"Did something happen to you over the summer?": Tensions in Intentions for Chemistry Education

Brian Lewthwaite[1] Tanya Doyle[1] Thomas Owen [2]
James Cook University[1] Auckland University of Technology[2]

Abstract

This paper examines teachers' experiences in responding to a new Chemistry curriculum in the province of Manitoba in Canada informed by a 'tetrahedral' orientation (Mahaffy, 2005) as a pedagogical framework for the teaching of Chemistry. This tetrahedral orientation endorses macroscopic, microscopic, symbolic and human element teaching and learning experiences and, considering that most Chemistry teaching typically focuses on the symbolic level (Johnstone, 1991), affords a much more diversified Chemistry teacher pedagogy and student-centred learning experience. The teachers self-selected for this study were a part of a larger group of 74 participants in a five-year professional development initiative focusing on fostering the enactment of the intended Chemistry curriculum with its tetrahedral orientation. These teachers were those whose orientations to teaching were statistically significantly different from other participants, as evidenced in the 'narrowing' of their teaching practice to, predominantly, a symbolic representation for their Grade 12 classes in contrast to their more diversified practice in Grade 11. Using Aoki's reference to 'tensionality' (1986), the study focuses on elucidating the tensions the teachers experienced in working in the space between Chemistry 'curriculum-as-planned and curriculum-as-lived'. Implications of this study in relation to Chemistry education curriculum policy and practice are discussed.

Abstract Keywords

Chemistry education, tetrahedral orientation, tensionality

Introduction

It is commonly known that science curriculum development and implementation efforts often do not get past the classroom door (Lewthwaite & Fisher, 2004, 2005) suggesting that despite all the effort, time and resourcing committed to the preparatory phases of the 'intended' curriculum, the actual delivery or enactment of the intended curriculum at the classroom level rarely occurs leaving the basic practices of science classrooms unchanged. Although a range of factors (Lewthwaite & Fisher, 2004, 2005) are identified as impediments in seeing the intended curriculum become the 'enacted' curriculum, as Fullan (1992) suggests, the reason can often be attributed to teachers' not being convinced of the 'worthwhileness' of such intentions. Fullan's reference is important, especially for this study, because it affirms teachers' beliefs and, ultimately, choices are integral in and to the enactment process. As William Pinar (2000) suggests, each stage of the curriculum process, including the design, development and, in this study's case, implementation at the classroom level, involves a 'reconceptualization'. Similar to what occurs in the reconceptualization of an intended curriculum at the design and development phase is the reconceptualization that occurs at the interface between teacher and students as teachers consider, adjust and recreate the intended curriculum in an effort to enact it in a manner consistent with their own beliefs and the environment in which they are situated. Pinar refers to this reconceptualization as evidence of a teacher's 'personal conversation' about the interplay between personal beliefs, environmental determinants and the intended curriculum. Ted Aoki captures this premise when he states, "[a teacher's] pedagogic position is a living in tensionality – a tensionality that emerges, in part, from the indwelling in a zone between two curriculum worlds: the worlds of curriculum-as-plan and curriculum-as-lived-experiences." (1987, p. 354).

The reference to this 'zone between two worlds' or 'tensionality' between or among opposing forces is not uncommon in the education literature. Schön (1995) refers to this position as 'an indeterminate swampy zone' of practice. Clandinin et al (2006) refer to this position being occupied by 'conflicting stories'. Berry (2007) refers to tensions as a useful way of describing the complex and conflicting pedagogical demands teachers of science experience. For these reasons, it is not surprising that Pinar refers to curriculum as 'autobiographical' referring to the thought process and reconstruction teachers engage in, in this tensioned position. Pinar (2004) asserts that this autobiographical stance of reconstruction is more than simply action based on reflection. It is the "action of teachers who are able to act for themselves", affirming that teachers "make a wise and prudent practical judgement about how to act in *this* situation" (Carr and Kemmis, 1986, p. 190) taking into consideration the importance of the contextual features of their situation.

The intent of this study is to explore the nature of the tensionality teachers experience in the delivery of a new Chemistry curriculum that explicitly calls for a widened and student-centred Chemistry education experience for students and, consequently, a diversification of pedagogic practice for teachers. The context of the study is similar to what many chemistry teachers experience today – new curriculum initiatives calling for a change in practice. This places teachers in a situation, as Carr and Kemmis refer to as 'the space between curriculum as expected and curriculum as expressed'. It is inferred that within this tensioned position there are choices and alternatives. Teachers will decide on *how* to act in this space of alternatives. Although this reference to the 'indeterminate swampy zone' is not uncommon in the education literature, capturing this deliberation and the outcomes of this deliberation in a teacher's practice in the space associated with a new curriculum in Chemistry education, especially with its tetrahedral orientation, is undocumented. This study seeks to understand the thinking and acting teachers experience between a Chemistry curriculum-as-plan and Chemistry curriculum-as-lived experiences for both teacher and students. It seeks to capture the autobiography of this space and Chemistry teachers' experience in decision-making in this reconstruction. In this study we focus on three teachers who over five years of professional development provided a 'widened' learning experience consistent with the intentions of an intended curriculum for students in Grade 11 and then 'revert' to or, in fact, retain a narrowed experience for students in Grade 12, the final year of Chemistry provided at the school level. The study seeks to answer the questions: What informs teachers' Chemistry teaching practice during an implementation phase of a new Chemistry curriculum? Does a teacher's thinking demonstrate the 'deliberating about alternatives' between 'curriculum-as-intended and curriculum-as-lived' (Aoki, 1987)? How and why do teachers respond as they do when faced with these alternatives?

Background to the Study: Tensions in Intentions for Chemistry Education

The pedagogical choices made by teachers of Chemistry that constitute their autobiographical stance are influenced by a range of factors, both environmental and personal. As Bronfenbrenner (2005) suggests these factors are interactive and dynamic multisystem elements. For example, and important to this study, societal and political imperatives occurring at the classroom, school, community and macro-provincial and national level for Chemistry education are regarded as examples of system factors that may work to influence a teacher's pedagogical orientation. Fensham (2009) states that for too long science educators have been naive to the role of factors such as policy in science education, and further consideration of the "interplay between the stakeholders beyond and in-school who determine the nature of the curriculum, especially as enacted by teachers at the classroom level, for science education" (2009, p. 1076) is warranted. In this statement, the nature of the curriculum for science education is problematised; the curriculum, in both its intended and enacted form, may be derived for a variety of purposes.

Tensions in Societal Purposes for Chemistry Education

Arguably, a trend evident in the contemporary literature is that the purpose of Science, Technology, Engineering and Mathematics (STEM) education is largely constructed as a binary of purpose across tiers of schooling. On one hand, much of the literature around the purpose of STEM education aspires to an inclusive approach, for the development of scientific literacy, or a scientifically literate citizenry (see, for example, Goodrum and Rennie, 2007). On the other, this view is often held at odds with an approach that is concerned with mastery of disciplinary knowledge (Marginson, Tytler, Freeman and Roberts, 2013). An 'inclusive approach' to STEM education may be positioned as a 'soft' or 'weak' approach; in order to make the science more accessible, much of the rigour of the discipline is lost. Further to this, there is the literature that presents a sense that the purpose of STEM education shifts as students move from the compulsory years of schooling to the post-compulsory years of schooling (Goodrum, Druhan and Abbs, 2012). Overall, it could be argued that tensions around the purpose of STEM education exist, and that the changing purposes of STEM education across the years of schooling underpin these tensions.

Further to the debate around the shifting purposes of STEM education, is the idea that subjects, such as Chemistry, now form part of a curriculum marketplace (Marginson, 1997; Teese, 2000; Teese, 2007; Teese & Polesel, 2003). As such, each subject is imbued with a range of strategic purposes – for students, for schools, for universities and for the broader political landscape. For example, to students, the successful completion of a subject such as Chemistry in the "enabling sciences" (Tytler, 2007, p. 7) establishes pathways for entry into the Higher Education setting. With regards to the political landscape, the enabling sciences play a strategic role in leveraging the transition to a post-industrial, innovation-driven, economy (Marginson, Tytler, Freeman & Roberts, 2013. STEM, as a set of key disciplinary knowledges, is positioned as central to the development of the human capital needed to drive such an economic transition – these imperatives are evident in much of the contemporary Innovation policy of developed countries such as Australia, the United States of America and the United Kingdom (see for example Commonwealth of Australia, 2009; United Kingdom Council for Science and Technology, 2012). In much of this policy, teachers are positioned to play a pivotal role in the development of STEM-capable graduates. The ability of a teacher to enact these policy imperatives is tied, through a policy discourse of "quality" to the disciplinary expertise of teachers and the pedagogical decisions enacted in the classroom (Office of the Chief Scientist, 2012).

