims were supported from the analysis of her responses to the assessment instruments. The key issues that emerged from the data were that Amanda made three types of responses to the contextual assessment instruments: *fluid transition responses*; *conceptual responses* where she responded to contextual questions by presenting chemical concepts only; and *contextual responses* where she had not referred to the chemical concepts. The fluid transition responses served either descriptive or explanatory purposes. Fluid transition responses also tended to be associated with units of study involving field excursions. In contrast, none of her responses to assessment in the traditional (concept based) course referred to contexts. For this reason, we provide one example from her cookbook reports in the next section to illustrate the kinds of responses Amanda provided in the traditional assessment system. We focus our subsequent analyses on her response to the context-based assessment instruments in the new course.

Cookbook experiment reports

Students were given a cookbook experiment report to complete in the traditional course experienced by Amanda before her repeat year. The tasks required students to carry out the provided experiment and then report on it. The example provided below required students to complete an organic chemistry experiment that involved a REDOX reaction. When compared to the EEIs and ERTs in the context-based course, there were clear differences evident in the instructions given to students for the cookbook reports in the traditional course. The following extract provides a typical example of instructions for cookbook reports related to REDOX reactions and organic chemistry:

Extract 1

In this experiment, we will *investigate* the oxidation sequence

	1^0 alkanol (alcohol)	$\longrightarrow$	Alkanal	$\longrightarrow$	alkanoic acid
and	2^0 alkanol	$\longrightarrow$	alkanone (ketone)		

> In the first part, the oxidation of primary (1^0), secondary (2^0), and tertiary (3^0) alcohols will be tested using 1-butanol, 2-butanol, and 2-methyl-2-propanol. In the second part, the further oxidation of an alkanal (aldehyde) and an alkanone (ketone) will be investigated. (Alcohol Experiment)

These initial instructions indicated the scripted nature of the cookbook experiments that provided students with a clear outline of the chemistry they should observe. The task did not invite students to manipulate a range of variables despite the word *investigate* appearing in the first instruction. The requirements for the cookbook reports continued from those outlined in Extract 1 by detailing the apparatus required and the method the students were to follow. Once the practical-laboratory aspects of the task were completed, students were required to present a written report. This involved copying the given aim, apparatus and methods into their own report, discussing their responses to a series of given questions, and concluding by suggesting whether the aim of the experiment was achieved, how reliable the results were, and any modifications they thought should be made for future iterations of the experiment. Although students were required to discuss how the experiment could be modified to improve the outcomes, follow-up experiments based on these recommendations were not conducted. Two examples of the questions students were required to discuss in their reports included the following: (1) Identify the alcohols in [the experiment] as primary, secondary, or tertiary; (2) Does the color of the solutions in [the experiment] indicate that an oxidation reaction has taken place? Explain using your knowledge of oxidation/reduction reactions of $Cr_2O_7^{2-}$.

In the second question, the last word *explain* afforded students the opportunity to give a more in-depth response than implied by the first question that began with the word *identify*. However, the second question was heavily scaffolded with the identification of the chemistry that was required in the explanation (i.e. oxidation/reduction of $Cr_2O_7^{2-}$). Amanda's response to the second question was: 'Yes because a color change is one sign of a chemical reaction.' This response is superficial because it does not provide any detailed explanation using oxidation/reduction reactions.

The instructions for the conclusion section required students to comment on the adequacy of their experimental findings, to suggest ways of improving the experiment, and to link their results with the aim of the experiment. The following example contains Amanda's entire conclusion based on the alcohol experiment:

> This experiment has shown that 1^0 and 2^0 alcohols do react and that 3^0 do not react. It has also shown that 1^0 alcohols have a two-step reaction and that 2^0 alcohols have only one-step reaction. (Amanda, Reaction of Alcohols Report)

In her opening sentence, Amanda provides an observation without offering a possible explanation. The second sentence reports a chemical fact that was not observable during her experiment. Her responses indicate that the experiment involved learnt concepts. That is, the fact that 1^0 alcohols undergo a two-step reaction is not observable in the experiment that was completed by the students. Amanda could only have reproduced this information in her report by having studied it previously. The instructions did not require students to consider applying chemical concepts to societal applications, so it is unsurprising that no such connections were made.

The ERT and report

The ERT involved a field study investigating the water quality of a local creek. ERTs were inquiry activities (e.g. field studies, correlational studies) involving the study of relevant chemical concepts, and the generation and analysis of empirical data by the students. For example, students collected water samples from various locations along a section of a local creek during a one-day field excursion. The samples were analyzed on-site using electronic probes that tested for water quality parameters including salinity, pH, dissolved oxygen, turbidity, total dissolved solids, water temperature, and air temperature. In addition, records of visual observations were made regarding the kinds of activities that took place along the creek for comparison with the water quality parameters. Students then used these empirical data to evaluate a given statement about the quality of the water when compared to State guidelines for potable-water quality. Before and after fieldwork, students also conducted Internet and library research to learn various chemical concepts (see Appendix 1) associated with the water quality unit. Data analyses and conclusions were then reported in an ERT report structured with an introduction section, a results section, and an evaluation section. In the introduction section, students were required to explain the chemistry involved with water quality testing. The results section required the presentation of graphs of the trends in water quality parameters and analyses of any identified trends. In the evaluation section, students needed to ascertain the validity of a given statement about the suitability of the creek's water as a drinking water supply based on their data analyses.

Amanda's experience with the ERT

During an interview (Extract 2), Amanda compared her experience with the ERT in the context-based course to her experiences of the related chemical concepts that she studied during the concept-based approach (cf. Extract 1). Some of the relevant chemical concepts in both courses included solubility of compounds and the molecular structure of water.

Extract 2

> Amanda: um … like this solubility unit last year [i.e. concept-based course] we were just shown okay these ions [i.e. ionic compounds] aren't soluble where this year we see how certain ions [ionic compounds] 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 [i.e. chemical compounds] to it to get those ions out of water like you understand the theory behind it and you see a practical use … .

Amanda alluded to the way in which the concepts were learnt in relation to some authentic scenarios such as in the purification of water under the context-based course. This, she claimed, made her see a 'practical use for it [i.e. the concepts]' and indicated that contexts and concepts were studied in a connected and meaningful way for her. Her comments indicated that the structure of the ERT and the context-based course afforded her opportunities to articulate the overlaps existing between the field of classroom chemistry and societal fields such as those of town water supplies.

In order to complete the ERT, students learnt about the factors that could affect the solubility of different classes of compounds in water (e.g. ionic compounds, molecular compounds; see Appendix 1). They also were required to connect these factors with the observations that they made during the field excursion, and to compare water quality parameters with the National water quality guidelines. The ERT report information instructed students to develop possible chemical explanations for the values of different water quality parameters they had tested. This requirement provided an opportunity for students to make fluid transitions between the context of the creek's water quality and concepts such as solubility in their written reports.

The instructions given to students for the introduction – the 'theoretical section' – of their ERT report explicitly required students to establish connections between water quality testing and chemical concepts as shown in Extract 3.

Extract 3 ERT report instructions to students

> This [theoretical section of the report] involves the adaptation, translation and reconstruction of your understandings of the chemistry of water to the field of water quality testing. [You] must include the structure and properties of water molecules and [the structure and properties of] other substances found in naturally occurring water systems that govern the solubility of these substances in water.

The instructions required students to translate their conceptual understanding relating to water structure and properties to explain the solubility of materials that affected the creek system (i.e. the context). Students were also expected to explain the structure and properties of other 'substances' that were found in the water. We note that the language used here (i.e. *substances*) by the teacher could have been more specific in articulating examples such as organic and inorganic compounds or composite materials. Alberto (i.e. the teacher at the time) explains that the general term *substances* was chosen to keep the task open to any contingent observations students were likely to make during their field excursions. Such openness was necessary so that teachers could create opportunities for students to demonstrate achievement at the highest levels expected in the marking criteria. Students were required to identify the substances according to the class of chemical compound to which they belonged. Nevertheless, the wording of the question 'water molecules and other substances' could be misinterpreted to mean that water molecules *are* substances. We return to this point later (cf. Extract 4), when we analyze an example of Amanda's response to the ERT.

