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## **New perspectives on context-based chemistry education: Using a dialectical sociocultural approach to view teaching and learning**

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Context-based chemistry education aims to improve student interest and motivation in chemistry by connecting canonical chemistry concepts with real-world contexts. Implementation of context-based chemistry programs began 20 years ago in an attempt to make the learning of chemistry meaningful for students. This paper reviews such programs through empirical studies on six international courses, *ChemCom* (USA), *Salter's* (UK), *Industrial Science* (Israel), *Chemie im Kontext* (Germany), *Chemistry in Practice* (The Netherlands) and *PLON* (The Netherlands). These studies are categorized through emergent characteristics of: relevance, interest/attitudes/motivation and deeper understanding. These characteristics can be found to an extent in a number of other curricular initiatives; such as, science-technology-society (STS) approaches and problem-based learning (PBL) or project-based science (PBS), the latter of which often incorporates an inquiry-based approach to science education. These initiatives in science education are also considered with a focus on the characteristics of these approaches that are emphasised in context-based education. While such curricular studies provide a starting point for discussing context-based approaches in chemistry, to advance our understanding of how students connect canonical science concepts with the real-world context, a new theoretical framework is required. A dialectical sociocultural framework originating in the work of Vygotsky (1978) is used as a referent for analyzing the complex human interactions that occur in context-based classrooms providing teachers with recent information about the pedagogical structures and resources that afford students the agency to learn.

**Keywords:** context-based, chemistry education, dialectics, sociocultural, structure | agency, agency | passivity

## Introduction

Internationally and nationally there is a growing concern about the need to stimulate chemistry education that is relevant for the new knowledge society. Despite a rapidly changing world, there have been few changes in the pedagogical approaches used in the chemistry classroom. Chemistry teaching has focused on the communication of conceptual knowledge, the use of key, abstract concepts to interpret and explain standard problems, the treatment of context as mainly subsidiary to concepts, and the use of practical work to merely illustrate principles and practices (Tytler, 2007). There is concern that these pedagogical approaches commonly known as “traditional” approaches are not motivating students to continue to study chemistry at more senior levels.

While such traditional approaches have dominated mainstream chemistry classrooms throughout the last 20 years, an alternative approach to chemistry teaching has emerged in a minority of classrooms during this time. These pedagogical approaches fall under the umbrella of “context-based” teaching and have been trialled in an attempt to make the learning of chemistry meaningful for students by situating the learning in students’ real-worlds. Therefore, it is time for a review of the origin of context-based approaches and related approaches such as science-technology-society (STS), problem-based learning (PBL), and project-based science (PBS). This review will compare the learning outcomes of context-based courses with those of traditional chemistry approaches and include a discussion of the affective outcomes such as interest, attitudes and motivation for learning chemistry. Furthermore, a review of STS, PBL and PBS approaches highlights the similarities to context-based approaches where students are encouraged to link science concepts with the real-world. After a thorough review of context-based approaches and related approaches over the last 20 years, a new theoretical framework is developed to advance our understanding of how students connect canonical science concepts with the real-world context.

Since previous studies have focussed predominantly on quantitative comparisons between “traditional” and context-based chemistry classes, a new dialectical sociocultural theoretical approach affords opportunities to view the teaching and learning through fine grained analyses of teacher-student and student-student interactions in a context-based chemistry class. Through this lens, interactions in a context-based chemistry classroom are scrutinised providing teachers with recent information about pedagogical structures and resources that afford students opportunities to learn and the circumstances by which students connect concepts and context. While past research has

focused on the broader view of cognitive and affective outcomes through comparative studies, the new dialectical sociocultural lens gives recent information about teaching approaches that can be translated to relevant professional development for teachers as discussed in the conclusion.

## **Context-based approaches in chemistry education**

### ***Defining “context” and “context-based approaches” in chemistry education***

Since the use of “context” is central to this paper, the meaning of the word itself needs clarification before the meaning of “context-based approaches” can be explored. Gilbert (2006) explained that the word originated from the Latin language in the verb “contexere”, “to weave together”. He further explained that its related noun “contextus”, expresses “coherence”, “connection”, and/or “relationship” (Gilbert, 2006, p. 960). Therefore, “context” describes a situation that gives meaning to words, phrases and sentences (Gilbert, 2006). In other words, a context provides a “coherent structural meaning” for a new idea that can be situated within a broader framework (Gilbert, 2006, p. 960). This explanation is consistent with the use of context-based in chemical education where the chemistry becomes meaningful to students; the learning of chemistry connects with an aspect of students’ lives and students construct logical “mental maps” of the subject (Gilbert, 2006).

Literature exploring the meaning or meanings of “context-based approaches” as applied to science education has revealed a variety of views. Whitelegg and Parry (1999) suggested that context-based learning could have several meanings “at its broadest it means the social and cultural environment in which the student, teacher and institution are situated” (p. 68). More narrowly it “focuses on a specific application of a theory, for example, the application of a physics theory for the purposes of illumination and reinforcement” (p. 68). This narrower view does not define context-based learning in a helpful way since the application of a principle is a common teaching tool and nearly all teaching could be classified as context-based with this view. Therefore, “context-based approaches” in science education needs a more precise definition to distinguish it from common teaching approaches.

Elaborating on Gilbert’s (2006) definition of context, a context-based approach in chemistry education suggests the learning will be “meaningful” for students. One interpretation of

“meaningful” science learning requires students to connect canonical science concepts with a real-world context. By utilising a resource of real-world applications, such as addressing relevant societal issues, discussions may occur between teachers and students that encourage links between concepts and context (Sutman & Bruce, 1992). After students use ideas in familiar situations and consolidate relationships between science concepts and the experiences or contexts with which they are familiar, students’ confidence in the chemistry concepts may increase. Furthermore, students who are afforded opportunities for applications of the concepts may apply them to make sense of a wider range of tasks (Brook & Driver, 1984). Vygotsky’s (1978) perspective, that a mature concept is achieved when the scientific and everyday versions have merged, can be seen as an underpinning of the suggestion to teach chemistry contextually.

A context-based approach focuses on the application of science as a means of enhancing scientific understanding of students’ real-worlds while developing students’ capacities to function as responsible participants in their everyday lives (Aikenhead, 2006; Bennett, 2005). Such an instructional framework embodies a “need-to-know” principle: the context must legitimise the learning of chemical concepts from the perspective of the students and thus make their learning both intrinsically and extrinsically meaningful (Beasley & Butler, 2002; Bulte, Westbroek, de Jong, & Pilot, 2006). For this review, the definition of a context-based approach will be as follows:

A context-based approach is when the “context” or “application of the chemistry to a real-world situation” is central to the teaching of the chemistry. In such a way, the chemical concepts are taught on a “need-to-know” basis; that is, when the students require the concepts to understand further the real-world application.

Since context-based chemistry begins with a real-world application for which the scientific explanations are provided through canonical chemistry, what results for students is an example of Robert’s (2007) Vision II for scientific literacy. He sets out two visions of SL (science literacy and scientific literacy) as extremes of a continuum; Vision I envisions literacy within science or the products and processes of science itself and Vision II envisions “literacy (or thorough knowledgeability) about science-related situations in which considerations other than science have an important place at the table” (Roberts, 2007, p. 730). In other words, Vision II encompasses real-world situations with a scientific component; that is, the science that students are likely to encounter as citizens. Context-based chemistry affords students opportunities to understand real-world contexts

in which science can be seen to have a role. By starting with the real-world situations or contexts, the canonical science of the context is then used to explain what is relevant to the students' lives (Roberts, 2007).

The context-based approach finds its place among a large number of curricular developments, such as problem or project-based learning (PBL and PBS), science-technology-society (STS) and inquiry-based science education (Abd-El-Khalick et al., 1998; Bennett, 2005; Schneider, Krajcik, Marx, & Soloway, 2002), that attempt to make the learning of science more meaningful for students. These initiatives have similar goals to context-based approaches because they have tried to enhance learning, improve the relevance of the science being taught and the engagement of the students as well as increase personal satisfaction for participating students. A comprehensive review of teaching approaches that adopt an alternative rationale for learning experiences for students in science more generally and chemistry more specifically, compared with traditional or conceptually focussed programs, includes new developments such as STS, PBL and PBS. Therefore, following a review of context-based approaches, STS, PBL and PBS approaches are reviewed.

Context-based programs have been experimented within a number of countries. To understand the variety of programs and approaches used, a review of these context-based programs follows, highlighting the specific characteristics of their design and implementation.

### *A review of international context-based programs*

Internationally, there are five context-based chemistry programs that have been the main focus of research studies over the last 20 years. They are recognised by leading international researchers in context-based chemistry education as representing programs that have used "contexts" as a starting point for the design of curricula and units. Pilot and Bulte (2006) chose to include these five programs in the special issue on context-based education in the International Journal of Science Education in 2006. The five programs originated from five different countries representing different educational systems and include: Chemistry in Context in the USA (American Chemical Society [ACS], 2001), Salters in the UK (University of York Science education group [UYSEG], 2000), Industrial Science in Israel (Hofstein, Kesner, & Ben-Zvi, 2000), Chemie im Kontext in Germany (Parchmann et al., 2006) and Chemistry in Practice in The Netherlands (Pilot & Bulte, 2006).

The author began with these five programs as a starting point for a literature review on the prior research conducted on context-based chemistry education and found valuable insights into the

issues concerning context-based chemistry education. Also important to this review is previous research conducted in the 1970s and 1980s for context-based physics (see, for example, Physics Curriculum Development Project, PLON, in Eijkelhof & Kortland, 1988). While this research was conducted some time ago, PLON research contributes to the review on context-based approaches by providing substantive evidence on the relevance of context-based approaches, and students' conceptual understanding after completing a context-based course compared to a more traditional course. Since such studies are important for a complete summary of past research on context-based approaches, PLON is included in this review. A full account of the six programs is discussed below. This is followed by a table that includes a brief description of each program and the authors of the research that will be discussed later.

A suite of context-based chemistry programs designed by the American Chemical Society (ACS) and the National Science Foundation (NSF) were written in response to a need for chemistry courses for students who were not contemplating careers in science. *ChemCom: Chemistry in the Community*, began as a secondary school text written in an attempt to improve students' scientific literacy and increase enrolments in school science courses. The *ChemCom* course uses a context-based student-centred approach to chemistry, in which chemical principles are introduced on a need-to-know-basis (Schwartz, 2006). After extensive trialling, the first edition was published in 1988 and due to its large success has been revised many times with the fifth edition published in 2005.