Tensions in Teacher Beliefs about Chemistry Education

Considering these apparent tensions within the purpose of Chemistry education, it is not surprising that at the individual level, a teacher's *beliefs about the purpose* of Chemistry education will influence a teacher's judgment of the 'worthwhileness' of a curriculum initiative and how they respond to a new curriculum initiative. The science education literature is well-established in the influence of a teacher's pedagogic position and decisions (for example, Coenders, Terlouw & Dijkstra, 2008; Tobin, 1993; Tobin & McRobbie, 1995). As Aoki (1987) asserts, the pedagogic position is fraught with tensions such as the tension between the role of the curriculum as intended and the multisystem promptings or demands for what curriculum should be as enacted. Central to this is the socially-constructed view of what Chemistry teachers see as their roles. Similar to the constructivist tenets often touted in the science education and adult education literature, teacher's views of Chemistry and their role as teachers of Chemistry are durable and actively developed as a result of an adaptive activity (von Glaserfield, 1995) through their own personal experiences. Lamote and Engels' (2010) writings on teacher identity suggest, similar to other teacher education researchers (for example, Rots, 2007), that there are various constructed teacher 'sub-identities', one of which is teacher task orientation. This orientation refers to teachers' answers to questions such as: "What do I want to achieve with my students? How do I want to do this? What is my role as a teacher? What is their role as students?" Denessen (1999) specifies that task orientation focuses on aspects such as the (1) pedagogical relation between teacher and students; (2) the educational goals motivating the teaching; and (3) the instructional emphasis. Of importance to this inquiry is the suggestion by Denessen (1999) that the task orientations are primarily associated with two major ideologies or belief binaries – a less frequently identified student-centered approach in contrast to a more commonly identified content-centered approach. A pupil-oriented ideology will focus on a pedagogical relation that responds to students' learning styles through a range of teaching and assessment practices, fosters involvement, educational goals that are social and personal and an instructional emphasis that is more process-oriented. In contrast, a content-oriented ideology will largely disregard students' learning styles, use a limited range of teaching and assessment practices, focus on a pedagogical relation focused on discipline, educational goals that are geared towards career development and an instructional emphasis that focuses on academic knowledge acquisition as a product necessary for further study.

Although this binary on the sub-identity of teacher task orientation has its limitations, especially since all characteristics for one ideology may not be symptomatic of a teacher's orientation (Tsai, 2002, 2006), teacher identity is a valuable construct underpinning the focus of this study and the experiences of the teachers involved in this study. The inquiry outlined in this paper investigates the nature of teacher belief about Chemistry and their role as Chemistry educators and the competing stories both informing and influencing their pedagogical decisions when teaching Chemistry and how these decisions manifest in their observable practices. In this study, we explore this interface and expose the tensionality experienced by Chemistry educators in the implementation of a new Chemistry curriculum.

Context for the Study

A Tetrahedral Chemistry Curriculum

This study is located in Manitoba, Canada where the chemistry curriculum for Grade 11 and 12 chemistry curricula (Manitoba Education, Citizenship and Youth (MECY), 2006 and 2007 respectively) explicitly emphasize a 'tetrahedral orientation' as a pedagogical framework for the teaching of chemistry (Mahaffy, 2006). Mahaffy's model is an extension of the chemistry 'triplet' often espoused in the chemistry education literature (Gilbert, 2005; Gilbert & Treagust, 2008; Taber, 2013). The Manitoba provincial curricula were developed in response to the curriculum development teams' understanding of evidence-based appropriate pedagogy for both *experiencing* and *fostering learning* in science (Osborne & Wittrock, 1985) and, especially, chemistry through explicit reference to the multi-dimensional modes of representation – microscopic, macroscopic and symbolic (as examples, Gabel, 1993; Gilbert, 2005; Taber, 2013).The authors assert (Lewthwaite & Wiebe, 2012, 2014) that Mahaffy's (2006) extension of the 'triplet' model to include the 'human element' is synonymous with a contextual approach to the teaching of science. He encourages chemistry educators to move beyond the triangular planar (which he asserts focuses chemistry education on conceptual understanding and content acquisition) to incorporate a further dimension of experience and communication, thus changing the model to a tetrahedron as illustrated in Figure 1 below. As Mahaffy (2006) states "…this rehybridization emphasizes [the] need to situate chemical concepts, symbolic representations, and chemical substances and processes in the authentic contexts of the human beings who create substances, the cultures that use them, and the students who try to understand them". Mahaffy describes the need to develop public understanding and trust through the exploration of contemporary applications of chemistry and the social and environmental issues associated with chemical production and use. Overall, his advocacy for the inclusion of the human element rests in a supposition that engagement with, learning and communication in and appreciation of chemistry may be hampered by an insufficient integration of the human element into the content of chemistry and a three mode pedagogical framework. This 'tetrahedral' approach not only includes the explicit learning *of* chemistry, but also includes the learning *about* chemistry as it is dealt with in society (Burmeister, Rauch & Eilks, 2012).

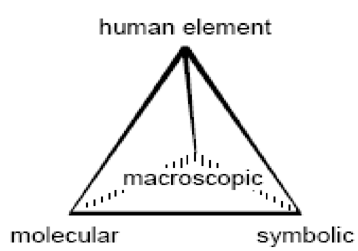

Fig. 1 Tetrahedron of chemistry experiencing, thinking and communicating dimensions

The tetrahedral orientation is evidenced consistently throughout the Grade 11 and 12 chemistry curriculum. As an example, in the example of strong and weak acids at the Grade 12 level, students are expected to examine the differences between strong and weak acids at the experimental level (macroscopic) and seek to understand these differences in properties through their molecular dissociation differences (microscopic) and how this difference is represented through chemical equations and quantitative data (symbolically) and influences biochemical processes such as blood pH, equilibrium and stomach digestion in the human body (human element) (MECY, 2007). It is important to note for this study that although quantitative chemistry is not located only in the 'symbolic' dimension, for this study we include it within this dimension.

The variety of experiences provided by the tetrahedral approach as evidenced in the strong acid-weak acid example provide evidence of a curriculum advocating for a variety and, potentially, a binary of purposes. It advocates for an inclusive and personal relevance approach that emphasizes the primacy of personal engagement, participation and meaning (Eisner, 1979). Further it advocates for the development of the intellectual cognitive faculties each student possesses (Eisner, 1979). As well, it encourages the development of a scientifically literate citizenry that is informed by and able to address societal needs. Finally, the goals indicate the purpose of the curriculum in developing students' intellectual growth in chemistry with a range of strategic purposes, one being the establishment of a pathway for entry into the higher education setting (Eisner, 1979). In summation, the new Manitoba chemistry curriculum provide evidence of, as characteristic of the STEM education aspirational discourse earlier described, an inclusive approach for the development of scientifically literate citizenry alongside of and possibility in opposition to an approach that is concerned with mastery of disciplinary knowledge.

The Professional Development Initiative

As might be expected, the new Manitoba Chemistry curricula with their advocacy for a tetrahedral and more learner-centred focus brings with it an orientation to Chemistry teaching and learning that is unlikely to be overall consistent with current Chemistry teaching practice among Chemistry teachers. As suggested by Johnstone (1991) most Chemistry teachers and, consequently their students, focus primarily on the abstract teaching, thinking and communicating level in the written symbolic form focusing on abstract content acquisition, and, thereby, any effort to bring about reform-based changes to Chemistry teaching and learning practice must be accompanied by significant support. As Hoffman and Laszlo (2001) assert, this shift requires teachers and students to engage in a "language" or communication of Chemistry beyond the written symbolic level. As research asserts, a new curriculum is rarely accompanied by teacher change unless accompanied by significant and strategic support (Fullan, 1992). In response to this challenge, the University of Manitoba's Centre for Research, Youth, Science Teaching and Learning (CRYSTAL) in 2007 embarked on a five-year research and development project to support the improvement of teaching and learning of Chemistry in Manitoba in accordance with the intent of the new curriculum and its tetrahedral orientation. Similar to all projects within the University of Manitoba CRYSTAL our focus in this research is on understanding the *developmental* pathway or teachers and their students. Bronfenbrenner describes development as the sustained, progressively more complex and activity in, the immediate environment (Bronfenbrenner, 2005, p. 97). This description of development is central to our CRYSTAL studies because if there is indeed teacher development, there should be evidence of progressively more complexactivity in the environment in which the individual is located, in this study's case, the widened repertoire of teaching behaviors a teacher may evidence in the teaching of Chemistry (Lewthwaite, 2008). The project endeavored to monitor its success based upon how three cohorts of teachers were teaching in accordance with the tetrahedral orientation of the curriculum and, correspondingly, students responded to and were influenced by this approach to teaching. As well, the focus of this CRYSTAL initiative was to understand how teacher personal attributes such as beliefs about Chemistry and Chemistry education and teachers' professional environment such as the professional development and contextual factors at the classroom, school, district and provincial level influenced their development. Building upon Bronfenbrenner's bio-ecological theory (2005), this study endeavored to understand the dialectic between teacher attribute and environmental factors and to capture this dialectic in teacher's autobiography of the enacted Chemistry curriculum.