ERT tasks were graded on the A–E scale using the criterion-referenced rubrics. As discussed earlier, Amanda's class had received instruction on using the rubric to plan a response to the ERT task. This meant that the instructions for the ERT report provided a structure that afforded students the opportunity to externalize through their written work, the intersections of the field of classroom chemistry with the field of water quality testing and the creek. Doing so could earn students up to an A standard (i.e. the highest standard) of achievement on the task based on the provided criteria.

In the 'evaluation' section of their ERT reports, students were required to evaluate a statement about the suitability of the creek as a source for drinking water. This involved the comparison of field data to national potable-water quality guidelines. Thus, there were further opportunities for students to provide fluid transition responses in the evaluation section of their reports.

Amanda's responses to the ERT. We identified eight responses containing fluid transitions in Amanda's ERT report. Of the eight fluid transitions that she made, seven were descriptive responses and one was an explanatory response. In the fluid transition response that served an explanatory function (see Extract 4), Amanda accounted for the factors affecting turbidity of water such as tidal flows (context) and the chemical concepts relating to the insoluble particles (concept) that cause turbidity.

Extract 4 An explanatory fluid transition response to ERT

> Turbidity is a measure of the amount of suspended particles that [are] in water. Because water is a polar molecule any particles [of other substances in the water] that are non-polar [compounds] won't dissolve easily so the particles will remain suspended in the water. Some factors that influence the turbidity levels of water include the silt loads from the catchments or the strengths of the tidal currents or the size of the estuary. (Amanda, ERT report)

Extract 4 represented a fluid transition response because Amanda linked the context of the creek (i.e. factors affecting tidal flow) to explain the concept of turbidity that was caused by non-polar compounds being present in the water. This fluid transition served an explanatory function because she identified the contextual factors that cause turbidity (i.e. silt loads) and explained their insolubility through chemical concepts relating to turbidity (i.e. polarity, solubility). Her use of language could have been more specific had she replaced the term *substances* with *compounds,* or more specifically the class of compounds, and it is possible that she was adopting here the language used in the question statement discussed earlier in Extract 3.

The level of explanation in the response shown in Extract 4 could have been deeper based on the requirements outlined in the marking criteria. There was an opportunity for students to provide a detailed explanation of the kinds of materials washing into the creek from catchments and linking this with the chemical structures and properties of these materials to explain why they are insoluble and remain suspended. For example, Amanda could have explained that insoluble molecular compounds and insoluble ionic compounds contributed to turbidity whereas soluble molecular and ionic compounds do not affect turbidity. Responding in this way would have represented a deeper level of explanation earning her a higher grade based on the assessment criteria. The explanation that she gave in Extract 4 represented a division of contexts and concepts rather than fragmentation because she established connections between the concepts of polarity to explain the turbidity of water that was related to tidal currents and silt loads. This suggests that Amanda approached the context and concepts in the question as being interrelated and relevant for crafting her response rather than seeing them as disconnected fragments.

Amanda generated the following fluid transition response that served a descriptive purpose in the discussion of her results: 'All the values for conductivity were too high for the [potable-water quality] guidelines … . Therefore, none of the water is acceptable for drinking.' She was comparing the field data on electrical conductivity to the water quality guidelines to examine the context of drinking water. Amanda linked the concept of the conductivity of water from the creek to the potable-water guidelines and concluded that the water at the test sites along the creek was unsuitable for drinking. However, she did not explain the reasons for the high conductivity in chemical terms, or what effects these factors could have on humans. These points could have helped her to explain why the high conductivity of the water meant that it was physiologically unsuitable for drinking. The ERT afforded her opportunities to develop this depth of response, and she did not take up such opportunities extensively throughout the report. This response indicated the fragmentation of context and concepts because interrelations between the suitability of drinking water and conductivity were not explicated.

The EEI task and report

The context for the EEI was the conservation of rusted nails that simulated iron artifacts from a local shipwreck. Student groups (2–4 students) were required to determine the optimal conditions for the conservation of the nails using a method called electrolytic reduction. Briefly, electrolytic reduction involved attaching a nail to an electrode of a power supply and immersing the nail and another electrode into a conducting solution (i.e. electrolyte). A potential difference across the electrodes was then applied to the system for a length of time. Students conducted the experimental aspects of the EEI over a 2-week period in their class laboratory. Before commencing the task, students had attended a field excursion at the local museum where they learnt about marine-artifact conservation from the museum staff, and they had conducted library research to plan their investigation methods and to learn chemical concepts relevant to marine corrosion and artifact restoration (see Appendix 1). This included a discussion on the application of electrolytic reduction in the conservation of large metal artifacts such as cannons. In a similar way to the ERT, the students used the criterion-reference rubric to guide them in providing responses targeted at the required depth.

The EEI report required students to present an introduction where they detailed the purpose of their investigation, and an explanation of the chemical concepts related to the restoration of the nail through electrolytic reduction. This was followed by the research questions, hypotheses, methods, results, and a discussion of their research findings. The discussion section required students to explain their empirical observations using chemical concepts and to evaluate the effectiveness of their procedures in attaining the aims of the study.

Amanda's experiences with the EEI

Amanda was asked to compare her experiences with the assessment instruments used in the concept-based curriculum (i.e. when she completed Year 12 for the first time) with those used in the context-based curriculum (i.e. in the year that she repeated Year 12) during interviews. Extract 5 presents an example of her recalled experiences relating to her experience with the EEI when compared to cookbook reports in the previous concept-based curriculum:

Extract 5

> The pracs we did last year [see Extract 1] you read the textbook or sheet you are given and you just do it … you're not really researching *why you are using this chemical for this reason* where this time with the EEI we had to work out what chemical we would use and why … where the pracs last year you are using this chemical and sort of that's it.

In Amanda's response, she claimed that in the cookbook experiments she was simply required to follow a set procedure whereas the EEI required her to investigate the reason for using a particular chemical. Her response indicated the connectedness of the EEI with authentic situations. That is, knowing why a particular chemical should be used for a specific purpose is precisely the type of decision-making required of chemists such as museum conservators. This demonstrated that the EEI afforded Amanda the opportunity to make connections with the decision-making processes required of chemists, thereby creating a structure that supported the externalization of the overlap between the classroom chemistry field and the field of artifact conservation.

The decisions that Amanda made were driven by the context of marine-artifact conservation presented to her in the instructions for the EEI and the introduction section of the written report. These instructions asked students explicitly to link the purpose of their investigation to the conservation of iron artifacts and to translate their general understandings of corrosion and electrolysis to the conservation of metal artifacts in a marine environment. Amanda's interview response in Extract 5 made reference to the need to find a suitable chemical, or electrolyte, for the electrolysis process used to conserve metal artifacts as required in EEI instructions. The context of metal artifact conservation ensured that students made decisions based on this societal field when choosing a suitable electrolyte. The reason for this was that not all chemicals serve as suitable electrolytes in marine-artifact conservation applications. In other words, students were to apply their conceptual understanding of electrolysis to the context of artifact conservation. The nature of the task, as presented in the instructions, invited students to articulate the connections between the context and chemical concepts in their reports.

Amanda's responses to the EEI. Amanda responded in two different ways to the requirements of the EEI report: by making fluid transitions that were descriptive (i.e. those in which the context and concepts were connected at a superficial level), and by making fluid transitions that were explanatory (i.e. connected concepts and context at a deeper level). In total, she made 11 descriptive responses and one explanatory response. The explanatory response was found in the introduction section of Amanda's EEI report (Example 1).