The second program *CiC* or *Chemistry in Context* was written for similar reasons to that of *ChemCom*: firstly, to address the need for a chemistry course at tertiary level for those students who were not preparing to be “chemistry majors;” and secondly, to improve the chemical literacy of students. The writers of *CiC* adopted a context-based approach similar to that already proved to be effective in the *ChemCom* program. *CiC* was designed to avoid the traditional linear progression of scientific concepts by starting with a problem of interest to students that required students to draw on their knowledge and skills to solve it (for a full explanation see Schwartz, 2006). In such a way, it was designed to expose students to the inquiring, experimental and often ambiguous nature of science which more closely approximates the methodology of scientific research (Schwartz, 2006). The first book was published in a preliminary version in 1990 by ACS as *Chemistry in Context: Applying Chemistry to Society*. After a few years of trials and improvements, it was produced and used on a large-scale in 1994.

An extension of *ChemCom* and *CiC* was the design of ChemConnections Modules (ChemConnections, 2005) that were developed by the ModularCHEM Consortium and the ChemLinks Coalition which were very similar in design, content and organisation to *CiC*. In each module, the chemistry is presented within a context created by some contemporary application or issue (e.g., ozone depletion, global warming, automobile airbag) (Schwartz, 2006). The modules were designed for use in general chemistry courses taken by first-year chemistry or science majors in American colleges and universities. They have been used in two ways: firstly, to enrich a traditional course by incorporating one or two modules; and secondly, as an entire semester long or one year course. One of the challenges of implementing the modules has been encouraging university professors to change their pedagogical approach from a traditional style that uses a sequential development of concepts to a context-based approach where the context is central and content is taught on a “need-to-know” basis (Schwartz, 2006). Research on the suite of American context-based programs is discussed later in the paper under emergent themes.

The suite of Salters programs began in 1983 when a group of teachers and science educators met at York to discuss ways in which chemistry might be made more attractive to school students (Bennett & Lubben, 2006). Initially, five context-based chemistry units for middle high school students (13 year old) were developed. Now, more than 20 years later, there is a whole suite of Salters courses (named after the sponsor of the original project, and co-sponsor of subsequent projects) that have been developed for biology, chemistry, and physics for high school students from 11-18 years of age. Of relevance to this review are three of the courses designed for secondary and pre-university students:

- Salters Advanced Chemistry (for students aged 17-18, developed in the early 1990s)
- Science: the Salters Approach (for students aged 14-16, developed in the late 1980s)
- Chemistry: the Salters Approach (for students aged 14-16, developed in the mid 1980s)

Similar to the suite of *Chemistry in Context* programs, the goal of Salters courses was to make science more appealing to students by emphasising the relevance to students’ everyday lives and involving them in a wide range of learning activities in which they could be actively engaged (Bennett & Lubben, 2006). Designed for schools in England and Wales, teachers can choose which courses their students follow, although all courses have to meet specified criteria in terms of scientific

content with most Salters courses having a dedicated assessment system (Bennett & Lubben, 2006). Since the “Salters Approach” became known as a prime example of a context-based approach, it is relevant to this review. Research studies involving these three programs are examined later in this review.

The Industrial Chemistry program was initially developed in the late 70s and early 80s to align with changes and reform in the Israeli education system. The development and implementation was conducted over a 15 year period by the Department of Science Teaching at the Weizmann Institute of Science in Israel (Hofstein & Kesner, 2006). The project’s general goal was to teach chemistry concepts in the context of industrial chemistry by situating the learning in a topic that was personally relevant to students and the society in which they lived. The new generation of learning materials (after 1989) were written as case studies providing an in-depth approach regarding a certain industrial plant (e.g., chemical fertilisers). These case studies became an important 20% part of the total chemistry course in upper-secondary school (year 12) in the Israeli education system. All students majoring in year 12 chemistry were obligated to study at least one industrial case study as an integral part of the matriculation exam (Hofstein & Kesner, 2006).

Chemie im Kontext or ChiK began in 1997 in Germany and drew on the experiences of the Salters’ course which had been implemented in the UK. Similar to the other programs discussed so far, the central goal was to implement context-based learning into the school systems of the federal states, but unlike the other programs, information about the implementation of school innovation was also a goal. Developed predominantly for year 10 and 11, the context-based units are based on relevant authentic topics and questions which structure the teaching and learning. An interesting feature of the design of CHiK is that concepts are developed in a variety of contexts and used for the explanation in various topics (Parchmann et al., 2006).

In the Netherlands there have been two important context-based programs: Chemistry in Practice or ChiP and PLON (Physics Curriculum Development Project). The PLON project preceded ChiP as a context-based physics course implemented between the years 1972 and 1986. Context-based courses for secondary physics education were developed in the PLON project through resources such as student textbooks, teacher guides, and technician manuals. These various resources catered for all Dutch ability streams i.e., lower, average and pre-university. Central to the PLON curricula, were issues relevant to students’ lifeworlds which emphasised technological artefacts and

natural phenomena in junior secondary education (grades 8-9, age 13-14), supplemented with an emphasis on socio-scientific issues and the nature of science in senior secondary education (grades 10-12, age 15-17) (Kortland, 2005). The aim of the PLON project was a balance between preparing students for future science education and preparing students for their future life roles as a consumer and citizen in a technological society (Kortland, 2005). Chemistry in Practice had similar goals to the PLON curricula since it was designed as a general secondary context-based chemistry program that makes meaningful connections between students' learning of chemistry and their daily life and societal issues (Pilot & Bulte, 2006). The units in the program are structured around themes such as water quality, designing a swimming pool, food and medicine. The ChiP program aimed to re-design the Dutch chemistry curriculum to cater for all students.

The six context-based programs are explained further through emergent themes that highlight the previous research on context-based teaching and learning. The table below provides a brief summary of each program and the authors of the research that will be discussed.

Table 1. A Summary of Six Context-based Programs

Program	Context-based Approach	Level /Age	Brief description	Researchers
1	Chemistry in Context (USA) or (CiC) (American Chemical Society, 2001)	Tertiary Age 18-20	Began in 1989 to address the needs of undergraduate students in universities and colleges and to improve their chemical literacy.  The book and other materials have been used by large numbers of students and teachers influencing other tertiary level courses in the US.	Nakhleh, Bunce, & Schwartz, (1995)  Schwartz, (2006)
	ChemConnections (USA) (ChemLinks Coalition, 2004)	Tertiary	Modular course for undergraduate beginners.  Modules can be used in conjunction with traditional modules.	Gutwill-Wise, (2001)
	ChemCom (USA) (American Chemical Society, 2001)	Upper Secondary	Structured around community issues related to chemistry.  Uses a context-based, student-centred approach to chemistry, in which chemical principles are introduced on a “need-to-know” basis.	Smith & Bitner, (1993)  Sutman & Bruce, (1992)
2	Salter's Advanced Chemistry (UK) (University of York Science Education Group, 2000)	17-18 year olds; pre-university	Developed in the late 1980s and early 1990s the family of Salter's courses spans the whole of the secondary and pre-university age range in England and Wales.  The “Salter's Approach” became known as a prime example of a context-based approach.  Emphasis on “what chemists do.”	Barber, (2000)  Barker & Millar, (1996, 2000)  Bennett & Lubben, (2005)

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	Science: The Salters Approach (UK) (University of York Science Education Group, 2000)	14-16 year olds (Foundation course for generalists)	Two courses: one for generalists and one for specialists where the contexts are the same but scientific concepts differ.	Ramsden, (1992, 1994, 1997)
	Chemistry: The Salters Approach (UK) (University of York Science Education Group, 2000)	14-16 year olds (Secondary with two strands)		
3	Industrial Chemistry (IC) (Israel)	12 <sup>th</sup> grade students only	Goal of the project was to teach chemistry concepts in the context of industrial chemistry.  Greater emphasis on applied chemistry and its socio-economic and environmental consequences.	Hofstein & Kesner, (2006)  Hofstein, Kesner, & Ben-Zvi, (2000)  Key, (1998)
4	Chemie im Kontext (ChiK) (Germany)	Year 10/11	All context-based units are based on relevant, authentic topics and questions which are the backbone and guidelines for teaching and learning purposes.  There are three relevant topics: daily life situations, issues important for society, scientific and technical issues.	Lange & Parchmann, (2003)  Parchmann et.al., (2006)
5	Chemistry in Practice (ChiP) (The Netherlands)	Secondary	Project attempts to make a meaningful connection between students' learning of chemistry and their daily life and societal issues.	Bulte, Westbroek, de Jong & Pilot, (2006)  Pilot & Bulte, (2006)

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6	PLON (Physics Curriculum Development Project) (The Netherlands)	Secondary Years 8-9 and 10-12	Students' life-worlds were taken as the starting point for PLON curricula with an emphasis on technological artefacts and natural phenomena in junior secondary education. This was supplemented with an emphasis on socio-scientific issues and the nature of science in senior secondary education.	Eijkelhof & Kortland, (1988) Eijelhof & Lijnse, (1988) Kortland, (2005) Wierstra, (1984) Wierstra, (1990) Wierstra & Wubbels, (1992, 1994)
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Common themes that emerged from the literature review conducted by the author on the six context-based projects fall into three key areas: relevance of the chemistry, students' interest, attitudes and motivation, and deeper understanding of chemistry concepts. Each theme will now be discussed separately.