Methodology

Although the teacher development focus, processes and outcomes for the three cohorts over the five years of the project are described and detailed in another study (Lewthwaite & Wiebe, 2011), we focus in this study upon the autobiography of three teachers who showed significant adjustments in their teaching *inconsistent* with the remaining teachers involved in this project. For these three teachers, similar to the overall statistical changes the teachers experienced, this progressive and developmental change over the five years was from, initially in year one, a two-dimensional (macroscopic and symbolic form) to a four-dimensional tetrahedral orientation in the teaching of Grade 11 chemistry. This adjustment for Grade 11 was sustained for the duration of the remaining three years of development project. Despite this adjustment for their Grade 11 classes, these three teachers 'reverted' to or 'retained', predominantly, a uni-dimensional, symbolic orientation, emphasizing especially content acquisition, especially quantitative aspects, in the Grade 12 subject. In all three examples, the majority of the students in Grade 11 were also taught by the same teacher in Grade 12, albeit with a much different emphasis. The three teacher participants in this five year study, occurring between 2007 and 2011, were members of two of the three groups of 74 chemistry teachers from different geographical regions of Manitoba. Because the three groups were relatively stable over time and experienced a common professional development experience, the study, overall, was regarded as a cohort study. Each cohort averaged 20 self-selected participants, the large majority of whom taught both Grades 11 and 12 chemistry. During the course of a year, teachers from each cohort attended at least four and as many as six professional development days. Teachers in attendance and CRYSTAL facilitators participated in tangible teaching examples (for example, demonstrations, laboratory experiments and investigations, practical applications, computer simulations) that addressed these outcomes in a manner consistent with the curriculum's tetrahedral orientation. Sessions were seen as an opportunity to collaboratively assist teachers and facilitators in becoming more familiar and comfortable with the pedagogy associated with the three vertices of the tetrahedron that they were least accustomed to, in particular the human element, molecular and macroscopic. It is estimated that these three dimensions combined for the majority of the focus of the sessions. Because they are regarded as less orthodox teaching strategies, special emphasis was placed on effective pedagogy associated with the use of computer-based visualizations, historical accounts of chemistry ideas, practical applications of chemistry, and engaging macroscopic experiences such as experiments, demonstrations and investigations. In all, the sessions focused on focusing on supporting the development of practices consistent with the development of a more student-centered approach in contrast to a more commonly identified content-centered approach (Denessen, 1999).

During the five year study, data to ascertain teacher development and reasons for changed practice were collected by a variety of methods. These included: (1) interviews with teachers prior to and, subsequently, annually during the professional development; (2) at least one annual observation of teacher's teaching and a post-teaching conversation about teacher's teaching; (3) statistical data collected from teacher completion of an instrument used to gauge teacher development in this project – the Chemistry Teacher Inventory (CTI) (Appendix One) and (4) student completion of a student version of the Chemistry Classroom Inventory (CCI – not included with this submission). The focus of the interviews, observations, conversations and instrument completion and statistical analysis associated with the CTI was to determine how teachers were teaching and why they were teaching the way they were. The multiple sources of data, especially from the teacher, researchers and students provided for data triangulation. The development process of the CTI and CCI is detailed elsewhere (Lewthwaite & Wiebe, 2011), but it is important to recognize for this inquiry that the teacher (CTI) and student (CCI) forms of the instrument had been developed specifically for this project within the context of the Manitoba curriculum and its' tetrahedral orientation. In brief, both contain 33 items identified by students, teachers and the research literature as easily observable, low-inference (Murray, 1999) teaching practices that influence (either positive or negative) student learning of chemistry.

The data collected from all three sources over the course of the project data indicated that teachers, overall, made a statistically significant movement towards a tetrahedral orientation and that teachers of Grade 12 were showing a more substantial movement towards a tetrahedral orientation despite placing considerably more emphasis on quantitative Chemistry, a characteristic of the Grade 12 curriculum. What was noticeable from the statistical and interpretive comments and the classroom observations of some Grade 12 teachers, in contrast to the other teachers, was their retention of a more 'restrictive' chemistry education experience evidenced by little human element, microscopic and macroscopic experiences with retained emphasis on only the symbolic aspects of the Grade 12 subject. That is although teachers, overall, were providing students with an increased emphasis on the symbolic and quantitative in Grade 12, these teachers were doing this with a significant *reduction* in attention to any reference to the macroscopic, human element and microscopic dimensions. It was these teachers that became the focus of our puzzlement and the focus of this research. Despite the focus of the curriculum on a tetrahedral orientation, why were these teachers maintaining a *narrowed* very content-oriented experience with heavy reliance on the symbolic level in their teaching of Grade 12? What was informing teachers' Chemistry teaching practice during the implementation phase of this new Chemistry curriculum? Does teacher's thinking demonstrate the 'deliberating about alternatives' between 'curriculum-as-intended and curriculum-as-lived' (Aoki, 1987)? How and why do these teachers respond as they do when faced with these alternatives?

The Instrumental Case Study

As described by Stake (1995) this qualitative study is best categorized as an instrumental case study where three particular cases are of interest. They, in themselves, reveal a story. The instrumental case study is best utilized in "a situation where there is a research question, a puzzlement, a need for general understanding, and feeling that we may get insight into the question by studying a particular case". In instrumental case study what is most important is the identification of the revealing case rather than the typical case. Our statistical data had identified only a few teachers 'narrowing' the learning experience between Grade 11 and 12. This statistical identification was based on an analysis of the four items contained in the CTI that specifically pertained to the symbolic and quantitative dimension of the tetrahedron (Appendix One). These include (1) students perform calculations; (2) students are required to know what a formula means before calculating; (3) on tests students perform calculations; and (4) students complete problems from texts or other textual material. Based on teachers' completion of the CTI and students' response to their teaching, these three teachers, in contrast to other participants, 'always' or 'almost always' used these strategies in the teaching of Grade 12 in contrast to never, rarely or sometimes using these strategies in Grade 11. Unlike all other teachers, no other teaching behaviors representative of the other dimensions of the tetrahedron were in the 'always' or 'almost always' scoring of the 33 Likert-type items on the CTI scale for their Grade 12 class. Unlike all other teachers , they were also evidenced to be (1) never or (2) seldom or (3) sometimes using behaviors associated with the macroscopic, human element and microscopic in Grade 12 although using it (3) sometimes, (4) almost always or (5) always in Grade 11. As mentioned, this statistic was corroborated by observations of these teachers' teaching as well as students' results from the CCI. At a professional development day at the end of year 4 of the Professional Development three months in advance of the research reported on here, the researchers asked teachers to anonymously self-identify if their teaching had 'narrowed' between Grade 11 and 12, and consider participating in this study so we as researchers could understand their reasons for this adjusted practice. The three teachers to be described volunteered to be participants in this study. Ethics approval for all data collection methods to be described was attained through the first author's university ethics board and each teacher's school board, which required informed consent by each participating teacher and their principal.

Because we sought to understand the nature of their position in the space between curriculum-as-intended and curriculum-as-enacted, a variety of data were collected to provide validity to the relationship between practice and beliefs. These included document analysis, classroom observations and teacher self- and student-reporting on each teacher's practice. The first researcher sighted and engaged with each teacher in discussion around the outline for both their Grade 11 and 12 Chemistry subjects with special emphasis on the assessment focus for each year level. Of interest to us as researchers was determining which of the dimensions of the tetrahedral orientation was most emphasized in assessment. Based upon the prior analysis of the CTI, we assumed, and correctly, that for these three teachers, the Grade 12 assessment, in contrast to Grade11, would predominantly focus on the most abstract dimension of the tetrahedron, the symbolic and that this would be increasingly evidenced in Grade 12 in summative assessments such as unit tests and exams. Further classroom observations and post-observation discussions would focus on the pedagogical practice of classrooms. This amounted to three observations each of both Grade 11 and 12 classes over a three week period in the final month of the Chemistry subject at a time that was convenient for both the teachers and the researchers. In the observations, the authors used the CTI was to monitor the breadth and frequency of teacher actions. Further, a week prior to each classroom observation, teachers completed the CTI. As well, before the second observation students completed the CCI. In the third interview, teachers were asked to comment on students' response to their teaching as evidenced in their CCI completion (Table 1). Although the collated data only from students' completion of the CCI is included here, we do provide one example of one teacher's (Lyle) CTI for his Grade 11 class in the Appendix. After each lesson observation the first author conducted follow-up interviews with each teacher that focused upon their practice and the reasons for their practice. The interviews were, on average, one hour long and were conducted from a phenomenological methodological stance where we sought for teachers to describe their teaching free from our hypotheses or preconceptions (Husserl, 1970). The teachers were asked, with little intervention, to consider the lesson observed and, most importantly, their reasoning behind the emphasis and action in the lesson, especially in relation to the tetrahedral orientation of the curriculum. The interview questions asked were: (1) In this lesson, giving consideration to the (intended) curriculum's emphasis, what has informed your decision about was enacted? (2) Do you experience tensions in enacting this curriculum and, if so, what tensions? and (3) How do you work to resolve any tensions that might arise as a result of a difference between curriculum as it is intended and how it is enacted? All interviews were transcribed and verified as accurate by the participants. As suggested by Bogdan and Biklen (2007), the transcribed data were then coded around the schemes of (1) identified actions, (2) reasons for actions and (3) tensions associated with such actions.