Example 1 An Explanatory Fluid Transition Response to the EEI

> Iron corrodes according to the reaction $4Fe + 3O_2 \rightarrow 2\,Fe_2O_3$ which is the oxidation reaction of the REDOX reaction … . *In seawater this process happens faster because the salt in the water makes the transfer of electrons easier* [emphasis added]. (Amanda, EEI report)

This response represented a fluid transition because Amanda established a correct relationship between the chemical concepts of corrosion (represented by the equation) with the context of marine artifacts (by reference to the seawater). The statement served an explanatory function as Amanda used the presence of salt in seawater to state why there is an enhanced rate of corrosion when artifacts are submerged in seawater (i.e. 'the transfer of electrons easier'). However, this explanation could have been improved if she offered the detailed chemistry relating to the role of ionic compounds in increasing the conductivity of the seawater. Amanda also did not explain that this chemistry was most significant to the corrosion process when artifacts were extracted from seawater rather than when they remained submerged. Hence, some details of the context that were salient to a more in-depth explanation were ignored. She would have benefitted from providing more in-depth explanatory responses because such responses were more highly valued (i.e. an A standard) in the State mandated criteria used to grade her work.

Example 1 contained a clear division between the context and concept; however, Amanda did not fragment the two constructs. That is, in her paragraph the context and concepts remained connected as she explained how they were related by stating that seawater contains ions and that they improve the transfer of electrons which is important for the corrosion of iron (i.e. the context).

A representative example of a fluid transition that was descriptive occurred in the analysis section of the investigation report where Amanda described the reactions involved with the removal of rust from the nail:

Example 2 A descriptive Fluid Transition Response to the EEI

> The results do show that electrolysis does reverse the corrosion by reversing the REDOX reaction that corrodes the iron. $2Fe_2O_3 + X\,H_2O \rightarrow 6Fe + 3O_2 + X\,H_2O$ is the reaction that occurred to clean the rusty nails. (Amanda, EEI Report)

In this statement, Amanda refers to the condition of the nail (i.e. corroded iron) in relation to the REDOX reaction. The condition of the nail pertained to the context of corrosion of marine artifacts. Her statement about the equation simply reported that it was 'the reaction.' She did not use the equation for the reaction to explain how electrolysis affected the corroded condition of the nail. Amanda had described the context and concept in her response rather than using the equation that she presented to explain the removal of rust from the nail. This response represents the fragmentation of concepts and context. To establish a stronger relationship she needed to explain the empirical evidence that could be used to demonstrate that the process had been 'reversed.' For example, she could have made reference to the chemical equation by explaining the observation that red rust (Fe_2O_3) was no longer present on the nail, which could indicate that the reaction represented by the equation had occurred.

As Amanda indicated during interviews, the EEI afforded her opportunities to make connections between contexts and concepts and thereby apply the chemistry she was learning to authentic situations such as the conservation of marine metal artifacts. Her claims during the interviews were supported by her assessment responses that provided further evidence of the connections she had made. Although there were 12 occasions where Amanda made fluid transitions in her report, the large number of fluid transitions that were descriptive (11 responses) when compared to the one response containing a fluid transition that was explanatory indicated that she connected contexts and concepts mainly at a superficially descriptive level and treated them as fragmented constructs. Such superficial responses indicate in our research that Amanda may not have perceived there to be any strong connection between the context and concepts in these circumstances.

Contextual tests

Amanda was assessed by class tests on two occasions during the context-based curriculum: first at mid-year and finally at the end of the year (see Appendix 1). The question items used on the tests included multiple-choice items, short written response items and extended written response items (see Bellocchi et al., 2011). For the written response items, some required the applications of algorithms to arrive at numerical answers to problems, whereas others required qualitative responses with no applications of algorithms. Test responses were graded using the same criterion-referenced system used with the EEI and ERT. More details and extended elaboration on the test questions can be found in Bellocchi et al. (2011) (see also Fensham & Bellocchi, 2013). Given that tests consisted of multiple question items, the teachers aligned each item to a criterion standard. Questions that required recall or application of basic knowledge were rated at a maximum standard of C. More complex questions were ranked up to an A or B standard and thereby required greater depth in the level of response provided by students.

Test 1 took place at mid-year and was used to assess a unit called *The Chemistry of the Body* and Test 2 took place at the end of the year and was related to the water quality unit. In the *Body* unit, students learnt about different systems (e.g. respiratory, circulatory) and organs (e.g. teeth) from a chemical perspective. For example, in relation to the respiratory and circulatory systems students studied the ways in which an equilibrium system operates to buffer the pH levels of blood. The effects of exercise on blood pH levels and the equilibrium system formed a more specific topic of inquiry. Equilibria related to tooth decay also formed part of the course content. In relation to tooth decay, students learnt about the equilibrium that establishes in the mouth between saliva and tooth enamel. The teachers developed test questions to elicit students' responses that connected the contexts to the relevant chemical concepts. In this way, the structure of the questions was aligned to the structure of the context-based course. This meant that there were numerous opportunities for students to make fluid transitions due to the contextualized nature of question items in the tests. However, unlike the units that were associated with the inquiry tasks, there were no field excursions and fewer laboratory-based inquiries in the unit associated with Test 1. In contrast, Test 2 contained some questions that were related to the water quality unit that involved the excursion to the local creek.

Although Amanda's responses to tests from the first year in which she completed the 12th grade (i.e. the concept-based course) were no longer available[5] at the time of our study, this did not affect our analyses because some of the conceptual questions in the tests we analyzed were similar to those used in the previous year's tests. We were able to compare her responses to conceptual questions and contextual questions within the tests during Amanda's repeat year. This provided a basis for comparing the way in which she responded to these two types of test items which is in line with the focus of our research questions.

Amanda's responses to contextual test questions. Test 1 and Test 2 in the context-based course contained questions that were conceptual and those that were contextual. Conceptual questions were those that did not involve any realistic scenarios or societal issues. An example of a conceptual question was the following question: *Calculate the concentration of a solution containing 5 g of sodium carbonate in 500 mL of water.* Contextual questions were those in which an issue or scenario was presented and then students were required to explain the issue or solve a problem related to the issue using chemical concepts (Bellocchi et al., 2011).

Amanda responded to all 29 conceptual questions in Tests 1 and 2 with conceptual responses. For example, for a question like the example above, Amanda responded by carrying out the calculation and presenting the final answer of the concentration. As the question did not give an authentic scenario for performing the calculation, Amanda did not contextualize her responses to questions of this type. Of the 29 conceptual questions in Tests 1 and 2 that she answered, 20 (67%) responses were awarded full marks, one response was awarded part marks, and seven responses were awarded no marks. Amanda did not attempt one of the questions.

A contextual question item was one where authentic applications of chemical concepts to a context were required to answer the question as presented in Example 3.

Example 3

> Tablets are designed to dissolve in different parts of the digestive tract depending on where their action is required. A new tablet for stomach upsets dissolves only in Hydrogen ion concentrations exceeding 0.5 mol/L. Given that saliva has a pH of 5, will the tablet perform the desired function in the stomach? Justify your answer.

Questions like this one required students to solve authentic problems and make connections between contexts and concepts in their responses. That is, these questions presented scenarios or problems that could be explained through the application of chemical concepts. Students could achieve up to an A standard on this question item based on the criteria rubric, so a deep level of response was expected by the teachers. In Example 3, a student would need to perform a calculation and then use their quantitative answer to make a justified statement regarding whether the tablet would dissolve in the mouth or not.

Overall, Amanda responded to 26 of the 28 contextual questions in Test 1 and Test 2. Her responses were categorized into three different types: (1) *conceptual responses* (using chemical concepts with no reference to the context; 13 responses); (2) *contextual* *responses* (making reference to contexts with no application of concepts; 7 responses); and (3) *fluid transition responses* (6 responses).