### ***Relevance***

Two key studies revealed that context-based education helps students see and appreciate more clearly links between the science they studied and their everyday lives (Hofstein, Kesner, & Ben-Zvi, 2000; Wierstra & Wubbels, 1994). The first study was on the Industrial Chemistry project in Israel designed to teach chemistry concepts in the context of industrial chemistry (Hofstein, Kesner, & Ben-Zvi, 2000). One part of the study focussed on how learning industrial chemistry case studies affected students' perceptions of their classroom learning environment. Three groups of Grade 12 high school students majoring in chemistry were selected for the study. Two of the groups (Group 1 and Group 2) were exposed to an industrial chemistry case study whereas the third group of students, a control group, did not study an industrial chemistry case study. Also, Group 1 and 2 teachers attended a four-day regular inservice education course that included an overview of the case studies, presentation of teaching methods, enrichment lectures given by industrialists and a visit to a chemical plant (Hofstein, Kesner, & Ben-Zvi, 2000). However, only Group 1 teachers participated in an intensive annual professional development workshop that included training on pedagogical approaches and the opportunity to plan and develop a short teaching episode which they tried out in

their classes. In comparison, Group 3 teachers did not participate in any inservice development activities. A questionnaire developed specifically for the study aimed at measuring students' perceptions of their classroom learning environment in chemistry, in general, and industrial chemistry, in particular. Interestingly, the analysis revealed that Group 1 students outperformed the other two groups of students regarding their perceptions of the relevance of their chemistry studies. In addition, they achieved higher awareness of the social implications of their chemistry studies, for example, students reported that their chemistry studies better prepared them to become future citizens and informed them about occupational possibilities (Hofstein, Kesner, & Ben-Zvi, 2000). Not only did this study show that a context-based chemistry course helped students see the relevance of the chemistry they were studying, but it also revealed that teachers who had attended an intensive training workshop were the most successful of the three groups in the study for raising students' awareness of the social implications of chemistry studies.

A second study that investigated the relevance to students' lives of a context-based curriculum occurred during the evaluation of the PLON project. The study investigated the activity-centredness and reality-centredness of the PLON materials. Activity-centredness referred to activity learning where the students performed a learning task in an independent and autonomous way rather than being guided and controlled by the teacher. Reality-centredness referred to the extent to which the subject of physics was presented explicitly in relation to everyday life and to students' out-of-school experiences (Wierstra & Wubbels, 1992, 1994). The two groups of students that were selected for the study included a PLON group of students and a control group. The control group of students were from classrooms taught with a more traditional textbook. Student perceptions of the classroom environment (reality- and activity- centredness) were measured by a classroom environment survey administered after a mechanics lesson in the context of "Traffic." Statistical analysis of the results revealed that the PLON students experienced the lessons of the context-based unit "Traffic" as more reality- and activity- centred compared to survey ratings by students in the traditional course (Wierstra & Wubbels, 1994). Furthermore, other evaluation studies of the PLON project confirmed this result and showed that in most cases reality-centredness also promoted student appreciation of physics lessons (Wierstra, 1990).

Evaluation research from the PLON project revealed that students experienced the content taught as more relevant when the physics was taught in a life-world context (Wierstra, 1990). Similarly, the study on the Industrial Chemistry project showed that students developed a better

awareness of the social implications of chemistry and that it provided a significant contribution to their preparation as future citizens and for possible careers in chemistry (Hofstien & Kesner, 2006). Also, visits to an industrial chemistry site during a context-based chemistry unit have been shown to increase students' appreciation of the relevance of school chemistry and/or of the industry itself (Key, 1998). Further research supporting the perceived personal relevance of chemistry as important for the positive development of students' interest is discussed in the next section. While interest, attitudes and motivation are three separate dimensions that contribute to a student's perception of chemistry, they have been combined to represent an overarching theme that emerged from the literature.

### ***Interest / Attitudes / Motivation***

Students' interest in and enjoyment of their science lessons are generally increased when they engage in context-based courses (Barber, 2000; Gutwill-Wise, 2001; Parchmann et al., 2006; Ramsden, 1992, 1994, 1997). Research studies conducted on four international context-based programs: Salters, ChemConnections, Chemistry in Context (CiC) and Chemie im Kontext (see Table 1) revealed that most students had a positive experience in context-based courses.

The key principle which underpins the Salters approach is that the ideas and concepts selected and the contexts within which they are studied, should enhance young people's appreciation of how science contributes to their lives or the lives of others. Thus science ideas are developed through contexts exemplified by the course unit titles which include units such as Food, Transporting Chemicals and Making Use of Oil (Ramsden, 1997). The main concepts are introduced in a "drip-feed" manner throughout the course and once introduced are constantly reinforced in different ways (Barber, 2000). The course makes use of a wide range of learning strategies, such as, group discussion, problem-solving exercises, role play and creative writing (Ramsden, 1992). Barber (2000) compared students' learning in a traditional syllabus (i.e., with a strong emphasis on pure chemical facts, theory and concepts with little emphasis on the application of chemistry to everyday life), with students studying the Salters context-based course. She found that the Salters course was seen as more interesting and varied since it related better to the outside world than the traditional course (Barber, 2000). However, the less able students in the Salters course explained in interviews how they found it difficult coping with the problems and assignments that were not similar to exam questions (Barber, 2000).

The performance of students on a range of diagnostic questions following both a context-based approach (Salters) and a more traditional approach to high school chemistry was compared by Ramsden (1997). The diagnostic questions were designed around four key chemical ideas which form part of the majority of high school chemistry courses and are central to students' understanding of chemistry at this level. They include: elements, compounds and mixtures; conservation of mass in chemical reactions, chemical change and the Periodic Table (for a full explanation of the diagnostic questionnaire see Ramsden, 1997). The questionnaire was completed by 216 students, 124 following Salters courses, and 92 students following other more traditional courses. The study showed there was little difference in levels of understanding, but there appeared to be some benefits associated with a context-based approach in terms of stimulating students' interest in science (Ramsden, 1997). In two studies conducted by Ramsden (1992, 1997) it was found that students who experienced the context-based approach reported enjoyment of science lessons and, where they had earlier experience of more conventional courses, an increased enjoyment of science lessons.

Further research by Gutwill-Wise (2001) investigated the impact of context-based learning in two introductory chemistry courses in two universities. The study focused on the outcomes of implementing the ChemConnections modular materials which were intended for use in general chemistry courses taken by first-year chemistry or science majors in American colleges and universities (Schwartz, 2006). The first study was conducted at a small private college, Grange College (a pseudonym) and the second study was conducted at a large public university, University of Charles (a pseudonym). The study involved an early evaluation of the ChemConnections modular materials. The modular approach was very similar to the context-based approach since it involved a change in the content and pedagogy of the chemistry classroom. The shift in content emphasised chemistry as real-life problems such as building a better automobile air-bag system, investigating global warming, and understanding atmospheric ozone depletion (Gutwill-Wise, 2001). Each module was scheduled for about 3-4 weeks and used a single real-world topic as a vehicle for teaching a coherent set of chemistry concepts. The new pedagogy driven by the modules required greater interaction between students and instructors and among the students themselves. Classroom environments featured students working in groups, solving problems individually, participating in whole class discussion, and using multimedia (Gutwill-Wise, 2001).

Gutwill-Wise (2001) compared students' attitudes from matched groups. One group had followed the context-based (modular) approach of ChemConnections while the other group of

students had followed the traditional (non-modular) approach. Students in the context-based class Grange College, had more positive attitudes than their traditional counterparts, but the reverse was found at the larger university Charles (Gutwill-Wise, 2001). The surveys and informal focus groups revealed several factors that led to negative attitudes at Charles. One finding showed that the attitudes of the Graduate Student Instructors influenced those of the students, hence more time and effort needed to be put into instructor training for modular approaches. Also, the study found that students were disappointed with being part of an experiment where the style of teaching (modular or non-modular) was randomly decided without student consultation days before the course started. Students were also dissatisfied with some aspects of the modules themselves such as the many errors in the first edition of the modules. Interestingly, when the course was taught for a second time at Charles using only modules that had undergone rigorous editing, the surveys found these students more positive than students from the previous study. Therefore, some of the problems were resolved in subsequent courses (Gutwill-Wise, 2001). The consortia involved in this study believed that modular (context-based) courses were improving attitudes towards chemistry beyond the level currently seen in traditional courses (Gutwill-Wise, 2001).

Nakhleh, Bunce, and Schwartz (1995) conducted a survey in an effort to ascertain students' experience of the Chemistry in Context (CiC) course designed for use in tertiary chemistry courses. The questionnaire consisted of 20 statements investigating students' beliefs about chemistry as a topic of study. The instrument was administered to non-science majors enrolled in CiC-based courses in nine of the colleges and universities in the autumn of 1991 (Schwartz, 2006). The same survey was administered both before and after the course to determine changes in attitude that might be attributed to the course. Responses to 16 of the 20 statements suggested that the enrolment in a CiC-based course resulted in significant changes in attitude that were favourable to students' perceiving chemistry as important (Schwartz, 2006).

“Chemie im Kontext” (ChiK), a context-based project that aims at the improvement of chemistry teaching in secondary schools in Germany, has been implemented through a process that integrates a framework designed by science educators and teachers where the different individual conditions and experiences of teachers and classes participating in the project have been taken into account. This innovative implementation process is called a “symbiotic approach” to indicate the reciprocal dependency and profit of curriculum designers, researchers, and practitioners (Parchmann et al., 2006). The framework incorporates three principles (context-based learning, the development

of basic concepts, and the design of student-oriented learning activities) and is based on constructivist learning theories where the context enables students to see the relevance and application of their learning but also link to their pre-knowledge, interest and ideas (Parchmann et al., 2006). One branch of ChiK is a developmental project, aimed at the development and dissemination of structures, exemplary units, and teaching and learning materials for upper and lower secondary education. The other branch involves several research topics that are being investigated within this project, to enlarge knowledge about the design, effects, and implementation of context-based teaching and learning in schools (Parchmann et al., 2006). Research evidence gleaned from questionnaires and interviews given to teachers and students who were involved in the initial implementation of the project is relevant to this literature review.

A comparison between the motivation to learn chemistry of ChiK students and students learning within a conventional curriculum showed that at the beginning of the school year the two groups were comparable in their motivation towards learning chemistry, as well as in their overall evaluation of the chemical education they had experienced (Parchmann et al., 2006). However, at the end of the school year the motivation of students following a conventional curriculum decreased significantly compared with the ChiK group (Parchmann et al., 2006). After two years, the interest of all students participating in ChiK was significantly higher than at the beginning of the project and more than 60% of the ChiK students at the end of Grade 10 and Grade 11 stated that they wanted to choose chemistry in the upper secondary level. The application of knowledge, the perceived personal relevance of chemistry, and the influence of the teacher were regarded as important for students developing a positive interest in chemistry (Parchmann et al., 2006). The students were, however, not uncritical towards their new learning experience. Getting lost in the complexity of a context and losing the clear direction of what they were learning were judged as discouraging for students (Parchmann et al., 2006).