Participants

The three participants in this study, as stated, were all full participants in the five-year professional development project. John was a chemistry and mathematics teacher at a highly academic school in an urban centre. At the time of this study, he had taught chemistry for 12 years. He holds a Bachelor of Science in Chemistry and a Bachelor of Education (Secondary). It is well-known in the city that students at this school who study matriculation subjects will likely go to university. In the cohort of students who graduated from this school in 2011, 92% of the 212 graduating students went on to university, the majority to STEM-related careers. Lyle, also in his twelfth year of teaching, teaches chemistry, biology and mathematics at a rural school in Manitoba. He holds a Bachelor of Education (Secondary) with a major in biology and minor in chemistry. In the year of this study, 32% of the 54 students graduating went on to university, only a few to STEM-related areas. Finally, Helen, a seventh year teacher, taught chemistry and biology at an urban school where 54% of the 242 graduating students went on to university in the year after high school graduation, a minority of these to STEM-related careers. Helen holds a Master of Science in Environmental Science and Bachelor of Education (Secondary).

In the section that follows, because of space constraints, we provide a description of the focus of one of the three Grade 12 lessons observed and an abbreviated account of the interviews that followed for both the three Grade 11 and 12 observations, especially with reference to the comparison between the information provided by the CCI and CTI completion. In the vignettes we purposely try to focus on each teacher's (1) actions, (2) reasons for actions and (3) tensions associated with such actions.

Results

John's Observation and Post-Teaching Conversation

The three lessons observed and discussed in Grade 11 focused on the topics of physical properties of matter, balancing chemical equations and organic chemistry. The Grade 12 lessons focused on curriculum objectives associated with equilibrium constants, weak and strong acids, and electrolysis. In the observation of all classes at the grade 11 level we saw evidence of all dimensions of the tetrahedron. For example in the teaching of balancing chemical equations, amongst other things, John (1) reviewed, through example, how equations can be balanced to show conservation of atoms, (2) modeled for students how atoms are conserved in a reaction through the use of styrofoam balls, (3) demonstrated the electrolysis of water in a Hoffman's Apparatus and focused on the stoichiometric outcome and the quantity of hydrogen and oxygen produced in the electrolytic process, and (4) discussed the implications of electrolysis in terms of energy requirements. In his Year 12 observation focusing on equilibrium constants (K values), the lesson focused exclusively on assisting students in developing a deep understanding of the concept of equilibrium and, specifically, what the equilibrium constant represented. No reference was made to macroscopic or human element applications or experiences although the very nature of the topic called for reference to the microscopic although this dimension was not visually represented in the lesson. Although attention was given to how K values were calculated, the teaching focused primarily on what the ratio of K represented in terms of presence of chemical species as reactants relative to products. The interactions between John and students and, to a lesser extent amongst his students, although focused exclusively on the symbolic level were dialogic. Problems from the text, primarily quantitative in nature, were assigned in the last twenty minutes of class which students worked on collaboratively.

Our post-teaching conversations with John focused on seeking to understand what had informed his decision about was enacted and to identify any tensions experienced in enacting this curriculum. In this conversation we, in addition, discussed students' responses to his teaching as documented through the CCI. In the table below those items of the CCI that pertain to, primarily, the symbolic teaching emphases are listed. These include (1) students perform calculations; (2) students are required to know what a formula means before calculating; (3) on tests students perform calculations; and (4) Students complete problems from texts or other textual material. For each item, the number of students of each of the three teachers preferring an increase (+), no change (o) or decrease (-) in this teaching behavior is recorded.

In John's Grade 11 class (Table 1), the majority of students did not seek reduction in his emphasis on those behaviors primarily associated with the symbolic. In fact, most students preferred for him to retain his current emphasis on this or increase its emphasis. In contrast, the majority of students in Grade 12 sought no change to his current emphasis. John's comments repeatedly made mention of "expectations".

> Our students are all geared towards university and many of them are off to top universities in North America under full scholarship. The expectations for them are high, primarily from their families and the school as a whole. But they place just as high expectations on themselves. I don't think I set a tone that is different than what they want. The expectations are high and we work towards that. It doesn't surprise me [that they so not seek change as indicated in Table 1]. I am surprised by the Grade 11s though. It says something when *they* want more emphasis [on the symbolic]. What is the message there [he asks rhetorically]. They have it figured out - haven't they [referring to the emphasis on the symbolic]!

In the conversations around priorities, John described his emphasis in Grade 11 in respect to the intended curriculum and its tetrahedral orientation.

> The Grade 11 course focuses on developing a deep understanding of the nature of matter, especially from a practical [macroscopic] emphasis. The [Grade 11] subject requires students to think conceptually about matter [at the microscopic level] and how this relates to what we

see macroscopically. There is a strong emphasis on formal practical work to ensure they can perform procedures [manipulative laboratory skills] but, overall, it is highly conceptual focusing on links [amongst the dimensions of the tetrahedron]. I don't do as much at the applications [human element] level. It all builds a foundation for their future, not just Grade 12 but university and future careers as well.

Teacher	*Grade Number of Students*	*Item 12 Students perform calculations*			*Item 14 Students are required to know what a formula means before calculation*			*Item 17 On tests students perform calculations*			*Item 19 Students complete problems from texts or other textual material*		
		Student Suggested Change			Student Suggested Change			Student Suggested Change			Student Suggested Change		
		+	0	-	+	0	-	+	0	-	+	0	-
John	G 11 (n=21)	9	9	3	11	7	3	9	7	5	9	8	4
	G 12 (n=19)	6	11	4	6	11	4	3	16	2	5	15	1
Lyle	G 11 (n=16)	2	12	4	3	11	2	3	10	3	4	10	2
	G 12 (n=12)	1	4	7	1	2	9	2	2	8	2	2	8
Helen	G 11 (n=23)	9	9	5	9	8	6	9	9	5	8	9	6
	G 12 (n=25)	5	16	4	5	16	4	5	12	8	5	13	7

Table 1: Students' Response to Teacher's Teaching

In explaining the difference between Grade 11 and 12 [as indicated in his Table 1 data], John, again, repeatedly mentioned how he adjusted the curriculum's tetrahedral intent to privilege the symbolic, especially the quantitative, components of the Grade 12 curriculum.

I realize the change the students have experienced [moving from Grade 11 to 12], but I do forewarn them. Year 12 was going to be different and even though the [intended] curriculum was saying otherwise [with its tetrahedral orientation], I knew my [implemented] curriculum had to prepare them for [university and careers] chemistry. They have to be well-equipped to work mathematically, and that's where the emphasis has to be. I know what will help them long term and it has to come from a deep understanding of not just the molecular occurrences but more importantly how this is represented at that symbolic level. They have to *think* and understand the meaning of equations and formulae and what they represent. If they just do it blindly they are sunk. I know they have confidence in me to help them negotiate what is ahead. In fact, they don't want it to be easy.

John described tensions associated with the new curriculum and how he negotiated the interface between curriculum-as-intended and curriculum-as-lived.

I think the [intended] curriculum [over the two years] gives a good message. Students need to be exposed to all dimensions, but, more importantly, see how they interconnect. I get that. But, I have to think about my students and their futures and Chemistry overall. The de-

> emphasis on the symbolic, and especially the quantitative, in Grade 12, I think, is not appropriate for my students. I want them to do exceptionally well whatever science-related career they choose and they need to have a real deep understanding of why we do what we do [especially in working with the symbolic in Chemistry]. They get why I put the emphasis where I do. They know they are prepared.