An example of a conceptual response (i.e. Type 1) was in relation to the question in Example 3 about the solubility of medicine in the form of a tablet in the mouth or stomach. Based on provided information, students had to calculate the solubility of the tablet and ascertain where in the body (i.e. mouth or stomach) it would dissolve. Amanda's response involved a calculation of the hydrogen ion concentration of saliva presented as a final numerical answer. She did not refer to the context of whether the tablet could dissolve in the stomach in her response. Consistent with the criterion standards, Amanda was not awarded the highest grade possible based on the marking criteria because she did not connect the concepts of pH and solubility to the location where the tablet was to dissolve (i.e. in the stomach rather than the mouth). In her responses, Amanda had fragmented the concepts of pH and solubility from the context of the function of the tablet designed to dissolve in the stomach. Fragmentation in her response prevented her from articulating the interrelationships between context and concept that would have earned her a higher mark. This suggested that the overlap of the field of classroom chemistry with the field of pharmaceuticals was not evident or salient to Amanda when she provided conceptual responses to some contextual questions. An example of a contextual, or Type 2 response, was in relation to the following question:

Example 4

Fluoride compounds dissociate in water to form fluoride ions (e.g. $NaF_{(s)} \rightarrow Na^{+}_{(aq)} + F^{-}_{(aq)}$. The fluoride ions replace the hydroxide ions in some of the $Ca_5(PO_4)_3OH$ and form F F according to the equation

$$\underset{\text{hydroxyapatite}}{Ca_5(PO_4)_3OH_{(s)}} + F^{-}_{(aq)} \rightleftharpoons \underset{\text{fluorapatite}}{Ca_5(PO_4)_3F_{(s)}} + OH^{-}_{(aq)}$$

Fluorapatite is harder and denser than hydroxyapatite so tooth enamel is stronger and more resistant to bacterial attack. With reference to the equilibrium system shown above, justify the claim that when children drink water containing 1 part per million NaF, they have fewer cavities than those who drink non-fluoridated water. (Contextual test question)

Amanda responded to this question by stating that '… tooth enamel that is treated with fluoride is harder than untreated tooth enamel and thus is less likely to be attacked by bacteria.' In her response she made reference to dental hygiene aspects of the context (i.e. by referring to tooth enamel and bacteria) but she did not make connections to the chemical equilibrium and the information provided about sodium fluoride. Therefore, the contextual details were again fragmented from the concept because her response did not include the chemical concepts related to the equations in the question (e.g. shifting position of the equilibrium). The overlap between the field of dentistry with the field of classroom chemistry was not evident in Amanda's response. This could indicate that despite the support provided during classroom instruction for the level of response required for these kinds of questions, the question item itself may not be queuing students adequately to provide fluid transition responses.

An example of a *fluid transition response* (i.e. Type 3) that served an explanatory purpose was identified in relation to the question in Example 5.

Example 5 An Explanatory Fluid Transition Response in the Test

> Question: Reconstruct your understandings of equilibrium and/or acids and bases to validate the method/s of treatment recommended for the ailment.
> Ailment: Hiccups are repeated, involuntary spasms of your diaphragm, a muscle separating the chest area from the abdomen. When the diaphragm jerks, the air coming in is abruptly stopped when a small flap suddenly closes the opening to the windpipe, resulting in the familiar "hic". Hiccups may result from abnormal stimulation of nerves which control the diaphragm and windpipe. Slight decreases in pH may slow the activity of these nerves.
> Recommended Treatment:
> Have the patient breathe in and out of a paper bag or hold their breath.

Amanda addressed this question with the following explanatory fluid transition response:

> By holding their breath or by breathing into a paper bag this increases the concentration of CO_2 which then reacts with H_2O to form H_2CO_3 it then goes on further to form H^+ and HCO_3^- which would then lower the pH so holding their breath or breathing into a paper bag would work.

This response represented a fluid transition response as Amanda articulated the connections between the context of the treatment (i.e. by referring to 'breath,' 'breathing,' and 'bag') with the chemical species – or concepts – that she mentioned. More specifically, the concepts that she referred to included changes in concentration of CO_2, and Amanda also made indirect references to the equilibrium system when she stated that changes to the concentration of H^+ would occur. Her teacher awarded Amanda full marks for this response because she had articulated the connections between information about the context with the relevant chemical concepts in her response. Despite this fact, Amanda's explanation could have reached a deeper level. Partial explanations like Amanda's response were sufficient for achieving full marks for this type of question, as a deeper response was not required. Her response provided an example of the division of contexts and concepts rather than fragmentation this time because the language and concepts pertaining to chemistry were intermingled with the language and concepts related to the context to construct her explanation.

There were six instances in the two tests where Amanda provided responses containing fluid transitions in a similar way to Example 5. In 50% of these responses her teacher awarded her full marks when she made fluid transition responses that were explanatory. She was awarded part marks for two other questions to which she provided fluid transitions responses (one descriptive, one explanatory). An important finding was that Amanda referred only to contexts in her responses to contextual questions, indicating that she distinguished the need to use a context in her response when cued by the question. This demonstrates that students are sensitive to the alignment between contexts and concepts in test questions and answers and are able to discern when there is a genuine requirement for articulating the connections between these two constructs.

In her responses to Tests 1 and 2, Amanda answered contextual questions correctly on 13 of the 26 items that she had attempted (50% success rate). In comparison, she was less successful in being awarded a correct response with contextual questions in the tests when compared to correct responses to conceptual questions (67% success rate). This difference in achievement could have been affected by the fact that there was a greater number of more challenging questions that were also contextual in the test when compared with the number of challenging questions that were conceptual.

Another factor that could have affected the way in which Amanda responded was that the contextual test questions were contextualized to varying degrees of quality (see Bellocchi et al., 2011). That is, Example 4 presented a *focused* or genuine use of a context in the question because information relating to the context and chemical concepts was necessary for answering the question (see Appendix 3). Furthermore, the context and concepts were clearly connected by the fact that answering the question required information related to the context. In eight other questions, classed as *contrived* (Appendix 4), a contextual scenario was included in the question stem but it had no bearing on answering the question (Bellocchi et al., 2011). Such *questions* presented contexts and concepts as fragmented from one another. For example, one question stated that: 'Most of the acid-base chemistry in living systems occurs through interactions between weak acids and bases.' Then students were asked to give examples of strong and weak acids and bases. The inclusion of the context of living systems in such questions was contrived as there was no reason to refer to the information about living systems when answering the question. Amanda responded correctly to six of the contrived questions by providing the relevant chemical concept only. In these cases, her fragmented responses were justified by the contrived nature of the questions, which did not require connections to be drawn from a context to the concepts. The presence of eight contrived questions across the two tests could explain, in part, why Amanda provided responses containing fluid transitions to certain types of contextual test questions only; that is, she interpreted the contrived questions to require only a conceptual response and answered accordingly.

A possible explanation for the varying quality of contextualization in the questions was that Test 1 was associated with a unit that was mainly taught in the classroom whereas Test 2 was associated with the water quality field excursion. Thus, some of the questions in Test 2 required applications of chemical concepts related to the context of water quality as experienced by Amanda during the field excursion. We were unable to compare the *proportion* of Type 1, 2 or 3 responses made by Amanda in the ERT and EEI assessments with the proportion present in her test responses. The reason for this was that the maximum number of affordances for connecting contexts and concepts in open-ended tasks such as the ERT and EEI could not be calculated. In contrast, the finite number of questions in tests makes it possible to calculate the percentage of each response type as a proportion of the total number of questions.