The research studies discussed above show that students' interest in chemistry is heightened when they participate in context-based courses. Furthermore, two studies also revealed the importance of the role of the teacher in developing interest in chemistry (Gutwill-Wise, 2001; Parchmann et al., 2006). The following section offers insights into the research on the understanding of chemistry concepts.

### ***Deeper understanding***

Many research studies that have been conducted on programs such as ChemCom (upper secondary), ChemConnections (tertiary), Salters (secondary-tertiary), Chemie im Kontext (secondary) and PLON (secondary) have compared students' understanding of chemistry concepts in context-based courses with those in conventional courses. Students who have demonstrated that they understand specific science concepts at a higher level (or in more depth), compared to students in another course are referred to as having a “deeper understanding” of the content of the course.

The earliest comparative study of students' conceptual understanding was conducted in the 1980s on the Dutch Physics program PLON. The research revealed that PLON students did not achieve better results on traditional high school examination questions compared to students studying the traditional physics course (Wierstra, 1984). However, Eijkelhof and Lijnse (1988) argued that traditional education was fully aimed at the examinations and hence the conclusion could be made that PLON students were at least not harmed in their preparation for further studies through a context-based approach.

The ChemCom course was developed for upper secondary students in response to a need for a course which prepared students for effective resolution of science-related issues in the real-world through a knowledge and interest in chemistry (Sutman & Bruce, 1992). Like ChemConnections, a ChemCom unit begins with a topic related to the students' real-lives; for example, “Petroleum: To Build or Burn?” The students are challenged to assess the role of petroleum in our society as well as utilising the organic chemistry content to understand the context. In such a way, the context is used as the vehicle for understanding traditionally taught chemical principles at a reasonable conceptual level. Furthermore, the “laboratory” is embedded in the instruction in the form of investigations. The completion of the investigations leads naturally to the development and understanding of the next instructional step (Sutman & Bruce, 1992).

A study compared cognitive test results from two groups of students, one group who had completed a “traditional” course in high school and the other group had completed the ChemCom course. The results of the testing program that assessed both chemistry learned and applications of chemistry, indicated that students completing the entire year-long ChemCom course significantly outperformed students completing more traditional college preparatory chemistry on test items designed by ChemCom writers (Sutman & Bruce, 1992). Smith and Bitner (1993) completed a

quantitative study comparing conceptual understanding of ChemCom students with students studying a traditional unit called GenChem. They found that no significant difference in levels of understanding emerged between the two groups of students. Interestingly, significant gains in formal operational modes of reasoning as measured by a valid and reliable written test called “the Group Assessment of Logical Thinking test” (GALT) were apparent in both groups indicating that exposure to techniques in both classes may have promoted students’ reasoning gains. Another explanation may be that individual student maturation occurred affording students opportunities to understand better the concepts requiring formal operational skills as the 9 month study progressed (Smith & Bitner, 1993).

Two comparative evaluation studies on ChemConnections (Gutwill-Wise, 2001) assessed the impact of the modular (context-based) approach on students’ understanding, reasoning skills and attitudes towards chemistry. The same experimental design was conducted at two universities with the instructors alternating between modular and non-modular (traditional, text book and lecture format) sections throughout the semester, to control for the effect of changing instructor. However, there were a number of discrepancies between the two universities in implementation of the modular course. This included differences in the length of class time allocated, availability of the course for students to choose, and topics covered. Therefore, comparisons could only be made between modular and non-modular sections within the same university and not between institutions.

The results of the study showed that within both universities, several assessments such as an examination and quiz questions created by the faculty as part of the course, and in-depth interview questions regarding the gas laws, revealed significantly better performance by the students in the modular (context-based) classes, while other tests found no differences. Interestingly, there were no cases of students in the non-modular classes outperforming those in the modular classes (Gutwill-Wise, 2001). There was some evidence from the University of Charles that students who had completed the modular course went onto the next course, organic chemistry, with a slight edge and certainly performed at least as well as students from a non-modular introductory course (Gutwill-Wise, 2001). Even at this early stage in the implementation of the modular or context-based approach, the study showed the approach was providing an overall benefit to students learning introductory chemistry (Gutwill-Wise, 2001).

Two similar studies comparing the understanding of chemical ideas between context-based (Salters) chemistry students and traditional chemistry students occurred in England (Barber, 2000; Barker & Millar, 1996). Firstly, Barker and Millar (1996) undertook a large-scale, comparative, longitudinal study of 400 upper secondary level students at 36 schools in England following A Level chemistry courses, including Salters Advanced Chemistry. The study employed a series of diagnostic questions on key areas of chemical understanding that students completed at three different times over an 18-month period. The results revealed comparable levels of understanding across all courses. In particular, they found that students who experienced gradual introduction and revisiting of ideas in different contexts at several points during the Salters course appeared to develop better understanding of these ideas than students following more conventional courses (Barker & Millar, 2000). However, some aspects of chemical bonding—including ionic bonding and intermolecular bonds other than Hydrogen bonds—remained problematic for students in the Salters course despite explicit teaching (Barker & Millar, 2000). Secondly, interesting data came from a study by Barber (2000), who used a range of value added performance indicators to compare predicted and actual grades in Advanced level Chemistry examinations for two groups of students. One group was taking Salters Advanced Chemistry and the other group a more conventional course. Her study indicated that there was no particular disadvantage or advantage to students in either course in terms of the final examination grade they achieved. Although students took different examination papers, all examinations met externally imposed standards. Consequently, the study provided additional evidence that the learning by students on context-based courses is comparable with that of students on more conventional courses (Bennett & Lubben, 2005).

Another comparative study was conducted on the German context-based course *Chemie im Kontext* (ChiK). Lange and Parchmann (2003) studied students' understanding of acids and bases in both a ChiK class and a traditional chemistry class. The results showed slightly better results (statistically significant), for ChiK classes, compared to other classes who were taught a traditional unit.

The evidence from three studies investigating students' conceptual understanding in context-based courses suggests that students studying chemistry contextually learn chemistry at least as effectively as students studying a traditional context-based course (Barber, 2000; Smith & Bitner, 1993; Wierstra, 1984). More convincingly, four of these studies reported students in context-based courses demonstrated a deeper understanding of concepts than students following more conventional

courses (Barker & Millar, 1996; Gutwill-Wise, 2001; Lange & Parchmann, 2003; Sutman & Bruce, 1992). Furthermore, there was some evidence that a “drip-feed” approach which allowed students’ knowledge to develop over time was successful for developing a deeper understanding of chemistry ideas (Barker & Millar, 2000).

The review so far suggests that the context-based approach shows promise for engaging students in the study of chemistry through situating the learning in relevant real-world contexts. Furthermore, the research reveals students’ interest, attitudes and motivation for learning chemistry are enhanced through a context-based approach. Finally, the research suggests that students are not disadvantaged, and in the majority of studies, were advantaged, in conceptual understanding through learning science in context. The third of these findings will be elaborated through a discussion of context-based studies conducted predominantly in Australia.

### ***Student transfer of learning***

Although the third finding suggests students are not disadvantaged in conceptual understanding through learning science in context, two Australian studies will be discussed that reveal students were unable to transfer their learning of chemical concepts to situations beyond the context in which they were learned (Hart, Fry, & Vignouli, 2002; Wilkinson, 1999). This discussion will be expanded to draw on past research on transfer of learning in physics (i.e., Shipstone, 1985) and chemistry (Bulte, Westbroek, de Jong & Pilot, 2006). These outcomes will be contrasted with a more recent study demonstrating students can make connections between concepts and contexts within a context during context-based teaching (King, Bellocchi & Ritchie, 2008).

Hart et al. (2002) and Wilkinson (1999) found teachers were concerned that teaching physics within a context resulted in students being unable to transfer their learning and apply concepts in situations outside the context in which they were learned. Consequently, they feared that students would be unable to appreciate the general applicability of the physics principles. Such concerns about transfer are not unique to a context-based course. Traditional physics courses are still implicitly based in an abstract, idealised context, and assume that the student will be able to transfer their learning to a range of real-world or ideal situations. Furthermore, past research has demonstrated that students’ learning in physics courses does not generally develop the ability to transfer their learning (see, for example, Shipstone (1985). This is supported by significant research on conceptual change that has

revealed that due to students' prior conceptions they may emerge from a science classroom with very different understandings from those intended by the teacher (Duit, 2002; Osborne & Freyberg, 1985; Tytler, 2002; Wandersee, Mintzes, & Novak, 1995).

One international study has found similar results to the Australian studies regarding student transfer of learning. Bulte, Westbroek, de Jong & Pilot (2006) conducted a study on a context-based unit on water quality which incorporated a three-phase framework: (1) Orientation and motivation – introduction to the unit through a leading question and student generated ideas about what is “needed-to-be known” (2) Extending knowledge – laboratory work investigating the accuracy and reliability of colorimetric experiments (3) Applying knowledge and reflecting – collective reflection on the whole process of the determination of water quality (p. 1069). The study revealed that students were unable to apply concepts of accuracy of colorimetric measurements learnt in Phase 2 to written and presented judgements of water quality required in Phase 3. In other words, the students did not experience their learning in the experimental work on accuracy of colorimetric methods as meaningful for the follow-on activities investigating the water quality of neighbourhood water sources. Similarly, further studies have shown that students find it difficult to apply concepts learnt in one science context to other situations, especially out-of-school contexts (Bell, 1993; Venville, 2004).

These findings contrast with a more recent study (King et al., 2008) in Queensland where a student (Amanda - pseudonym) who had completed one year of a traditional chemistry course and then repeated the year in a context-based chemistry course, demonstrated “high road transfer” (Perkins & Salomon, 1991) of her learning. High road transfer occurs when there is a “deliberate, mindful abstraction of skill or knowledge from one context for application in another” (Perkins & Salomon, 1991, p. 376). In an interview after the completion of both courses, Amanda made a purposeful connection between a chemical concept and the context of water quality. On this occasion, the student explicitly abstracted principles from the solubility rule “all nitrates are soluble” that had been learnt in the traditional chemistry course, to the presence of insoluble materials in water, when she explained an experiment she had completed in the context-based unit on water quality (King et al., 2008). Despite teachers' fears that context-based teaching had “exacted a cost” (Hart et al., 2002), the study by King et al., (2008) revealed that one student could make connections between concepts and contexts during context-based teaching.