Lyle's Observation and Post-Teaching Conversation

The three lessons in Grade 11 focused on the topics of physical properties of matter, stoichiometry and organic chemistry. The Grade 12 lessons focused on equilibrium constants (Solubility Products), weak and strong acids (K_a), and calculating electron potentials for voltaic cells. In the observation of all three classes at the grade 11 level we saw evidence of all dimensions of the tetrahedron, especially the macroscopic. For example in the teaching of stoichiometry, the students reviewed mass-to-mass stoichiometric calculations and then performed a lab focusing on the calculation of mass product (sodium chloride) to be produced in a hydrochloric acid – sodium bicarbonate reaction. Students performed the lab and calculated percentage error. Sources of experimental error were then discussed as the lesson closed. In the Grade 12 lesson focusing on K_a values for weak and strong acids, the lesson started by defining acid strength and K_a. The lesson's focus was exclusively on writing and calculating K_a values from a list of provided word problems. The text was relied on heavily as students worked individually and collaboratively on assigned problems with occasional input from Lyle.

Our post-teaching conversations with Lyle focused on seeking to understand what had informed his decision about was enacted and to identify any tensions experienced in enacting this curriculum. In particular, with Lyle we focused on the opposition students were indicating towards his teaching (as evidenced in the CCI item responses in contrast to Lyle's own comments), again primarily associated with expectations.

> Our [rural] school enrolments are low in the sciences and we can't lose subjects like chemistry and physics and we are encouraged to allow students into Chemistry that might not really belong. In this community everyone wants their kids to do well and have every opportunity – and that's alright. So I'm expected to make that allowance and I do make that allowance. The new curriculum is really supportive of that. A lot of the students aren't that good with mathematics so the curriculum is really palatable. You can see it by their response [to Grade 11]. [We discuss that the majority of students seek no change in his emphasis on the symbolic in Grade 11 and, in contrast, the request for reduced emphasis in Grade 12.

In the conversations around priorities, Lyle described his emphasis in Grade 11 in respect to the intended curriculum and its tetrahedral orientation.

> They really enjoy the year. It mainly shows up in my assessment. I am not so test-driven, even though that is what really counts. I have to make sure though the marks don't get inflated because it really changes in Grade 12. Next year will be different. I know we are trying to be inclusive and all, but that's not really what is about. The curriculum has changed and the PD has really encouraged me to adjust and I have, but next year will stay pretty much the same. Students need to be prepared for university [and STEM-related studies] and the curriculum focus is a bit soft. I would put [more] emphasis on some of the things it emphasizes. It's been quite a shift in approach. I am not sure about the quality of the

> teaching, but students have been more engaged. Not sure if they are learning the right things though.

In explaining the difference between Grade 11 and 12, Lyle, again, repeatedly mentioned how he adjusted the curriculum's tetrahedral intent to privilege the symbolic, especially the quantitative, components of the Grade 12 curriculum.

> There are some [infers two or three] students who are now heading off to [STEM-related studies] at university. Every year I hear from parents that their children are finding Chemistry [in first year] a challenge and it always has to do with the quantitative-symbolic stuff. I just can't let the Grade 12 year not emphasize that. We do some labs and stuff but it pretty well focuses on their ability to do the mathematical parts. Just the K_a section today could take three periods…which equation to use…how to write equations based upon the word problems. Having that as a focus is imperative.

Lyle described tensions associated with the new curriculum and how he negotiated the interface between curriculum-as-intended and curriculum-as-lived.

> [Student] asked, "Did something happen to you over the summer?". "What do you mean?", I said. He went on about how last year was different and now he just felt he didn't belong in chemistry [in Year 12]. Well, he didn't really belong in Year 11 either. It's a real problem both for me and them. You want to give them every possibility and make allowances but they aren't really cut out for Chemistry. And the school wants us to make the allowance and parents believe they are geniuses. Then you're on the chopping block if the top ones struggle when they get to first year. I guess what ends up happening, overall, is my attempt to balance the demands as best I can. I can see [from the results] the dissatisfaction. I know that. I understand that.

Helen's Observation and Post-Teaching Conversation

The three lessons in Grade 11 focused on the topics of Gas Laws, the mole and organic chemistry. The Grade 12 lessons focused on reaction rates, galvanic cells and spontaneous-nonspontaneous reactions. In the observation of all three classes at the grade 11 level we saw evidence of all dimensions of the tetrahedron. For example in the teaching of Gas Laws, the students (1) performed an experiment that demonstrated gas volume-pressure relationships; (2) developed an understanding of a 'constant' as a result of data collected; (3) graphed results and (4) explained the changes observed at the molecular level using a teacher demonstrated on-line simulation. The hand-out students used for this laboratory exercise required them to relate Boyle's Law to contextual examples such as lung expansion and breathing. In Grade 12 Helen's lesson on Galvanic Cells focused on (1) a demonstration of how a galvanic cell is produced, (2) an on-line simulation which illustrated electron flow and chemical species change (atoms to ions and ions to atoms) in the cell's operation, (3) an explanation of why the electric current is generated because of the reduction potential differences between reducing agent and oxidizing agent and, (4) for the majority of the time allocated, calculations, from a worksheet, were completed to determine which metal-salt pairs would produce the highest cell voltages.

Our post-teaching conversations with Helen focused on seeking to understand what had informed her decision about what was enacted and to identify any tensions experienced in enacting this curriculum. Similar to Lyle we focused on the opposition students were indicating towards her teaching (as evidenced in the Table 1 CCI item responses in contrast to Helen's own comments), again primarily associated with expectations.

Helen's comments also made mention of "expectations".

> It has been a shift in emphasis and really [over the years] I haven't thought about adjusting my practice. I just thought it all had to be quantitative all the way through as that is what really counts. But the PD and everything has just made me realize this is a much better learning experience. I can't disregard what ultimately counts, but I can adjust it. [It has been] just a broader range of experiences over, especially, Grade 11 with more focus on the symbolic in [Grade] 12. [in response to the CCI data], I think we do well in Grade 11. It's a good balance but in 12 it becomes more of an issue. We talk a lot about the increased emphasis on [the symbolic] and I think I help them to navigate this. I'm not being a barrier. I'm working with them towards what is ahead and they respond ok to that.

In the conversations around priorities, Helen described her emphasis in Grade 11 in respect to the intended curriculum and its tetrahedral orientation.

> It was a bit of a stretch for me to adjust the Grade 11 course, but this year I do what I know is best for them. I can see this approach just helps them engage more and assist in their learning. The teachers I work with are pretty open to the change as long as we don't change Grade 12 too much. There's a lot more interest in the subject and I know students are understanding it better. I'm teaching it better. There is much more preparatory work but it's a much better experience for students

In explaining the difference between Grade 11 and 12, Helen, again, repeatedly mentioned how she adjusted the curriculum's tetrahedral intent to privilege the symbolic, especially the quantitative, components of the Grade 12 curriculum.

> The focus still needs to be on the symbolic. I know I reduce the focus on the other levels [macroscopic, human element, microscopic] in Grade 12, but they still are there. The students know that Grade 12 is the real "sifter". They want to get a good pass in Chemistry just to keep their options open and as long as they don't get overwhelmed, they stay with it. I think they all get a very realistic exposure to what might be ahead and some of them decide the sciences may not be for them, at least areas that require Chemistry. Not all of them, but there are 3 or 4 going to university [into STEM areas] and that is what matters. I sometimes wonder if we should have another chemistry subject, but then that wouldn't be Chemistry.

Helen described tensions associated with the new curriculum and how she negotiated the interface between curriculum-as-intended and curriculum-as-lived.

> I am really comfortable with what the focus of the curriculum. I actually feel better about my teaching [because of it and aligning my teaching with it]; it's truer or at least I am truer to myself. I know the students are less engaged [in Grade 12] and what we are doing is more technical, but I know the learning focus will serve them well for the future. Is it harder, yes! Was I softer last year? Yes! They understand that this is what is required next year. My [two teaching of Chemistry colleagues] who were not involved in the PD have taken on board a more open approach to Grade 11 but we are still pretty restrictive in Grade 12. They understand what I'm doing [in diversifying my practice] and there are tensions around common assessments, but I'm ok with not pushing my wheel-barrow [for increased emphasis on molecular, human element and macroscopic]. The assessment hasn't really changed [for

> Grade 12 with continued reliance on symbolic-quantitative aspects]. In the end, it just isn't as important.

Discussion

Making Explicit the Tensions

We begin this discussion by making explicit the tensions identified by our participants. In our analysis of the interviews we identified the 'conflicting stories' expressed by participants. The narratives in the results section are presented deliberately as vignettes to capture the competing stories or tensions referred to by the three teachers in their post-teaching discussions. The teacher interview excerpts illustrated that two macrosystem imperatives strongly influenced the teachers' pedagogical choices: the imperative for developing 'university preparedness' and the imperative to provide 'opportunities' for students to participate in the study of Chemistry. Each of these imperatives will now be explicated in turn, beginning with the imperative to develop 'preparedness'.