Illuminating contextual assessment practices through Amanda's experiences

The key outcomes of the study were that all three different types of contextual assessment instruments (i.e. EEI, ERT, and tests) used in the context-based course provided opportunities for Amanda to externalize the connections between contexts and concepts. The extent to which Amanda used these opportunities varied as she produced fluid transition responses that were either explanatory or descriptive in her reports and tests, and she responded to contextual test questions in three different ways; that is, with concepts-only (Type 1), with contexts-only (Type 2), or with responses containing fluid transitions (Type 3). Response Types 1 and 2 for well-contextualized questions represented the fragmentation of contexts and concepts because Amanda did not deal with each construct in complementary ways. Such responses corresponded with lower levels of achievement based on the criterion-referenced assessment system used in the jurisdiction. In contrast, Type 3 responses represented her seamless transitions between contextual information and chemistry concepts whereby each construct was important for arriving at a complete response. Consistent with previous research (Bennett & Holman, 2002), there was no difference in Amanda's overall achievement when studying the context-based course when compared to the concept-based course. Whereas Broman and Parchman (2014) found that students referred to contexts and concepts when responding to interview questions, it was not clear to what extent the connections made by the students represented viable answers to the problems. Through our study we have developed a system of coding student responses to context-based assessment items that can be adopted in future research to analyze systematically and classify the different *types* of responses students give to context-based problems and the extent to which responses are indicative of students perceiving the contexts and concepts as connected (i.e. fluid transitions, divisions) or disconnected (i.e. fragmentation). As an example, a quote taken from Broman and Parchmann's study will be analyzed through our coding scheme. In response to one question item in their study, a student explained the solubility of Taurine and Caffeine found in the popular energy drink RedBull™ as follows:

> I don't know what caffeine and taurine look like, but if they are soluble in water, and they must be since we drink RedBull ™, they have to be polar, so probably [they have] OH-groups. (Broman & Parchmann, 2014, p. 525)

In our scheme we can now classify this as an *explanatory fluid transitions* response. Initially the student refers to the idea of solubility and concludes that caffeine and taurine, which he or she knows little about, must be soluble. Based on this idea developed from the contextual features of the question (i.e. that we drink RedBull), the student assumes that the molecules must be polar and goes on to predict that they contain hydroxyl functional groups. The ease with which this student shifted between the context of the energy drink and the chemical concepts, by his or her toing and froing between terms from the two divisions (i.e. context and concepts), indicates that the contextual features were deemed relevant for answering the question. Theoretically we can infer from our framework that this student does not perceive the contextual features of this question as fragmented from the conceptual features. That is, the language used by the student indicates clearly the division of chemical concepts from the contextual aspects through reference to the energy drink, but the response indicates that the two are interconnected and not treated separately.

Our innovative theoretical framework and coding system has furthered our understanding of the effects of these forms of assessment on students' learning and understanding of chemical concepts. Most importantly, our study contributed necessary insights of the effects of context-based assessment within a context-based course. This is unique because previous research has either studied the effects of context-based courses with traditional exams (cf. Bennett & Holman, 2002) or traditional courses with context-based interview questions (i.e. Broman & Parchmann, 2014). The alignment of the context-based course and contextual assessment instruments provided complementary structures that allowed the overlaps between societal fields and the classroom chemistry field to become externalized, at times, for Amanda as evidenced by her fluid transition responses. The results of this study extend prior research by King and Ritchie (2013), which identified that students made fluid transitions during ERTs but did not identify the extent to which students connected context and concepts in either explanatory or descriptive ways or through division and fragmentation as shown in our study. Our findings provide evidence that explanatory fluid transitions represented deeper levels of conceptual understanding than the descriptive responses and represented division of contexts and concepts rather than fragmentation. In the descriptive responses, Amanda made no clear statements that connected the contexts to the concepts and this left the two constructs as fragments.

Our study also extends findings from Ahmed and Pollitt's (2007) work on ninth grade students' responses to contextual assessment in the TIMSS test. These researchers found that students responded differently to questions in which the context invoked clearly the science concepts required to answer the question correctly. We found that Amanda responded to some well-contextualized questions with responses demonstrating fluid transitions whereas her responses to contrived contextual questions included either concepts, or the contextual information (i.e. fragments), but not both. Unlike Ahmed and Pollitt's study which found that younger students become distracted by contrived contextual questions and responded with irrelevant information queued by the contexts, Amanda's responses to poorly contextualized questions demonstrated that she could still select information that was relevant to answering such items. Her answers to these questions tended to be fragmented rather than fluid transition responses but this was justified in these cases by the fact that these questions contained contrived contexts.

Resonance between the field of classroom chemistry and societal fields through assessment

The two tests and the inquiry reports afforded Amanda opportunities to connect contexts and concepts when the instruments were well contextualized and closely aligned, not only to the units, but also to out-of-school experiences (e.g. field trips). The three different ways in which Amanda responded to contextual test questions (i.e. concepts-only, contexts-only, or fluid transitions) meant that there was greater diversity in the way in which she responded to the requirements of tests when compared with her responses to the inquiry reports. Although we can partly account for some of the fragmented responses, that contained concepts-only or contexts-only, due to the contrived nature of some test questions, this was only the case for eight questions across the two tests (Appendix 4). There remained a large number of fragmented responses (20 of 26 questions) to well-contextualized questions in the tests (Appendix 3). In contrast, there were few instances of fragmented responses in the contextual inquiry reports. A possible explanation for this was that the nature of the test questions was different from the instructions that guided students in their inquiry activities and report writing. The structure of the instruments could have cued Amanda to respond differently to these different types of contextual items. An alternative explanation is that the field excursions and practical-laboratory aspects associated with the two inquiry tasks provided more authentic contexts for

Amanda than the class work associated with the tests. The field trips could have provided more genuine and efficient ways for Amanda to experience and identify the overlaps between the fields of classroom chemistry and societal fields and to think about how the concepts she was learning were related to the contexts that structured the school chemistry curriculum.

Excursions created structures that allowed the fields of classroom chemistry and the social contexts of the museum and creek to resonate more strongly during Amanda's studies than the societal fields represented in the tests. In this context, resonance refers to a way of seeing the chemistry in terms of the creek or the museum where the science and the contexts are completely interconnected (Conle, 1996). Perhaps upon returning to her classroom, her actions and experiences in the social fields continued to resonate for Amanda as she responded to the assessment requirements. Resonance between the classroom field and the fields of the creek and museum could help to explain why, during her interviews (King et al., 2008), and in her responses to assessment instruments in the present study she made better connections between contexts and concepts in the form of *explanatory fluid transitions*. This discussion allows us to propose that when students become exposed experientially to different fields such as that of the classroom and a societal context through curriculum and assessment, the overlap or merging that exists between these fields can become evident to the student and externalized in their responses to assessment items and interview questions. This can, in turn, facilitate the process of fluid transitions and enhance it so that higher quality transitions – explanatory fluid transitions – are produced as the connections between the two fields continue to resonate for the student. As seen in this study and other research (King & Ritchie, 2013) it is possible for fluid transitions to occur when context-based courses are not associated with real experiences in fields outside of the classroom (e.g. some of the fluid transitions that Amanda made in Test 1). A possible explanation for this is that in our study and in King and Ritchie's study, the contextual assessment instruments were aligned to a context-based course. In this way, the class instruction drew on knowledge about the societal fields even though the students had not attended excursions. Assessing the course through contextual instruments may have reinforced the connections between contexts and concepts that were afforded by studying the context-based course. As we noted in our results section, it is not possible to make direct comparisons between tests and ERT/EEI tasks based on the *number* of opportunities of fluid transition responses afforded by each instrument. For this reason, we focused on the quality of Amanda's responses to the different assessment instruments, rather than focusing on the proportion of each response type.