Connections such as those demonstrated by Amanda require students to develop a deep understanding of the canonical chemistry before applying it to the real-world context. In other words, Amanda's demonstration of high road transfer could be referred to as "higher order thinking" a term used in Queensland schools defined by the Productive Pedagogies framework (Queensland Government Department of Education and Training, 2004). By connecting a solubility rule to the presence of the sediment in the water, Amanda "manipulated information and ideas in ways that transform their meaning and implications" (Queensland Government Department of Education and Training, 2004).

The third theme distilled from the literature; that is, students' conceptual understanding is not compromised through a context-based approach, will be expanded further through a discussion of the significant challenges faced by teachers implementing context-based approaches in systems with external as well as internal assessment in Australian schools.

### *Assessment dilemmas*

Despite an early attempt in Australia to contextualise the learning of chemistry through the publication of Bucat's (1983) *Elements of Chemistry* textbook, there is only a small body of research on context-based teaching from two states, Victoria and Queensland. In Victoria, this approach has been adopted in the Victorian Certificate of Education (VCE) syllabuses for physics and chemistry with some claims to success. In Queensland, teaching chemistry contextually began with an initial 25 schools trialling the context-based syllabus in 2002. This was followed by a thorough review in 2003 (Lucas, 2003) that made 21 recommendations resulting in changes to the initial trial-pilot syllabus before an extended trial-pilot program was released in 2004. Subsequently, a further 96 schools volunteered to be part of the extended trial-pilot from 2005. Unlike Victoria, Queensland does not have external examinations. This means Queensland teachers are afforded greater flexibility for implementing the context-based approach as well as designing assessment tasks. The discussion will begin with the Victorian system which includes both internal and external assessment similar to many international school systems. Following this, assessment dilemmas in the Queensland system will be explained.

The new physics course for the Victorian Certificate of Education (VCE) was re-written to adopt an "approach through contexts" similar to the context-based approach of the PLON project (Hart, 1998, p. 22). The initial design allowed teachers to choose contexts with flexibility of content

giving them the freedom to introduce other related ideas necessary for understanding. The assessment was to consist of an Extended Experimental Investigation (EEI), a library research project and two centrally set and marked tests to assess content. It was agreed that the approach through contexts would require tests that were very different from the traditional examination. However, when significant changes to the VCE external exams were beginning to unfold, the design of the new curriculum began to be questioned by the Victorian Curriculum and Assessment Board (VCAB). Consequently, it was argued that a student had to study the same physics ideas whatever context selected. This was to ensure that all students had studied a common body of knowledge that could be unambiguously recognised as physics knowledge. The outcome was that the external assessment requirements prevented the significant changes to the physics curriculum that were initially so desirable (Hart, 1998).

Similar reform was attempted for the VCE chemistry that was set in a science-technology-society (STS) framework (elaborated in next section) where the knowledge was presented as concepts in contexts. The authorities at the time, FOOSC (the Field of Study Committee), had never clarified or been able to agree on whether the contexts as well as the concepts were part of the knowledge content to be taught and assessed in the new VCE chemistry syllabus. A study that interviewed 32 teachers from country and metropolitan schools, 15 months prior to the teachers implementing the new VCE chemistry syllabus, found little evidence of teachers who had constructed a meaning for the new content that included details of the contexts or saw these materials as having that potential (Fensham, Corrigan, Sheed, & Hutchinson, 1994). Interestingly, Fensham et al, reflected on the external assessment as inhibiting teachers' ability to implement a context-based approach. The following comment by Fensham et al. (1994) sums up the frustration of the science educators at the time who were supporting the new syllabus:

Perhaps only when external testing components of the VCE take the STS dimensions seriously – an unlikely event in the competitive university selection climate now prevailing – will most chemistry teachers believe that the socio-chemical concept of a waste is as well worth learning as the Lowry definition of an acid. (p. 32)

In Queensland, since there are no external exams, teachers are freer to choose contexts and forms of assessment. Thus teachers could choose from a range of contexts within the pilot context-based chemistry program (e.g., water quality, the air we breathe), those that they were prepared to

develop and implement. Since each key learning experience was covered in at least two contexts, it was assumed all students would be learning the same key ideas. However, from an early survey, it was found that there was hardly any overlap between schools in the contexts chosen (Beasley & Butler, 2002). Furthermore, Beasley and Butler (2002) conducted a survey of students in classes piloting the context-based chemistry syllabus in order to determine the degree of similarity between the important aspects of the syllabus and the students' classroom experiences. They found that nearly one third of the features categorised as highly important by the syllabus were not being addressed sufficiently in the classrooms, according to the students (Beasley & Butler, 2002). It is important to note, however, that the teachers' freedom to choose contexts in Queensland "stands in stark contrast to earlier initiatives in Victoria and New South Wales where external examination requirements did not allow such an open choice" (Beasley & Butler, 2002, p. 3).

In Queensland, all schools in a designated district met to compare standards of student work at moderation meetings. These meetings provided teachers with an opportunity to reassess student assessment tasks while comparing work of a similar standard from other schools. In the extended trial-pilot syllabus, which finished in 2007, at least one and no more than two tasks from each of the following three assessment categories were to be included in the verification folio (a folio that went to an external review panel) at the end of year 11: Extended Experimental Investigation (EEI), Extended Response Task (ERT) and Written Tests (WT) (Queensland Studies Authority, 2004). Briefly, the EEI is a research task with an experimental component where students are required to conduct an investigation over a lengthy period of time; the ERT is an extended response task that enables students to demonstrate an understanding of a chosen issue through an informed response; and the WT commonly includes quantitative and qualitative tasks that are carried out under examination conditions (Queensland Studies Authority, 2004, p. 29). Queensland teachers were forced to write new assessment tasks that satisfied the three categories while creating opportunities for students to link concepts and contexts. Consequently, the pedagogical approach or approaches chosen to teach the context needed to prepare students for new forms of assessment. This was challenging for teachers who had differing views of what it meant to teach chemistry in context (see e.g., King (2007)). Little research was undertaken on the new assessment tasks that were mandatory for schools in the trials, and on their effect on teaching and learning in a context-based classroom. Clearly, further research is required in Queensland to investigate context-based assessment and how this impacts on the learning and teaching in a context-based classroom.

## **New initiatives in chemistry education – Science Technology and Society (STS)**

Other curricular developments in science education that have aimed to make the learning of science more meaningful for students and adopt an alternative rationale for learning experiences for students, are science-technology-society (STS) approaches, and problem-based learning (PBL) or project-based science (PBS), the latter of which often incorporates an inquiry-based approach to science education. Since this paper aims for a thorough review of new initiatives in science education, a review of these approaches contributes to a holistic picture. In this section, examples in both chemistry education and science are used to highlight the characteristics of PBL, PBS and STS that feature in context-based approaches where students are encouraged to link canonical science with the real-world context. Embedded in the review of PBL and PBS is an explanation and discussion of inquiry-based approaches in science education.

### ***STS***

The literature on STS materials is extensive (e.g., Ben-Zvi, 1999; Lubben, Campbell, & Diamini, 1997; Smith & Matthews, 2000; Tsai, 2000; Winther & Volk, 1994; Yager, 1996) with several attempts to define STS and to characterise materials with “an STS approach.” In a comprehensive review of a number of STS-related publications (syllabi, curriculum materials, policy statements), Aikenhead (1994) identified a spectrum of categories of STS materials. This spectrum ran from courses which he described as having “motivation by STS content” where traditional school science is made more interesting by mentioning STS content, through courses which developed “science through STS content,” to courses which showed an “infusion of science into STS content” where applications are used as a starting point and there is less emphasis on the systematic development of science content (Aikenhead, 1994). Aikenhead’s review also allowed him to offer what he described as “a succinct definition of STS content:”

STS content in a science education curriculum is comprised of an interaction between science and technology, or between science and society, and any one or combination of the following:

- a technological artefact, process or expertise
- the interactions between technology and society
- a societal issue related to science or technology
- social science content that sheds light on a societal issue related to science and technology

- a philosophical, historical, or social issue within the scientific or technological community. (pp. 52-53)

A further study by Solomon (1994) examined the “STS features within science education” and found they included an understanding of environmental threats to the quality of life, an understanding of the fallible nature of science, the economic and industrial aspects of technology, discussions of personal opinions, and values in science including a multi-cultural dimension (p. 18). Clearly, the characteristics of STS courses as defined by Aikenhead (1994) and Solomon (1994) encompass a wide range of environmental and technological aspects of science education. It is worth noting that both Aikenhead and Solomon commented on the difficulties of defining STS precisely.

STS approaches share a number of similar features with context-based approaches, the main commonality being the application of science to students’ everyday experiences. Also, the spectrum of materials characterised as STS is much broader than those described as context-based. The latter tend to fall somewhere in the middle of Aikenhead’s spectrum, as their approach is to develop a systematic understanding of science through a study of its application in society (Bennett, 2002). The context-based approach affords teachers opportunities to choose societal issues that are relevant to their local area as the real-world context. In such a way, units connected to the students’ neighbouring community can be taught; for example, a chemistry unit for a mining town could focus on the chemistry of minerals and be titled “the minerals we mine.” Also, the science concepts in the context-based chemistry unit are understood through their application to the local “context.” Therefore, context-based units that link science to students’ everyday experiences would incorporate a science-technology-society dimension in their construction.

### ***Problem-based learning (PBL) and Project-based science (PBS)***

PBL and PBS are two recent curricular developments that have been used in science education in an attempt to engage students in relevant science and technology issues. There are characteristics of these two approaches that overlap with context-based education and STS curricular approaches. The commonalities of PBL and PBS will be highlighted following a review of these two approaches.