Overall, the interview data revealed that as teachers of Chemistry, John, Lyle and Helen all perceive developing preparedness for university study in their students to be a large part of their role, consistent with Denessen's 'content-centered approach' (1999), with its focus on future goals. Their pedagogical decisions are influenced by this imperative, which shapes the enacted curriculum in their classroom. In turn, and in light of the 'preparedness' imperative, the resultant enacted curriculum is used by the teachers to evaluate the 'strength' of the intended curriculum with its advocacy for a tetrahedral learning experience. Furthermore, the interview excerpts show that teachers perceive mastery over the symbolic and/or quantitative elements of the Chemistry curriculum to be a key feature of preparedness. For example, Helen clearly states that despite the tetrahedral orientation of the intended curriculum, the need for students to attain mastery over the symbolic dimension is central to her pedagogical decisions as a teacher of Chemistry; she states "I can't disregard what ultimately counts, but I can adjust it." Helen goes on to emphasise the change in her approach from Year 11 to Year 12, with the need to expand the orientation to the symbolic as students move into Year 12 as she "know[s] what is best for them". In this instance, Helen is drawing out a key feature of the macrosystem which impacts on the enacted Chemistry curriculum – the need to develop preparedness for university study. At this point, it is useful to recall Fensham's (2009) note that for too long science educators have been naïve to the interplay between policy and the range of stakeholders that influence what is 'taught' in science classrooms. In her statement "she knows what is best", Helen gestures to a set of curriculum messages that reach beyond the expectations explicated in the curriculum. It is argued here that, while not explicitly articulated, the curriculum is imbued with a range of socio-political imperatives for teaching Chemistry – a range of strategic reasons for students to have the 'opportunity' to study Chemistry, and then to actually participate in the study of Chemistry, in the socio-political context of a curriculum marketplace. These socio-political imperatives work strongly to influence the enacted curriculum and, in doing so, differences between the enacted curriculum and the intended curriculum arise.

'University preparedness' as Fensham (2009) asserts is a socio-political imperative that also shaped the enacted curriculum in John's classroom. In the interview data, John articulated a heightened awareness of the socio-political imperative of developing preparedness for university study in his Chemistry students; he states "I have to think about my students and their futures and Chemistry overall. The de-emphasis on the symbolic, and especially the quantitative, in Grade 12, I think, is not appropriate for my students". In making this statement, John alludes to his understanding of what his students 'need' and that, once again, these needs reach outside those of the intended curriculum. Moreover, the development of university–preparedness, as a meta-cognitive awareness in his students, is also valued; John states "they get why I put the emphasis where I do, [the students] know they are prepared". Such a statement indicates that despite the students not having completed university level studies in Chemistry themselves, they bring with them an understanding of the demands of university level Chemistry – in other words, John's students bring a store of academic and cultural capital to their studies of Chemistry. These capitals shape the expectations held by teachers and parents and underpin the imperative for the development of university preparedness.

In contrast to the imperative for developing university preparedness described by both Helen and John, Lyle's interview data described different socio-political imperatives for students studying Chemistry in his school setting. Largely, these imperatives were underpinned by community aspirations for "their kids to do well and have every opportunity". Here, Lyle alludes to a broad awareness in the community about the options that the successful completion of secondary school Chemistry opens up for students. The awareness of Chemistry's strategic value does not escape Helen who, when describing her students reasons for studying Chemistry, states "they want to get a good pass in Chemistry just to keep their options open". In the excerpts from both Lyle and Helen, the imperatives to facilitate both 'aspiration' and 'opportunity' in their students shape the enacted curriculum in their classrooms. Moreover, the socio-political imperative of 'opportunity' extends to ensuring that the enabling sciences, such as Chemistry and Physics, continue to be offered in his school setting, despite dwindling enrolments. In order to provide this opportunity, Lyle states "we are encouraged to allow students into Chemistry that might not really belong". As a consequence of providing this 'opportunity', Lyle states that he "makes allowances" and adjusts his approach to teaching Chemistry accordingly. Lyle reports that the tetrahedral orientation of the curriculum supports the students for whom he is making allowances - those who might be regarded as non-traditional students of Chemistry. However, Lyle also makes a statement that speaks to the heart of the issue for Chemistry teachers operating in a socio-political context under tension: "I know we are trying to be inclusive and all, but that's not really what it is about … Students need to be prepared for university [and STEM-related studies] and the curriculum focus is a bit soft". Lyle's position is echoed by Helen who states that "Grade 12 is the real sifter". In these statements, both Helen and Lyle epitomize the tensions involved in the teaching of Chemistry – they both indicate that it is possible to facilitate the development of 'aspirations' and 'opportunities', but only to a point. Tensions arise as these imperatives for inclusion through a student-centred approach (Denessen, 1999) are held by the teachers to conflict with the imperative for 'university preparedness' with its focus on content acquisition (Marginson, Tytler, Freeman and Roberts, 2013). Here, the conflicting purpose for a Chemistry education comes to the fore. An inclusive approach (facilitated by student-centred pedagogy) is regarded as synonymous with an academically deficient approach which does not facilitate the development of discipline mastery (often facilitated by a content-centred approach). Instead, the perceived purpose of an inclusive approach is to develop student engagement over and above the development of discipline mastery. Once again, the teacher statements in this study indicate that the imperatives of 'preparedness' and 'opportunity' are held in a discursive binary, implying that they perceive it is not possible to develop both mastery and engagement within the one curriculum framework.

What is clear is that Chemistry, as a subject in a secondary school curriculum marketplace, is more than a domain of complex scientific knowledge (Marginson, 1997; Teese, 2000; Teese, 2007; Teese & Polesel, 2003). Chemistry, too, is imbued with a range of sophisticated socio-political functions – on one hand, Chemistry serves as a strategic pre-requisite or “sifter” to university entrance, while on the other hand, the opportunity to engage with the study of Chemistry enables all students with access to the Innovation agenda, which underpins the economic transformations underway in developed countries across the globe. Both the teachers, and the resultant enacted Chemistry curriculum, are squeezed by these socio-political tensions. The intended curriculum, with its tetrahedral orientation, was developed with a view to encouraging and supporting all students, including non-traditional students, in the study of Chemistry. Encouraging more students to participate in the enabling sciences is an imperative evident in the Innovation policy agendas of countries such as Canada, the USA, the United Kingdom and Australia (Commonwealth of Australia, 2009; The United States Government, 2013; United Kingdom Council for Science and Technology, 2012). However, the teachers in this study have positioned the goal of inclusion such that it sits at odds with the role Chemistry plays as a strategic pre-requisite and a “sifter”. The Chemistry teachers, then, attempt to reconcile these perceived tensionalities through differential pedagogical decisions enacted in their classrooms as students move from Year 11 to Year 12.

The challenges teachers face in attempting to reconcile these perceived tensions resulting from the macrosystem imperatives of ‘preparedness’ and ‘opportunity’ is exemplified in a statement made by Lyle. One of his students felt that something had changed between Year 11 and Year 12, and that “he didn’t belong in Chemistry [in Year 12]” and that “something had happened to him over the summer [holidays between Grade 11 and 12]. In response, Lyle stated “well, he [the student] didn’t really belong in Year 11 either. It’s a real problem both for me and them. You want to give them every possibility and make allowances but they aren’t really cut out for Chemistry. And the school wants us to make the allowance and parents believe they are geniuses. Then you’re on the chopping block if the top ones struggle when they get to first year. I guess what ends up happening, overall, is my attempt to balance the demands as best I can.” Here, Lyle is implying that the pedagogical choices he makes will work to disadvantage either the traditional students (who are positioned to benefit from a content-centred approach in order to achieve discipline mastery) or the non-traditional students (who are positioned to benefit from a student-centred approach in order to achieve engagement with the discipline) of Chemistry in his class. In other words, Lyle is attempting to balance the imperative for ‘opportunity’ with the imperative for ‘university preparedness’ – a task which he finds problematic. Lyle’s position is echoed by Helen who states “I sometimes wonder if we should have another Chemistry subject, but then that wouldn’t be Chemistry”.