In the specific case of Type 1 and Type 2 responses to *test questions*, we can offer an alternative explanation to those we have presented so far. When responding to test questions, Amanda may have considered that her teacher audience was knowledgeable about the contextual information provided by the question stem. In this case, she may have seen her Type 1 and Type 2 responses to be complete just as speakers in naturally occurring conversations respond to questions sequentially without necessarily repeating the information that was offered by the questioner (cf. Duranti & Goodwin, 1992). In future studies, students could be asked to verbalize their thinking or be interviewed to garner their perspectives on the nature of responses in relation to the assessment questions (e.g. with think-aloud protocols). Such investigations would provide scope for clarifying the nature of the fragmented Type 1 and Type 2 responses identified in our study.

Revisiting the fluid transitions construct

To explain our findings we extend King and Ritchie's (2013) conceptualization of fluid transitions that initially informed our study. The fluid transitions construct focused on explaining how students made connections between contexts and concepts by alternating between contexts and concepts when they generated utterances in response to interview questions or responses to assessment items (see King et al., 2008). Our empirical observations in the current study clearly indicated that Amanda articulated fluid transitions in two different ways. One way involved the expression of descriptive relationships between contexts and concepts. The second way involved Amanda using concepts to explain phenomena related to the context. These two different ways of responding to contextual assessment suggests that distinguishing between descriptive fluid transitions and explanatory fluid transitions can refine the construct of *fluid transitions* in relation to the analysis of contextual assessment instruments and student responses.

A further consideration is required in relation to our theoretical framework to account for the ways in which Amanda responded to contextual test questions that were not *fluid transitions* responses. Amanda answered some well-contextualized test questions by providing concepts with no connection to the context in the question (i.e. Type 1). In other cases, she responded to contextual questions by referring to features of the contexts with no connection to the chemical concepts (i.e. Type 2). Neither of these two types of responses to contextual problems represents fluid transitions because in both cases, the contexts and concepts remained fragmented from one another. It is possible that students may respond to contextual questions, as Amanda did, with responses that demonstrated fluid transitions (i.e. Type 3) that are either descriptive or explanatory, or by providing fragmented responses.

When Amanda responded to certain well-contextualized test questions by providing only the concepts involved, this indicated that she had treated the context and concepts in a fragmented way in her responses. In such cases, she did not establish connections between the concepts and the context implied by the question. In contrast to the fragmented responses, contexts and concepts were clearly identifiable (i.e. *divisions*) in Amanda's responses containing *explanatory* fluid transitions. Although division was evident in her responses, she connected the contexts and concepts in her explanations by *toing and froing* between the systems of representation pertaining to chemistry and systems of representation related to the context. Her descriptive fluid transition responses also referred to contexts and concepts but the connections between the systems of representation were superficial and lacked the *toing and froing* that was evident in the other responses. Perhaps with future research it will be possible to refine this further by determining whether or not fragmented responses belong in the *fluid transitions* category.

Implications and limitations

Qualitative differences in Amanda's assessment responses were understood through the theoretical lenses of fluid transitions, division and fragmentation at the micro-level of analysis. This micro-level understanding was linked to macro-level processes through the application of the *fields* construct. Future studies could apply the theoretical framework refined in this study to understand better the connections between macro-social phenomena, such as school excursions, and how they impact on micro-social processes such as students' responses to assessment items. Our theoretical constructs can also serve as referents for practitioners who wish to design well-contextualized assessment items that are most likely to encourage students to articulate deep connections (i.e. explanatory fluid transitions responses) in task responses.

The results of this study suggest that contextual assessment can complement context-based courses by extending the opportunities for students to articulate the connections that exist between contexts and concepts. This can provide students with opportunities to view chemistry as relevant for understanding their world by using assessment instruments aligned to the curriculum. Our study indicates that the extent to which assessment can support the intent of context-based curriculum can depend on the quality of the questions and assessment tasks. We found that the quality of Amanda's responses in terms of achieving fluid transitions was greater when the tasks were well contextualized. For example, poorly contextualized test questions did not elicit fluid transitions responses. In combination with suggestions from our earlier study (Bellocchi et al., 2011), we can now offer that by analyzing student responses to context-based assessment as we have demonstrated in the present study, could inform subsequent revision to items or assessment instruments that did not yield the desired responses from students. This point extends beyond questions on tests because we found that Amanda's responses to the ERT and EEI also varied in the extent to which she established fluid transition responses that involved either a *division* or a *fragmentation* of contexts and concepts. It was not clear to what extent this could be accounted for by Amanda's particular approach to the tasks, or whether the tasks themselves were not written effectively to achieve a greater extent of fluid transition responses. Future studies need to investigate the way in which a larger number and more diverse students respond to tasks that are contextualized. We also found no cases of fragmented fluid transition responses in the *explanatory* category of our coding scheme (see Appendix 2). By studying a larger number of student assessment responses, it would be possible to determine whether this category is necessary in our coding scheme. Our findings related to fluid transition responses in relation to the ERT and EEI would suggest that experiencing the environments where these contextual tasks unfold could scaffold students' capacities to generate fluid transition responses better than the scenarios in test questions with which students are likely to have varying levels of direct experience. Once again, studies with larger numbers of students and in a greater diversity of settings could help to unpack this issue further.

This study has shown that well-contextualized assessment can encourage students to recognize the overlapping fields of science and social contexts in a way that resonates with students long after their initial experiences. The contextual assessment in our study did not have negative impacts on Amanda's overall results when compared to her concept-based assessment the first time that she completed Year 12. Although this is an encouraging result, we note that the curriculum and assessment Amanda experienced were aligned. From this study, we suggest that contextual assessment is best used when teaching through a context-based approach; that is, when the curriculum and assessment are aligned. One issue that has been highlighted in the past about the kinds of criterion-referenced and performance-based assessment like the EEI and ERT instruments in this study is the potential variation in grading by different teachers (Madaus & O'Dwyer, 1999). Practitioners could apply our coding scheme for test questions (Bellocchi et al., 2011) and Amanda's responses developed in the present study for grading student responses systematically and reliably. For example, higher grades awarded by the teacher in our study aligned with the explanatory fluid transitions responses. Lower grades were awarded for the fragmented responses (i.e. Types 1 and 2). Adopting this system of classifying student responses could enhance the level of reliability used by different markers.

We discussed at the beginning of this manuscript the notion of authenticity in context-based assessment (cf. Brown et al., 1989) as a simulation of the work of experts in a scientific field. *Authenticity* has been at the heart of efforts to design context-based curriculum (e.g. Bulte et al., 2006) where it is defined as the provision of experiences to school students that offer insight into the work of chemists/scientists. We are now in a position, through our study of context-based assessment, to offer further insights into the role of authenticity in context-based chemistry curriculum and assessment design. To do so, we reflect on the intentions that were promoted by the state-mandated context-based approach in our study. The subject which students were studying came under the label *Chemistry*; not 'water quality,' 'marine-artifact conservation,' or 'dental chemistry.' In this way, the aforementioned contexts (see Appendix 1) were vehicles for the teachers and students to study chemical concepts (i.e. structure and properties of compounds, chemical reactions, and chemical inquiry). This can be seen in the names given to each contextual unit in Appendix 1. In contrast, in Bulte et al.'s (2006) study we see an example of a 'water quality' context-based course where the focus was not on arriving at microscopic, sub-microscopic or symbolic representational *chemical* understandings of the underlying phenomena associated with water quality or water quality testing. The scientific concepts relevant to their water unit focused on the *design* of water quality investigations. In their study, student responses that focused on comparing macroscopic observations with literature-based values of water quality parameters were considered to be complete responses. The chemical concepts pertinent to their study included inquiry processes such as establishing the validity of water quality test results and any assertions about the health of a water system under investigation. This case presents a situation whereby, what we would call the context (i.e. *water quality analysis*, or the *work of a water quality analyst*), is the main organizing principle of the curriculum; it is an end itself to an extent. One interpretation of such an approach is that students were learning to be (one type of) *water quality analyst*, rather than learning *chemistry* that is pertinent to understanding the methods and factors associated with water quality testing. The students in their study, like *some* water quality analysts, learnt one sub-set of chemical ideas related to the health of a water-body and water quality testing (e.g. the pH is higher than recommended guidelines). Although this is an authentic practice for some water quality analysts, the focus on the relevant chemistry could be approached differently. In contrast, the approach that was used in the school and jurisdiction at the center of our study prefaced the learning of *chemistry* in the contexts of, for example 'water quality,' 'marine-artifact conservation,' and so on. So what we have here is the possibility for a different understanding of *authenticity*, because students were learning authentic chemical knowledge and processes pertinent to different *applied fields* (jobs, profession, etc.) such as water quality analysis or marine-artifact conservation. The different curricular approaches taken by the jurisdiction in which our naturalistic study took place and Bulte et al.'s (2006) design-based research suggests that in presenting context-based assessment and curriculum to students, the notion of *authenticity* that is being applied needs to be made explicit for students. In our study, students had met the types of water quality analysts (volunteers with the local council) similar to those described by Bulte et al. so that students could learn the techniques of water sampling. These volunteers were not chemists, but understood enough chemistry to gather data about water quality using various instruments. During classwork and assessment, learning experiences were directed toward analytical and physical chemistry concepts pertaining to the functioning of the instrumentation and the chemical meaning of the results produced from the application of this instrumentation during fieldwork. The approach taken by the teachers in our study (similarly in the *Shipwreck* unit) represents an authentic application of analytical and physical chemistry to the general context of water quality analysis that goes beyond the approach described in previous research (cf. Bulte et al., 2006).