Research on problem-based learning (PBL) and project-based science (PBS) seems to fall into three main areas. Firstly, there is research on PBL with undergraduate students, predominantly in the field of medicine (Juha, Pekka, & Kirsti, 2003; Stromoso, Grottum, & Lycke, 2004; Thomas, 2000). Secondly, there is research on inquiry projects conducted by pre-service secondary teachers (Roth,

1999; vanZee, Lay, & Roberts, 2000; Windschitl, 2003) and thirdly, project-based science (PBS) with elementary, middle, and high school students (Schneider, Krajcik, Marx, & Soloway, 2002), the last of which has been studied quite intensively (Chin & Chia, 2004; Krajcik, Czerniak, & Berger, 1999; Lee & Stake, 2004; Marx, Blumenfeld, Krajcik, & Soloway, 1997; Toolin, 2004). While the distinction between PBL and PBS is sometimes marginal in the literature, PBL focuses predominantly on a problem to be solved using an inquiry-based approach at the tertiary level, while PBS focuses on student-directed scientific inquiry in primary and high school classrooms. Since both approaches utilise inquiry practices, it is appropriate to begin with an explanation of inquiry.

Despite numerous definitions that can be found in the education literature, there is a lack of a clear or an agreed-upon conception of what science inquiry involves. Many definitions encompass processes such as using investigative skills; actively seeking answers to questions about specific science concepts; and developing students' ability to engage, explore, consolidate and assess information (Barman, 2002; Lederman, 2002; Roth, 1995). Garnett, Garnett, and Hackling (1995) describe an inquiry-based science investigation as "a scientific problem which requires the student to plan a course of action, carry out the activity and collect the necessary data, organise and interpret the data, and reach a conclusion which is communicated in some form" (p. 27). The planning component and the problem solving task distinguish inquiry oriented tasks from other types of laboratory work. The degree of student-directed learning may vary in the investigation depending on whether the teacher prescribes the problem, the apparatus to be used, the procedure to be followed and the expected answer, or whether the students are required to make their own decisions about these steps.

More recently, Minner, Levy and Century (2010) have defined a framework for inquiry science instruction based on a synthesis of past research which is characterised by three aspects: (1) the presence of science content, (2) student engagement with science content, and (3) student responsibility for learning, student active thinking, or student motivation (p. 478). These characteristics incorporate skills students are expected to develop when they design and carry out a scientific investigation such as making decisions, engaging with the content through creativity and logic, and building on prior knowledge. All of these characteristics are desirable skills for students to achieve in science and are possible through an inquiry-based approach. Inquiry is an important component in both PBL and PBS approaches although there are some differences between the two approaches.

PBL methodology generally refers to teaching approaches where the students are given a problem or scenario to solve in tertiary settings such as the following problem:

Atlanta has a serious problem with water quality; there is a federal ruling requiring Atlanta to reduce the levels of pollutants in the city's rivers. In fall 1996, students were 'hired' by the Upper Chattahoochee RiverKeeper, an environmental advocacy group, to identify, understand, and run EPA-approved (Environmental Protection Agency) analysis on samples that they collected with the RiverKeeper's help. (Ram, 1999, p. 1123)

Through a suitably compelling problem such as the example above, students learn to gather facts specified in a problem, generate multiple hypotheses about how to solve the problem, identify topics that require new information, perform self-directed study in these topics, and evaluate their self-directed study and problem-solving skills (Ram, 1999). The problems often have relevance to students' real-lives such as the environmental issues affecting water quality in the example above; however, the problem may or may not require empirical science tests to be conducted. For example, in the field of medicine, students may be required to find the cause of a patient's illness as described by the problem. This may involve significant research and discussion but not include laboratory work.

In comparison, PBS refers to student-directed inquiry that occurs in school classrooms which often requires laboratory work. Krajcik and Mamlok-Naaman (2006) describe project-based science as follows:

Project-based science (PBS) takes an investigative approach to the teaching and learning of science. In PBS, students find solutions to meaningful questions through investigations, collaboration, and the use of learning technologies. The core principle underlying PBS is to create a meaningful context in which students can find value for engaging in the learning of science through an investigative process. (p. 318)

Since PBS occurs predominantly in school settings, the literature on project-based science is most relevant to this review. One empirical study collated in the USA by Schneider et al. (2002) links inquiry-based instruction with success on science achievement tests. The research was conducted in response to concerns that the movement away from teacher-disseminated coverage of content would disadvantage the students in large-scale achievement tests, which have become increasingly

important indicators of science learning in the USA. Students who had engaged in a PBS science program in years 10 and 11 were the subject of the research. Schneider et al. (2002) found that the PBS students scored significantly higher than students nationwide on many items. In particular, they found that the PBS students scored significantly higher on questions which had a lengthy response and on the scientific investigation questions. This may be due to the design of the tasks in the PBS course which encouraged students to extend their thinking using a variety of genres or due to participation in investigations that were student designed and extended over time. However, PBS students did not surpass the national sample on most practical reasoning items which asked students to apply their knowledge to real-life situations that they may not have encountered before. Although PBS is centred on a project, this research found that students still needed support in transferring their science and understanding to new situations (Schneider, et al., 2002). As discussed previously, similar results were found in the context-based physics research conducted in Australia (Hart et al., 2002; Wilkinson, 1999).

Despite these encouraging results in support of PBS, there were some limitations in this study by Schneider et al. (2002). Firstly, it is not known if the students in the national sample participated in a PBS program and therefore the national sample is not necessarily a non-PBS group. Also, many students in the PBS group had completed three years of science study and in the national sample they may have only completed two. However, the study does show educators that students in inquiry-based science courses will not be disadvantaged on large scale achievement tests. PBS students performed as well or better on almost all of the items used to make comparisons with similar white and middle-class students nationally (Schneider et al., 2002).

From the synthesis above, it appears that PBL and PBS approaches are related and sometimes associated. Their commonalities include; firstly, a problem or project central to the curriculum which focuses the inquiry; secondly, the problem or project is student-driven to some significant degree and requires students to construct discipline knowledge in the process and thirdly, the problem or project is a challenging real-world task set in a realistic or authentic context. While the context-based approach contains characteristics similar to PBL or PBS approaches, it is not identical to them. In context-based chemistry students may be required to investigate a project such as the water quality of their local creek. Such projects are central to the context-based unit, link to students' real-worlds and may be student-driven to a significant degree and so share the above criteria. However, not all context-based approaches are centred around a driving question, a problem or a project. For example,

the context could be “the air we breathe” and students may complete a series of experiments on the different gases in the atmosphere asking questions that require chemistry concepts to be taught to make sense of the context. In such a way, there is not one main investigation that structures the whole context-based unit. Moreover, if an assessment task such as an ERT (Extended Response Task) or EEI (Extended Experimental Investigation) structures the context-based unit then it is more likely to be designed with an authentic (real-world) inquiry-based investigation as the focus. Therefore, content taught on a “need-to-know” basis could be content taught as students ask questions about an inquiry or it could be content taught as students ask questions about the context as a result of individual experiments, their own reading or in-class discussions.

PBS and PBL are initiatives that focus on a realistic or authentic project or a problem to be investigated and hence contain a societal dimension similar to the STS curricular approaches (Thomas, 2000). Context-based approaches may also require students to complete an inquiry structured around a real-world societal issue in a similar way to PBL, PBS and STS approaches or they may require students to complete a series of experiments centered on the real-world context. Projects that immerse students in the context by taking students beyond the classroom into their local communities to learn about and apply science in their (out-of-school) lifeworlds, contribute to a broader understanding of context-based approaches. These projects are discussed in the next section.

### ***Society based science teaching***

Barton and colleagues have carried out two studies which situated students in their local community encouraging students to make connections between science and the real-world scenario. The first study by Barton, Furman, Muir, Barnes and Monaco (2007) found that the connections between science and student worlds were not readily evident in the classroom. On the contrary, the connections were successfully created when the teachers took students into the field of their local community to learn about the science of fresh food production. The students actively found connections by engaging in conversations with community representatives (in this case a farmer and local produce manager) so that the community issues became integrated into the students’ everyday lives. Barton et al. (2007) also found that the students were not only seeing scientific topics in their everyday lives but also using science to make choices and influence other people’s actions.

Another study by Barton, Lim and Tan (2008) examined students’ changing participation within middle school science projects. Projects that linked science with the students’ local

community (or society) were implemented, such as, the “pigeon project” that enabled the study of the local bird population in the urban centres in which the students lived. Also, projects such as “healthy food” and “antismoking” provided opportunities for students to learn about the science of the human body. Barton et al. (2008) found that science learning became more complicated, yet “real” when students could see “science in action” in their everyday lives. They found that when science was framed within the students’ life-worlds, it expanded the boundaries of science and enabled science to take up multiple positions in the science class, such as, supporting the students’ lived experiences and understandings of their worlds rather than being “wrapped in its own separated disciplinary world” (Barton et al., 2008, p. 25).

A similar study by Roth and Lee (2004) was conducted where middle school students participated in a community project to contribute knowledge about a local creek. The students conducted authentic inquiry investigations where their goals were motivated by the same concerns as other members of the community. The children used different tools to conduct the investigation and construct representations of the study e.g., maps, photographs, drawings, and microscopes to view invertebrates. The study found that students demonstrated scientific literacy of a community issue; that is, the students were competent in finding whatever they needed to know at the moment they needed it to understand the health of the creek (Roth & Lee, 2004). Such scientific literacy that incorporates science knowledge that students are likely to encounter as citizens aligns with Robert’s (2007) Vision II for scientific literacy.

Projects like the three discussed in this section that link science with society attempt to make the learning of science more meaningful and have similar goals to “context-based approaches.” PBL and PBS are initiatives that focus on a project or problem to be investigated. While they are more specific than STS approaches, the problem or project may incorporate a societal dimension like the community projects described above. Such studies provide useful comparisons for discussing context-based approaches in chemistry education, and advance our understanding of how students learn science in the context of their local community; however, a more theoretical framework is required to understand further the teaching practices that enable student agency for connections between canonical science concepts and real-world contexts.

Through a dialectical sociocultural theoretical framework the teaching and learning can be viewed as the result of the collaborative nature of social practice. Such a framework affords the

researcher opportunities to view both the teacher-student and student-student interactions through a new dialectical lens. Unlike previous studies that have focused either on student outcomes or comparisons between pedagogically different classrooms, a sociocultural theoretical framework may afford the researcher opportunities to focus on what the teacher did with the students in the classroom and what happened between the students as they socially constructed knowledge together. Such studies have not been conducted in context-based chemistry classrooms. Furthermore, this framework allows the researcher to “zoom in” on the day-to-day interactions between the teacher and students that facilitated the learning of context-based chemistry. The origin of such a sociocultural theoretical perspective is outlined below.