Although there is much more to drawn from the qualitative and quantitative data presented here, of considerable interest to us is that the actions of the teachers involved in this study and the explanation for these actions demonstrates the influence beliefs have on teacher behaviors in the classroom (Pajares, 1992). Also apparent in the data is the influence that epistemological beliefs about the nature of Chemistry have on teacher’s teaching of chemistry. The beliefs that individuals hold about the nature of knowledge are referred to as epistemological beliefs (Tsai, 2002, 2007). In the narratives, we see evidence that teachers’ pedagogic decision is potentially influenced, not just by the socio-political imperatives, but also by their own epistemological beliefs about the nature of Chemistry. Lyle and Helen provide some indication that that the symbolic-quantitative dimension of the tetrahedron, for them, *is* chemistry. Helen asserts, “I sometimes wonder if we should have another chemistry subject, but then that wouldn’t be Chemistry”. Her statement suggests that chemistry, by nature, is about, and potentially limited to or at least defined by, the symbolic. Similarly, Lyle asserts, “Not sure if they are learning the right things though”. The priorities of their classroom, especially in terms of what vertices of the tetrahedron are privileged, become represented in their teaching and assessment practices, and appear to be grounded in their beliefs regarding the very nature of Chemistry. We see John’s view of Chemistry different from that of Lyle and Helen. His comment, “students need to be exposed to all dimensions, but, more importantly, see how they interconnect. I get that. But, I have to think about my students and their futures and Chemistry overall”, indicates to us, an understanding of Chemistry that is more consistent epistemologically with the nature of Chemistry. His emphasis on the symbolic is not based upon a belief that it *is* Chemistry but, moreso, what needs to be emphasized in terms of preparedness. John’s assertions correspond with Taber’s claim that dealing with the ‘complexity’ of chemistry requires teachers to ‘slow the pace’ to provide sufficient opportunities through a range of contexts that include macroscopic, submicroscopic and symbolic representation and [contextual] application (2013). Despite this recognition of the ‘complex’ nature of chemistry, for all teachers their emphasis clearly indicates a reasoned privileging of the symbolic, especially as a perceived means of preparation for and success in tertiary study.

Summary

As researchers and curriculum writers, we are aware that teachers who do not adopt new curriculum initiatives are often cast in a negative light in the research literature assuming some sort of ‘deficit’ with their position. Similarly in this study we are cautious about reference to John, Lyle and Helen as ‘those’ teachers who ‘reverted’ to a primarily symbolic and quantitative pedagogical emphasis or ‘refused to adopt’ a more progressive learner-centred pedagogical approach. In fact, when we sought to involve the three teachers in this component of the study we were careful to affirm that the behavior being evidenced in their classrooms was not a ‘negative’ but likely, as Carr and Kemmis (1986, p. 190) suggest, a result of “mak[ing of] a wise and prudent practical judgement about how to act in *this* situation”. It was our opinion that the statistical and observational data emanating from the study was providing evidence that *all* 74 teachers were adjusting their practice, and that there were autobiographies being written by each Chemistry teacher as the dynamic between personal attribute and environmental factors played out in the decisions and judgments teachers were making as they deliberated about alternatives (Nichols, 1997). Our data suggested that although each of the teachers was engaged in an autobiography, for this study, we selected only one autobiographical tendency – the ‘narrowing’ of the teaching and learning experience being provided for their Grade 12 students after providing the same students with a much more diverse experience in Grade 11. Similar to all teachers charged with enacting curriculum, the teachers involved in this study and the overall professional development initiative did not follow a ‘recipe’ in the enactment of curriculum. Instead, they negotiated the in-between space responding to the dynamic between the personal and environmental, and in this study’s case, the imperatives of ‘preparedness’ and ‘opportunity’. As Pinar (2000) asserts each teacher is part of a reconceptualization – each is engaged in a personal conversation about, amongst other things, the interplay or dialectic between personal beliefs, environmental determinants and the intended curriculum.

When we started this study, we used Aoki's reference to tensionality (1986) to elucidate the tensions teachers experienced in working in the space between curriculum-as-required and curriculum-as-lived. Aoki reminds us that a teacher's pedagogic position is a living in tensionality – a tension that emerges, in part, from the indwelling in a zone between two curriculum worlds: the worlds of curriculum-as-plan and curriculum-as-lived experience (p. 159). Within this binary, one does not seek to extinguish the tensions but to dwell aright in them. It is the difference that really matters and one's attunement to these differences does not require one to eliminate the tensions but, instead, allow for the complexity of such binaries to exist and not be contradictions or polarized points of view. Our participants give evidence that they *do* dwell aright in them, making what they believe are wise and prudent judgments. They 'deliberate about alternatives' giving evidence to the complex and conflicting pedagogical demands Chemistry teacher's experience in the space between curriculum-as-intended and curriculum-as-lived, especially in responding to one that calls for a pedagogy requiring a diversified teaching and learning experience – a learning experience that some teachers would question is 'worthwhile' for their students, especially as they pursue university study and STEM-related careers.

References

Aoki, T. (1986). Teaching as indwelling between two curriculum worlds. In William Pinar & Rita Irwin (Eds., 2005), Curriculum in a new key: The collected works of Ted T. Aoki (pp. 159-165). Mahwah, NJ: Lawrence Erlbaum Associates.

Aoki, T. (1987). Revisiting the notions of leadership and identity. In William Pinar & Rita Irwin (Eds., 2005), Curriculum in a new key: The collected works of Ted T. Aoki (pp. 349-355). Mahwah, NJ: Lawrence Erlbaum Associates.

Berry, A. (2007). Tensions in teaching about teaching: Developing practice as a teacher educator. Dordrecht: Springer.

Bogdan, B. C., & Biklen, S. K. (2007). Qualitative research for education: An introduction to theories and methods (5th ed.). New York, NY: Pearson Education.

Bronfenbrenner, U. (2005). The bioecological theory of human development. Thousand Oaks, CA: Sage.

Burmesiter, M., Rauch, F., & Eilks, I. (2012). Education for sustainable development (ESD) and chemistry education. Chemistry Education Research and Practice, 13, 59-68.

Carr, W., & Kemmis, S. (1986). Becoming critical: Education, knowledge and action research. Geelong: Deakin University Press.

Clandinin, D. J., Huber, J., Huber, M.; Murphy, M., Murray-Orr, A., Pearce, M., & Steeves, P. (2006). Composing diverse identities: Narrative inquiries into the interwoven lives of children and teachers. London: Routledge.

Commonwealth of Australia. (2009). Powering Ideas: An innovation agenda for the 21st Century. Canberra, Australia: Australian Government Retrieved from http://www.innovation.gov.au/Innovation/Policy/Documents/PoweringIdeas.pdf.

Coenders, F., Terlouw, C., & Dijkstra, S. (2008). Journal of Science Teacher Education, 19(4), 317 – 335.

Denessen, E. (1999). Beliefs about education: Content- and pupil-orientedness in the Netherlands. Leuven-Apeldoorn: Garant.
Eisner, E. W. (1979). The educational imagination. New York: Macmillan.
Fensham, P. (2009). The link between policy and practice in science education: The role of research. Science Education, 93, 1076 – 1095.
Fullan, M. (1992). Successful school improvement. Buckingham: Open University Press.
Gilbert J. K. (2005). Visualization: a metacognitive skill in science and science education. In J. K. Gilbert, (Ed.), Visualization in science education (pp. 9-27). Dordrecht: Springer.
Gilbert, J.K., Justi, R., van Dreil, J.H., De Jong, O., & Treagust, D.F. (2004). Securing a future for chemistry education. Chemistry Education: Research and Practice, 5(1), 5-14.
Gilbert J. K., and Treagust D. F., (2008). Reforming the teaching and learning of the macro/submicro/symbolic representational relationship in chemical education, in B. Ralle and I. Eilks (Eds.). Promoting successful science learning – The worth of science education research (pp. 99-110). Aachen: Shaker.
Goodrum, D., Druhan, A., Abbs, J. (2012). The status and quality of Year 11 and 12 science in Australian schools. Canberra, Australia: Australian Academy of Science.
Goodrum, D., & Rennie, L. (2007). Australian school science education national action plan 2008 – 2012. Canberra, Australia: Department of Education, Science and Training.
Hoffmann, R., and Laszlo, P. (2001). The say of things. Retrieved from http://www.pierrelaszlo.com/articles/9-science-communication/57-the-say-of-things.
Husserl E (1970) *The Crisis of European Sciences and Transcendental Phenomenology*. Evanston, Ill.: Northwestern University Press. (Original work published 1936).
Johnstone, A.H. (1991). Why is chemistry difficult to learn? Things are seldom what they see. Journal of Computer Assisted Learning, 7(2), 75–83.
Lamote, C., and Engels, N. (2010). The development of student teachers' professional identity. European Journal of Teacher Education, 33(1), 3-18.
Lewthwaite, B.E. (2008). Towards treating chemistry teacher candidates as human. Research in Science Education, 38(3) 343-363.
Lewthwaite, B.E. (2014). Thinking about practical work in chemistry: Teachers' consideration of selected practices for the macroscopic experience. Chemistry Education Research and Practice DOI: 10.1039/C3RP00122A.
Lewthwaite, B.E., & Fisher, D.L. (2004). The application of a primary science curriculum evaluation questionnaire. Research in Science Education, 34(1), 55-70.
Lewthwaite, B.E., & Fisher, D.L. (2005). The development and validation of a primary science curriculum delivery evaluation questionnaire. International Journal of Science Education, 27(5), 593-606.
Lewthwaite, B.E., & Wiebe, R. (2011) Fostering teacher development towards a tetrahedral orientation in the teaching of chemistry. Research in Science Education. 40(11). 667-689.
Lewthwaite, B.E., and Wiebe, R. (2012) Fostering the development of chemistry teacher candidates: a bioecological approach. Canadian Journal of Mathematics, Science and Technology Education, 12 (1), 36-61.