As we noted at the beginning of this article, we cannot make statistically generalizable claims from the case-study of one student. However, this case does provide us with examples of the qualitative ways in which one student responded to contextual assessment in a context-based course and these have informed our understandings of the way in which assessment and courses can be aligned to afford students the opportunities to connect their classroom experiences with the world outside of class. The variety of questions analyzed in the assessment instruments and the identification of contrived and well-contextualized questions can inform practitioners in the design of context-based courses that are complemented by contextual assessment instruments. These are likely to provide more valid assessment of learning than the administration of conceptual instruments. Importantly, the use of investigation reports in this study provided the best examples of well-contextualized tasks that afforded Amanda opportunities to see the relevance of chemistry to real issues.

One possible direction for future studies is to combine Gilbert et al.'s (2011) classification scheme of the four context-based models with our categories of fluid transitions, division and fragmentation into a single analytical scheme for classifying assessment tasks and student responses. Such an approach could offer even deeper understandings about the effect of the quality of contextualization of assessment items and the different types of responses (i.e. fluid transitions, etc.) that are elicited from students. Not only could such an approach inform our theoretical perspectives on context-based education but it may also provide direction to practitioners on how to design context-based assessment that supports the curriculum most effectively.

Notes

1. EEIs are inquiry-based assessment instruments that require students to develop their own investigations into questions of their interest. ERTs are non-experimental tasks that can involve literature-based research alone or in combination with field-based excursions. Both EEI and ERT tasks require students to submit reports of their inquiries.
2. As outlined earlier, Alberto was one of Amanda's teachers at the time that the assessment and curriculum were being implemented.
3. Alberto was the auditor for Test 1, co-author of Test 2, and the author of the EEI and ERT.
4. School-based assessment standards were based on State mandated levels of achievement in which students could achieve one of five levels: A, B, C, D, and E. A 'C' level of achievement was considered a passing grade whereas 'D' and 'E' levels of achievement were fail grades.

5. As part of the school's standard practices, test items were destroyed after a period of time. We were able to access the grades Amanda had achieved in the first year when she completed the 12th grade but not the responses to the tests.

Disclosure statement

No potential conflict of interest was reported by the authors.

Notes on contributor

Alberto Bellocchi is a STEM education researcher at the Queensland University of Technology. He currently holds a three-year research fellowship funded by the Australian Research Council (DE160101053). His research has focused on context-based teaching and learning and assessment practices. His more recent research program investigates the interactions between social bonds, emotions, and teaching and learning science.

Donna King is a senior lecturer at the Queensland University of Technology and her research interests include context-based science, emotional engagement of secondary students in science and innovative approaches to STEM education in the primary and secondary years. Recently, she has been a Chief Investigator on two Australian Research Council grants that focused on researching students' emotions in both tertiary and secondary settings.

Stephen Ritchie is the Dean of Education at Murdoch University. Steve's research has been focused mostly on classroom issues that relate to teaching and learning science. He currently conducts research on the emotional engagement of science classes as they become more scientifically literate. He is also interested in the emotional experiences of beginning science teachers and the quality of the pre-service science teacher education. He was the Editor-in-Chief (2008–2012) of Research in Science Education.

References

Ahmed, A., & Pollitt, A. (2007). Improving the quality of contextualized questions: An experimental investigation of focus. *Assessment in Education*, *14*, 201–232.

Avargil, S., Herscovitz, O., & Dori, Y. H. (2012). Teaching thinking skills in context-based leaning: Teachers' challenges and assessment knowledge. *Journal of Science Education and Technology*, *21*, 207–225.

Barker, V., & Millar, R. (2000). Students' reasoning about basic chemical thermodynamics and chemical bonding: What changes occur during a context-based post-16 chemistry course? *International Journal of Science Education*, *22*, 1171–1200.

Beach, K. (2003). Consequential transitions: A developmental view of knowledge propagation through social organizations. In T. Tuomi-Grohn, & Y. Engeström (Eds.), *Between school and work: New perspectives on transfer and boundary-crossing* (pp. 39–61). Amsterdam: Pergemon.

Beasley, W., & Butler, J. (2002, July). *Implementation of context-based science within the freedoms offered by Queensland schooling*. Paper presented at the annual meeting of Australasian Science and Education Research Association Conference, Townsville, Queensland.

Bellocchi, A., King, D. T., & Ritchie, S. M. (2011). Assessing students in senior science: An analysis of questions in contextualized chemistry exams. In Lee, K.- T., King, D. T., Hudson, P. B., & Chandra, V. (Eds.), *Proceedings of the 1st international conference of STEM in Education 2010*, Science, Technology, Engineering and Mathematics in Education Conference, Brisbane, Australia.

Bennett, J., & Holman, J. (2002). Context-based approaches to the teaching of chemistry: What are they and what are their effects? In J. K. Gilbert, O. de Jong, R. Justi, D. F. Treagust, & J. H. van Driel (Eds.), *Chemical education: Towards research-based practice* (pp. 165–184). New York, NY: Kluwer Academic.