## **A sociocultural theoretical perspective**

### ***Sociocultural theoretical origins: Vygotsky***

The sociocultural approaches to cognitive development are premised on the idea that higher cognitive skills of individuals develop through participation in socially and culturally organised activities. This perspective, founded in the work of Vygotsky (1978), indicates that robust understanding and knowledge are constructed through collaborative talk and interaction in and around meaningful activities. Furthermore, sociocultural theory views learning as an aspect of social practice which involves the whole person, not only through their relation to specific activities but through their relation to social communities. Lave and Wenger (1991) describe this process of enculturation of individual participation into socially organised practices as becoming a full participant, a member, a kind of person (p. 53). They explain how this involves the construction of identities and that learning through participating in social practice requires the participants to become different people as they relate to the activities, tasks, functions and understandings in the social setting. In other words, the identities are seen as “long-term, living relations between persons and their place and participation in communities of practice” (Lave & Wenger, 1991, p. 53). One example of a community of practice is the science classroom where students and teachers participate in the social construction of knowledge.

Vygotsky (1978) considered the growth of the individual to become a functioning member of society as part of the process of societal change. He wrote that the roots of our intellectual functioning were first to be found in our surroundings and through interactions with others before

they appeared internally (p. 57). Applying this to the classroom setting, children have to learn how to make sense of knowledge constructed with others prior to organising the knowledge for individual understanding. This means that at some stage the learner transforms the knowledge from cultural knowledge to individual knowledge.

Hedegaard (1988) provided an interpretation of Vygotsky's "zone of proximal development"; that is, the distance between understood knowledge as provided by instruction and active knowledge as owned by the students. This interpretation is based on Vygotsky's distinction between scientific (understood knowledge) and everyday concepts (active knowledge); that is, he argued that a mature concept is achieved when the scientific and everyday versions have merged (Vygotsky, 1978). In problem-based, context-based or inquiry-based approaches to teaching science, knowledge provided in the classroom through teacher-facilitated interactions in groups that relates to a real-world context, may provide the starting point for the understood knowledge and active knowledge to merge. In other words, these new approaches to teaching science may provide opportunities for students to learn through the real-world context and through interactions with others before the concepts appear internally (Vygotsky, 1978).

This Vygotskian perspective views learning through a broader context of the structure of the social world; that is, important parts of learning are the discourses and communities in which this knowledge is produced. For example, students are part of a community, their chemistry class, and their development of knowledge and understanding may occur in the societal activity with other class members. Hence a broader view of the zone of proximal development incorporates this societal dimension; that is, the learning that occurs in a context-based chemistry classroom occurs in the social world of classroom interactions. Under such societal interpretations of the concept of the zone of proximal development, learning can be viewed as a result of the collaborative nature of social practice. Adopting this sociocultural perspective allows teaching and learning to be viewed as a form of cultural enactment.

### ***Sociocultural dialectical framework***

Vygotsky's sociocultural theory which views learning as a collaborative activity, underpins the sociocultural dialectical framework. King (2009) used a dialectical sociocultural framework influenced by the work of American sociologist William Sewell (1992) and French sociologist Pierre Bourdieu (1990), as a means of analysing how learning occurred between participants in the context-

based chemistry classroom. Such a theoretical framework acted as a “lens” in which teaching and learning was viewed as a form of cultural enactment and where meaningful consistencies were discerned from the complexity of human interactions (Roth, 1995; Sewell, 1999). Furthermore, the culture of the classroom was viewed as a dialectic or a pair of things or concepts that mutually presuppose or constitute one another. The use of two dialectical relationships; namely, agency | structure and agency | passivity, provided the opportunity for King’s (2009) in-depth analysis of learning and teaching in the context-based chemistry class affording new insights into pedagogical structures that afforded students the agency to learn. An explanation of the agency | structure dialectic precedes the discussion of its application. Following this, the agency | passivity dialectic is elaborated in relation to King’s (2009) study.

### *Agency / Structure*

Sewell’s (1992) definition of a dialectical approach to understanding culture is influenced by the work of the English social philosopher, Anthony Giddens. Since the mid-1970s Giddens has been insisting that structures must be regarded as “dual” (Giddens, 1981, 1984). By this he means that they are “both the medium and the outcome of the practices which constitute social systems” (Giddens, 1981, p. 27). Structures shape people’s practices but it is also people’s practices that constitute (and reproduce) structures (Sewell, 1992). “Structure,” can be explained simplistically as referring to the social arrangements, relations and practices that exert power and constraint over our lives (Osterkamp, 1999). For example, what a teacher or student can do in a classroom is mediated by the structures they find in it, such as the material structures of a chemistry classroom with laboratory facilities at the back and a whiteboard at the front, or the social structure of teacher-led lessons compared to group work.

The term “agency” refers to social actions by individuals and groups that “question the ‘normality’ of the given order and their own part in it” (Osterkamp, 1999, p. 380). Structures are enacted by what Giddens calls “knowledgeable” human agents (i.e., people who know what they are doing and how they do it), and agents act by putting into practice their necessarily structured knowledge (Sewell, 1992). Hence, “structures must not be conceptualised as simply placing constraints on human agency, but as enabling” (Giddens, 1976, p. 161). For example, in a science classroom the teacher-led instruction could utilise the whiteboard at the front and limit the agency of the students; that is, the opportunity for them to interact in the lesson. However, the structure of small

group work may provide the students with opportunities to exercise their agency (i.e., power to act) as they work on laboratory activities. The successful interactions in the group work may lead to the teacher incorporating more student-led lessons and changing the structure. Thus, what can be done in a science classroom and therefore agency depends on the material and social (i.e., group work) structures.

Simultaneously, structures make no sense apart from agency: a salient structure in a context-based chemistry class depends on participants in the situation (the students) acting under their past experiences and the rules that have been developed in the classroom. This means that agency and structure presuppose each other in action – they cannot be considered to be independent theoretical categories that at times *interact* (Tobin, 2006). To highlight the mutual codependence of particular concepts they have been turned into a single concept by collating them separated by a vertical line “|”, known as the Sheffer stroke (Roth, 2005, p. xxi). Thus, because agency and structure are mutually presupposing concepts, they have been combined to form the agency | structure dialectic (Tobin, 2006). In the study by King (2009), the agency | structure dialectic explained the interrelationships between the agency of the students and teacher and the structures in the chemistry classroom that were crucial for teaching and learning to occur.

To apply the agency | structure dialectic to the context-based chemistry classroom, Bourdieu’s (1977) construct of a field defined as both a physical location and the structure, resources and schema that constitute that location is helpful. Two fields are highlighted in the context-based chemistry classroom; the real-world field (or context) and the field of the formal chemistry classroom. Human beings are empowered by access to resources which consist of two types: human resources and nonhuman or material resources. Examples of human resources include academic achievement, emotional commitments and prior experience (Sewell, 1999). Nonhuman resources include, for example, the whiteboard in a chemistry class, teacher notes or student journals.

In King’s (2009) study students selected as high achievers and sound achievers, based on the categorization of their written and oral work were empowered to change structures in whole class interactions and group work through their access to resources such as prior academic success, strong content knowledge, skill with equipment, experience as good science students and strong literacy skills. In other words, these students exercised their agency differentially depending on the resources to which they had access. One example from the study was a high

achieving student, George who had considerable experience with the topic of water from his involvement in a year 10 extension science course. This prior experience afforded him greater familiarity with the topic and possibly gave him greater access to relevant resources compared with most of the other students in the class. In the 10 week study which consisted of 19 lessons in this context-based chemistry study, George's interest in chemistry was evident as he would volunteer information and ask thought-provoking questions in whole-class interactions. George demonstrated agential and self-initiated classroom interactions throughout the 11 week unit when he probed the teacher in order to further develop his own understanding of the chemistry content. By exercising his agency in whole-class interactions, he changed the structure of the class from teacher-led to a teacher-student exchange affording more students opportunities to contribute. In King's (2009) study, the sound and high achieving students accessed human resources such as prior experience with water testing, previous academic achievement in science, good laboratory skills and sound literacy skills that were not part of the "cultural capital" of the low achieving students. In other words, the sound and high achieving students exercised their agency to change structures as they accessed their resources more frequently than the low achieving students.

King (2009) examined also the structures in the context-based chemistry class that afforded the sound and high achieving students' opportunities for agency. These students demonstrated their "power to act" in small groups as they worked together to construct an understanding of the water quality of the local creek. The group structure allowed conversations that demonstrated the power of the group to distribute resources. Not only did the sound and high achieving students exercise their agency to change structures in the context-based chemistry class, but they were advantaged by the structure of small groups which afforded opportunities for learning to occur (King, 2009).

### *Agency / Passivity*

The agency | passivity dialectic also provided a lens through which classroom interactions were viewed. Prior work by Roth (2007) provides an explanation of these terms where he suggests that the focus on agency in the past has been asymmetrical, failing to capture an essential component of human experience, *passivity*. He further explains how individuals are agential in that an actor has control over what she is doing, however other actions are passive. Moreover, Roth (2007) asserts passivity is important because agency cannot be thought of without it. Roth (2007) elaborates on the term passivity:

Passivity does not mean not speaking or not physically engaging with the situation because of this or that reason, which, from a theoretical perspective still is a form of agency. (Roth, 2007, p. 2)

He explains what he does not mean by the term passivity:

[It] does not refer to situations where someone decides not to speak—e.g., because someone else “silences” them, or because the person feels, as students from First Nations often feel in Western-style schools, that there is no space to get into the conversation. In such a situation, there is an intent that orients a particular form of agency: not doing something others in the situation already do. (Roth, 2007, p. 8)

On the contrary, passivity refers to an openness to learning that can be manifested through body and facial gestures, spatial orientations and pauses in conversation. In other words, a convenient way to think about passivity is as receptivity (Levinas, 1998; Hwang & Roth, 2009). Consequently, passivity can be a pathway for learning science. If students, for example, are receptive to learning from others then they unconsciously open themselves up to learning from being with others in the fields in which the activities are proceeding. In other words, passivity can be described as the student’s unconscious receptivity to learning.