Lewthwaite, B.E. (2014). Thinking about practical work in chemistry: teachers' considerations of selected practices for the macroscopic experience. Chemistry Education Research and Practice. DOI**:** 10.1039/C3RP00122A.

Lewthwaite, B.E., & Wiebe, R. (2014). “There’s real strength in the points they made. I can’t ignore that.” Responding to students’ learning preferences in chemistry. Journal of Science Teacher Education. DOI: 10.1007/s10972-013-9369-5.

Mahaffy, P. (2006). Moving chemistry education into the 3D: A tetrahedral metaphor for understanding chemistry. Journal of Chemical Education, 83(1), 49-55.

Manitoba Education Citizenship and Youth (2006). Grade 11 Chemistry: A framework for implementation. Winnipeg: Manitoba Education, Training and Youth.

Manitoba Education Citizenship and Youth (2007). Grade 12 Chemistry: A Framework for Implementation. Winnipeg: Manitoba Education, Training and Youth.

McRobbie, C.J., & Tobin, K. (1995). Restraints to reform: The congruence of teacher and student actions in a chemistry classroom. Journal of Research in Science Teaching, 32(4), 373-385.

Marginson, S. (1997). Markets in education. NSW, Australia: Allen & Unwin.

Marginson, S., Tytler, R., Freeman, B., and Roberts, K. (2013). STEM: Country Comparison. Report for the Australian Council of Learned Academies. www.acola.org.au

Murray, H. G. (1999). Low-inference teaching behaviors and college teaching effectiveness: Recent developments and controversies. In J. C. Smart (Ed.), Higher education: Handbook of theory and research: Vol. 15 (pp. 323 - 345). New York: Agathon Press.

Office of the Chief Scientist. (2012). Mathematics, Engineering and Science in the National Interest. Canberra, Australia: Commonwealth of Australia. Retrieved from http://www.chiefscientist.gov.au

Osborne, R. J., & Wittrock, M. (1985). The Generative Learning Model and its implications for science education. *Studies in Science Education*, 12, 59-87.

Pajares, M. F. (1992). Teachers’ beliefs and educational research: cleaning up a messy construct. Review of Educational Research, 62(3), 307-333.

Pinar, W. (2000). Curriculum studies: The reconceptualization. New York: Educator’s International Press.

Pinar, William F. (2004). What is curriculum theory? New Jersey: Lawrence ErlbaumAssociates.

Rots, I. (2007, July). An exploratory study on the relationship between teacher education graduates’ professional identity and their views on teacher education presented at the meeting of International Study Association on Teachers and Teaching.

Schön, D. A. (1995). The new scholarship requires a new epistemology. Change, 27 (6), 26-36.

Stake, R. (1995). The art of case research. Thousand Oaks: Sage Publications.

Taber, K. S. (2013). Revisiting the chemistry triplet: drawing upon the nature of chemical knowledge and the psychology of learning to inform chemistry education. Chemistry Education Research and Practice, 14, 156-168.

Tobin, K. (1993). Referents for making sense of science teaching. International Journal of Science Teaching, 15(3), 241-254.

Teese, R. (2000). Academic success and social power: Examinations of inequality. Australia: Melbourne University Press.

Teese, R. (2007) Structural inequality in Australian Education: Vertical and lateral stratification of Opportunity. In R. Teese, S. Lamb & M. Duru-Bellat (Eds.), International Studies in Educational Inequality, Theory and Practice: volume 2 – Inequality in Education Systems (Vol. 2, pp. 39-63). Netherlands: Springer.

Teese, R., & Polesel, J. (2003). Undemocratic schooling: Equity and quality in mass secondary education in Australia. Australia: Melbourne University Press.

Tsai, C.C. (2002). Nested epistemologies: science teachers´ beliefs of teaching, learning and science. International Journal of Science Education, 24(8), 771-783.

Tsai, C. C. (2007). Teachers’ scientific epistemological views: The coherence with instruction and students’ views. Science Education, 91, 222-243.

Tytler, R. (2007). Re-imagining science education: engaging students in science for Australia's future. Australian Council for Educational Research (ACER).

United Kingdom Council for Science and Technology. (2012). Letter of Advice: STEM Education. Retrieved from http://www.bis.gov.uk/assets/cst/docs/files/letters/12-1272-stem-education-letter-to-prime-minister.pdf

von Glasersfeld, E. (1995). Radical constructivism: A way of knowing and learning. London: The Falmer Press.

Appendix One

Chemistry Teacher Inventory (CTI)

Grade: 11

There are 33 items in this questionnaire pertaining to strategies or actions used in the teaching of chemistry. They are statements to be considered in the context of one chemistry class in which you work. Think about how well the statements describe your teaching of chemistry in this class. If you teach more than one class and you believe your teaching is different in this other setting you might consider completing a further CTI for this other setting.

Indicate your answer on the score sheet by circling:

N if you *never* use this strategy in your teaching of chemistry;
S if you *rarely* use this strategy in your teaching of chemistry;
F if you *sometimes* use this strategy in your teaching of chemistry;
O if you *often* use this strategy in your teaching of chemistry;
A if you *almost always* use this strategy in your teaching of chemistry;

If you change your mind about a response, cross out the old answer and circle the new choice.

1.	Students copy notes from overheads without explanations.	N R S O A + 0 -
2	I perform chemical demonstrations.	N R S O A + 0 -
3.	Visual images are used to clarify Chemistry ideas.	N R S O A + 0 -
4	Students plan investigations and then carry out the investigation.	N R S O A + 0 -
5.	Computer-based simulations are used to clarify Chemistry ideas.	N R S O A + 0 -
6.	I explain how chemistry topics relate to students' lives.	N R S O A + 0 -
7.	I talk about the historical development of Chemistry ideas.	N R S O A + 0 -
8.	Students carry out prescribed or set labs.	N R S O A + 0 -
9.	Students do laboratory formal write-ups.	N R S O A + 0 -
10.	Students are provided with pre-written notes and they are discussed.	N R S O A + 0 -
11.	Students are asked to explain what has been demonstrated.	N R S O A + 0 -
12.	Students perform calculations.	N R S O A + 0 -
13.	Students use manipulatives to help understand what is happening at the molecular level.	N R S O A + 0 -
14.	Students are required to know what a formula means before they calculate.	N R S O A + 0 -
15.	Students have to explain chemistry ideas at the molecular level.	N R S O A + 0 -
16.	I use a variety of strategies to get across Chemistry ideas.	N R S O A + 0 -
17.	On tests students perform calculations.	N R S O A + 0 -
18.	Students make notes from textbooks.	N R S O A + 0 -
19.	Students are assigned problems from texts.	N R S O A + 0
20.	Students work together on tasks.	N R S O A + 0 -
21.	Students are expected to explain their results by discussing with their group.	N R S O A + 0 -
22.	I use analogies or role plays to get across chemistry ideas.	N R S O A + 0 -
23.	I check to see if students grasp ideas before moving on to the next topic.	N R S O A + 0 -
24.	I refer to the history of chemistry applications in my teaching.	N R S O A + 0 -
25.	Chemical models are used to help students to learn.	N R S O A + 0 -
26.	Min-labs/short experiments are performed by students.	N R S O A + 0 -
27.	I assess student learning by tests.	N R S O A + 0 -
28.	I give students lots of examples to help assist them in their learning.	N R S O A + 0 -
29.	I get students to work together and help each other on activities & problems	N R S O A + 0 -
30.	I assist students with their work as they request assistance.	N R S O A + 0 -
31.	I use everyday examples to communicate Chemistry ideas.	N R S O A + 0 -
32.	I explain ideas as students copy notes.	N R S O A + 0 -
33.	I assess student learning of student experimental activities.	N R S O A + 0 -

Thanks for completing this questionnaire.