Bennett, J., & Lubben, F. (2006). Context-based chemistry: The Salters approach. *International Journal of Science Education*, *28*, 999–1015.
Bohm, D. (1994). *Thought as a system*. New York, NY: Routledge.
Bourdieu, P. (1977). *Outline of a theory of practice*. Cambridge, MA: Cambridge University Press.
Broman, K., & Parchmann, I. (2014). Students' application of chemical concepts when solving chemistry problems in different contexts. *Chemistry Education Research and Practice*, *15*, 516–529. doi:10.1039/c4rp00051j
Brown, J. S., Collins, A., & Duguid, P. (1989). Situated cognition and the culture of learning. *Educational Researcher*, *18*, 32–42.
Bucat, R. B. (1983). *Elements of chemistry: Earth, air, fire, & water*. Canberra City, ACT: Australian Academy of Sciences.
Bulte, A. M., W., Westbroek, H. B., de Jong, O., & Pilot, A. (2006). A research approach to designing chemistry education using authentic practices as contexts. *International Journal of Science Education*, *28*, 1063–1086. doi:10.1080/09500690600702520
Conle, C. (1996). Resonance in preservice teacher inquiry. *American Educational Research Journal*, *33*, 297–325.
Davidowitz, B., & Chittleborough, G. (2009). Linking the macroscopic and sub-microscopic levels: Diagrams. In J. K. Gilbert, & D. Treagust (Eds.), *Multiple representations in chemical education* (pp. 169–191). Dordrecht, The Netherlands: Springer.
Duranti, A., & Goodwin, C. (Eds.). (1992). *Rethinking context: Language as an interactive phenomenon*. New York, NY: Cambridge University Press.
Fensham, P. J., & Bellocchi, A. (2013). Higher order thinking in chemistry curriculum and its assessment. *Thinking Skills and Creativity*, *10*, 250–264.
Fensham, P. J., & Rennie, L. J. (2013). Towards and authentically assessed science curriculum. In D. Corrigan, R. Gunstone, & A. Jones (Eds.), *Valuing assessment in science education: Pedagogy, curriculum, policy* (pp. 69–100). Dordrecht: Springer.
Gilbert, J., Bulte, A. M. W., & Pilot, A. (2011). Concept development and transfer in context-based science education. *International Journal of Science Education*, *33*, 817–837.
de Jong, O. (2006). Making chemistry meaningful. Conditions for successful context-based teacher. *Education Quimica*, *17*, 215–221.
Kim, J.-S. (2010). Within-subjects design. In N. J. Saskind (Ed.), *Encyclopedia of research design* (pp. 1639–1645). Thousand Oaks, CA: Sage.
King, D. T., Bellocchi, A., & Ritchie, S. M. (2008). Making connections: Learning and teaching chemistry in context. *Research in Science Education*, *38*, 365–384.
King, D. T., & Ritchie, S. M. (2012). Learning science through real-world contexts. In B. J. Fraser, K. G. Tobin, & C. J. McRobbie (Eds.), *Second international handbook of science education* (pp. 69–80). Dordrecht: Springer.
King, D. T., & Ritchie, S. M. (2013). Academic success in context-based chemistry: Demonstrating fluid transitions between concepts and contexts. *International Journal of Science Education*, *35*, 1159–1182.
Latour, B., & Woolgar, S. (1986). *Laboratory life: The social construction of scientific facts*. Princeton, NJ: Princeton University Press.
Madaus, G. F., & O'Dwyer, L. M. (1999). A short history of performance assessment: Lesson learned. *Phi Delta Kappan*, *80*, 688–695.
Nentwig, P., Roennebeck, S., Schoeps, K., Rumann, S., & Carstensen, C. (2009). Performance and levels of contextualization in a selection of OECD countries in PISA 2006. *Journal of Research in Science Teaching*, *46*, 897–908.
Queensland Studies Authority. (2007). *Chemistry*. Spring Hill, Queensland: Queensland Studies Authority.
Stake, R. E. (2010). *Qualitative research*. New York, NY: The Guilford Press.
Webb, N. L. (2007). Issues related to judging the alignment of curriculum standards and assessments. *Applied Measurement in Education*, *20*, 7–25.
Wilbraham, A. C., Stanley, D. D., Matta, M. S., & Waterman, E. L. (2007). *Chemistry*. Boston: Prentice Hall.

Appendix 1

Alignment of context-based units with contextual assessment instruments in Year 12 Chemistry.

Semester	Term[a]	Context-based unit	Chemistry content areas	Contextual assessment instrument
1	1	The chemistry of the Pandora Shipwreck	Electrochemistry REDOX Material structure, properties, bonding Gas laws	EEI
	2	The chemistry of the Human Body	Equilibrium Acids and bases Reaction rates	Test 1
2	3–4	The chemistry of Pete Creek	Equilibrium Acids and bases Solubility (organic and inorganic) Intermolecular forces Reaction rates	ERT and Test 2

[a]School terms 1–3 were approximately 10 weeks in duration, and Term 4 was approximately 6 weeks in duration.

Appendix 2

Coding categories with sample responses presented in manuscript.

Coding categories				
Fragmentation				Division
Conceptual (Type 1) Student response offers chemical concepts with no connection to any contextual information.	Contextual (Type 2) Student response offers aspects of contextual information with no reference to chemical concepts.	**Response function**	Fluid transitions (Type 3) Student response presents relevant chemical concepts and aspects of the contextual information. No meaningful interrelationship exists between context and concept in the response.	Fluid transitions (Type 3) Student response contains relevant chemical concepts and aspects of the contextual information. Contextual information and conceptual information presented as interrelated.
Examples in manuscript: Amanda's response to **Example 3**- Amanda's response involved a calculation of the hydrogen ion concentration of saliva presented as a final numerical answer. She did not refer to the context of whether the tablet could dissolve in the stomach in her response.	*Example in manuscript:* Amanda's Response to **Example 4**- '… tooth enamel that is treated with fluoride is harder than untreated tooth enamel and thus is less likely to be attacked by bacteria.'	**Descriptive** The response presents a description of either chemical concepts or contextual aspects relevant to the assessment item.	*Example in manuscript:* Analyses of ERT responses (after Extract 4)- 'All the values for conductivity were too high for the [potable-water quality] guidelines … Therefore, none of the water is acceptable for drinking.' EEI-**Example 2**.	*Examples in manuscript:* ERT-**Extract 4**.
		Explanatory The response presents an explanation pertinent to answering the assessment item.	*Examples in manuscript:* Nil.	*Examples in manuscript:* EEI- **Example 1**. Tests- **Example 5.**

Notes: The school re-uses questions from the exams and the assignments from year to year so it is not possible to present all of the assessment questions that were analyzed for this study in this manuscript. Permission to use the question and assignment examples reported in this manuscript was granted by the school.

Appendix 3

Summary table for Tests 1 and 2 focused contextual questions.

	Qn No.	Response types: Correct	Incorrect	D/E	Fragmented: CO	CX	FT	Divided FT
EOS 1	2	X			X			
	3a	X			X			
	3c		X			X		
	4a		X	E				X
	4b (e.g. pp. 34–35)		X			X		
	5i	X			X			
	5ii	X				X		
	5iii (e.g. p. 36)	X		E				X
	10		X		X			
	11a		X			X		
	11b		X			X		
	11c		X			X		
	12		X			X		
EOS 1 total	**13**	**5**	**8**	**2E**	**4**	**7**		**1**
EOS 2	16i	X						X
	16iia	0.5X		E				X
	18	0.5X						X
	20		X	D	X			
	21		X		X			
EOS 2 total	**6**	**6 (2, 0.5 correct)**	**2**	**1D, 1E**	**2**	**0**	**0**	**0**
Overall total	**19**	**11**	**10**	**1D, 3E**	**6**	**7**	**0**	**1**

D, descriptive; E, explanatory; FT, fluid transition; CO, conceptual answer (i.e. fragmented); CX, contextual answer (i.e. fragmented); EOS1, end of semester test 1; EOS2, end of semester test 2; 0.5, partially correct response.

Appendix 4

Summary table for Tests 1 and 2 contrived contextual questions.

	Qn No.	Response types: Correct	Incorrect	D/E	Fragmented: CO	CX	FT	Divided FT
EOS 1	1b	X			X			
	1e	X			X			
	6a	X			X			
	6b	X			X			
	6c	X			X			
	7ai		X		X			
	8	X			X			
EOS 1 total	**7**	**6**	**1**	**0**	**7**	**0**	**0**	**0**
EOS 2	19	X		E				X
EOS 2 total	**1**	**1**	**0**	**1E**	**0**	**0**	**0**	**1**
Overall total[a]	**8**	**7**	**1**	**1E**	**7**	**0**	**0**	**1**

D, descriptive; E, explanatory; FT, fluid transition; CO, conceptual answer (i.e. fragmented); CX, contextual answer (i.e. fragmented); EOS1, end of semester Test 1; EOS2, end of semester Test 2.
[a]One multiple-choice item has been excluded from the totals in this table.