While receptivity, like passivity can be defined as an unconscious openness to new ideas, there is a difference between the two terms. Receptivity can also be a conscious decision that invokes agency. For example, a student may choose consciously to participate in a group discussion on the current chemistry topic she is learning. On this occasion, the student is choosing to be receptive to learning rather than learning passively since passivity is an unconscious act. Therefore, passivity and receptivity are interchangeable only when agency is not invoked by the student. Hwang and Roth (2009) explain that for new knowledge to be comprehended students need to be both agential, demonstrated by their actions and conversations and at the same time, passive, demonstrated by their willingness and openness to learn. Therefore, students’ learning can be viewed as a dialectic of agency | passivity.

King’s (2009) study found that the sound and high achieving students demonstrated agency as they supported the learning of others in their groups while at the same time demonstrating passivity as they unconsciously opened themselves up to learning from being with each other in the field. On

one occasion, a high achieving student accessed his resource of strong content knowledge to help a sound achieving student complete a task set by the teacher that required the students to order the chemistry terms learnt thus far into a concept map. When the teacher approached the students, the sound achieving student explained the order of the terms in the concept map demonstrating his passivity or openness to learning from the high achieving student. The sound achieving student was both receptive to new knowledge but also agential in sharing the knowledge with the teacher. In other words, the sound achieving student was both passive and agential in his construction of new knowledge.

In contrast, for the low achieving students, agency interfered with their passivity. The two low achieving students in the study had English as a second language and were from China. They rarely exercised their agency in group work or whole class interactions. However, when their learning resonated with chemistry learnt back home, they were not open to new ideas but rather reverted to prior knowledge they had learnt. The study found that the low achieving students' agency interfered with new learning and prevented them from passively learning from others in the field.

The two dialectics of agency | structure and agency | passivity can be used to explain the interactions in a context-based chemistry classroom that can assist students to connect canonical chemistry concepts with the real-world context. While certain structures afforded students the agency to make connections in the study, at the same time they were receptive to new knowledge and learning from each other. Through passivity “stocks of knowledge come to hand” (Tobin, 2009, p. 1) that can be communicated and shared in small groups. The sound and high achieving students' passivity or unconscious receptivity to learning afforded them the agency or the power to make contributions in the small group which led to a better understanding of the task at hand. In other words, the sound and high achieving students were both agential and passive in their learning. However, this was not the case for the low achieving students. The structures of group work did not enhance the low achieving students' agency while affording opportunities for passivity.

King's study explored also the connections students made between the concepts and context by using the metaphor of “fluid transitions” which is elaborated below.

### ***The metaphor of “Fluid Transitions”***

The metaphor of “fluid transitions” originating in the work by Beach (2003) defines the *toing and froing* that occurred in both students’ written work and conversations in context-based chemistry when students made connections between the real-world context and the canonical science (King, 2009).

Beach (2003) defines transitions as “a developmental change in the relation between an individual and one or more social activities” (p. 42). In particular, a collateral transition involves individuals’ relatively simultaneous participation in two or more historically-related activities (Beach, 2003). He further explains that collateral transitions involve back and forth movement between activities and hence are multi-directional. In Beach’s examples of “collateral transitions” the students physically moved between activities such as home and school, school and part-time work and language arts class and science lessons. However, when the students made these transitions; that is, moved back and forth between the activities, there was not always a developmental progress tied to the movement itself. For example, only two-thirds of the third grade students who attended special maths classes that were taught new ways of symbolising the combining and separating quantities could then transfer this process to regular maths lessons where they learnt standard algorithms for combining and separating quantities (Beach, 2003). The back and forth movement that Beach (2003) describes is similar to the *toing and froing* between concepts and context that may occur when students are learning in a context-based chemistry classroom. Beach’s metaphor of “transitions” could be elaborated further to the term “fluid transitions” to describe this back and forth movement. More specifically, the term “fluid” implies there is a *toing and froing* between concepts and context.

King (2009) used the metaphor to explain the *toing and froing* that occurred between the real-world field and classroom field in a year 11 context-based chemistry classroom. Even though the students in the study did not physically move between the two fields, the classroom and the real-world community, their conversations and written work moved back and forth between canonical chemistry and the context (King, 2009). For example, in the final written report students discussed their empirical test results linking them to the health of the creek. In such a way, they demonstrated evidence of Robert’s Vision II for scientific literacy; that is, by starting with the real-world context, the canonical science was used to explain the health of the local creek.

Similarly, in the small group conversations, the high and sound achieving students demonstrated *toing and froing* between concepts and context. The students shared ideas in groups

and used the discourse of science to make inferences about the water quality at the local creek. In these student-student exchanges there was evidence of *toing and froing* between concepts and context or fluid transitions. The information the students gleaned from these student-student exchanges became a resource for the Extended Response Task or written task. Consequently, for the sound and high achieving students, fluid transitions were realised in both the written activities and student-student interactions (King, 2009).

In contrast, King (2009) found that the low achieving students did not have access to the resources of strong content knowledge and previous success in science and did not make the necessary connections in the written task and student-student interactions. Low student achievement and confidence in science could be seen as partially resulting from the contradiction between the resources a teacher expects students to have for the learning of science, and the resources students actually bring to the classroom. The low achieving students were unable to fulfil the requirements of the written task due to their weak literacy skills, revealing that the task was too difficult for them. They lacked the resources that would enable fluid transitions or the merging of discourses between the concepts and context. In the conclusion some possibilities for improving access to resources for students with English as a second language (ESL) in context-based chemistry classes are discussed.

## **Conclusion**

### ***The contribution of the dialectical sociocultural approach for research into context-based chemistry education***

Despite substantial evidence from the review of literature that context-based approaches are increasing students' interest and motivation in chemistry while not diminishing their conceptual understanding, and in some cases, improving conceptual understanding, context-based approaches are still not used in the majority of chemistry classrooms. Approaches such as PBL, PBS, STS and established context-based courses (e.g., *ChemCom*, *Salters*, *Chem im Kontext*, *Chemistry in Practice*, *Industrial Chemistry* and *PLON*) which situate the learning of chemistry specifically, and science more generally, in real-world societal issues, still represent an "alternative" strand to the more traditional approaches that emphasise the learning of conceptual knowledge. Even after 20 years of implementation and research on context-based programs and associated approaches, teachers are still reluctant to change pedagogical

approaches. So how do we encourage teachers to try alternative approaches such as the context-based approach in their classrooms?

One way is to create a new set of dimensions informed by the outcomes of recent studies that adopt a sociocultural theoretical perspective, for incorporation into Professional Development for teachers of context-based chemistry. While previous Professional Development for context-based chemistry may have focused on preparing teachers to design context-based units through examples of models that can be adopted (see e.g., King, 2009) or phases that can be implemented (see e.g., Bulte, Westbroek, de Jong & Pilot, 2006) a new set of dimensions would incorporate information on the pedagogical structures that can be used to maintain the centrality of the context while providing opportunities for students to connect concepts and context (or make fluid transitions). Such Professional Development would encourage teachers to enact pedagogical change through examples of structures that increase students' agency and enable them to access and share their resources through collaboration within a community of learners. In particular, the Professional Development would encourage teachers to include the following pedagogical structures that:

- support a teacher-guided authentic inquiry-based investigation where students take the initiative to finding answers to real-world problems that are situated in the local community (e.g., EEI-Extended Experimental Investigation).
- emphasize student-student interactions over teacher-led lessons through group work and laboratory work.
- provide students with the opportunity to complete a written task (e.g., ERT-Extended Response Task).
- allow opportunities for teacher-student conversations where content is taught on a “need-to-know” basis.

Furthermore, the Professional Development could encourage teachers to acknowledge the differences in the cultural capital that students bring to the chemistry classroom and suggest teaching approaches that create opportunities for developing these skills. In the study by King (2009) the low achieving students did not develop the higher order thinking skills necessary for success in chemistry. Teachers could identify particular higher order thinking skills such as synthesizing information, hypothesizing, solving problems and drawing conclusions and teach

these skills explicitly. If Professional Development showed teachers how to teach such skills, and the structures required that afford students opportunities for fluid transitions, then they are more likely to engage in such teaching.

In particular, the Professional Development could prepare teachers to teach context-based chemistry to students with ESL (English as a Second Language). ESL students need structures in classrooms to provide them with the capacity to transform available resources (such as prior knowledge from China) as well as reinterpret these resources to create new forms of activity and participation in the Australian context. Therefore, teachers need to find structures that enhance the low achieving students' agency while affording opportunities for passivity. Tobin and McRobbie (1996) suggest Chinese students need opportunities to use their "mother tongue" in chemistry classrooms as well as access to chemistry texts written in their own language. Additional resources like an interpreter or multi-lingual teachers and teacher-aides in the classroom may help students with ESL comprehend the discourse in the classroom as well as the written work. Also, ESL students may exhibit more agency through increased opportunities for passivity by inhabiting more than the world of school science in the classroom if they are provided with opportunities to apply their scientific knowledge to their out-of-school communities. To encourage teachers to enact pedagogical change and enhance their teaching of context-based chemistry, Professional Development that shows explicit teaching strategies needs to be available.

Finally, this review has contributed to research in context-based chemistry through using Bourdieu's (1990) notion of borderless fields. This is a new way of theorizing fluid transitions in a context-based chemistry class. In the study by King (2009), connections between the canonical chemistry and the context occurred when the students' conversations and written work overlapped two or more fields simultaneously—the field of the local community and the field of the chemistry classroom. Consequently, the way forward in context-based chemistry is for teachers to provide opportunities for students to bring the two fields more closely together. Studies like Barton and colleagues and Roth and Lee (2004) demonstrate examples of such possibilities through society-based science teaching where science is used to understand community issues. If teachers and their students physically spend time in the real-world fields of their local community, the merging of its sociocultural knowledge with the students' conceptual

science knowledge can radically change the way chemistry has been taught in the past. No longer would chemistry be wrapped in its own separate disciplinary world, but rather it would be positioned within the complicated but interconnected real-worlds of the students' communities (Barton, et al., 2007). Such immersing of students in the real-world contexts of their local communities provides opportunities for the *toing and froing* between concepts and context to be replaced with a blending of canonical science and the real-world context.

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