

**AUTHENTIC SCIENTIFIC INQUIRY, STUDENT ENGAGEMENT AND  
TRANSFORMATIONAL LEARNING: ARE THEY RELATED?**

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in Partial Fulfillment of the Requirements for the Degree of Master of Education  
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By

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## Context

This is a manuscript style thesis containing six chapters. The manuscript format for this thesis consists of two manuscripts under preparation to be submitted for publication. The content of these manuscripts are based on research conducted at the University of Saskatchewan and the Canadian Light Source. I am the major contributor and writer of the manuscripts. Due to the nature of a manuscript style thesis, some duplication and overlap of content in the chapters is necessary.

Chapter one introduces the background for the study. Using a literature review I will outline the landscape of science education within which the study takes place including calls for change in science education to include more inquiry oriented and student-based practises. Some of these calls for change push for authentic scientific inquiry, a term that I will define and explain. Another call heard within education is for practises that encourage student engagement with learning. I will define what I mean when I use this term and, using a literature review, identify a framework of indicators to identify and understand engagement. The third part of the landscape for this study is transformational learning. I will use a literature review to define this piece as well. Finally, I will describe the site of investigation, a science outreach program at the CLS called Students on the Beamlines (SotB), and how it fits within this landscape.

The second chapter describes the methods used to conduct this qualitative study. I will outline the sources of data, how they were selected, recorded and organized. The interpretive framework used to analyse data is explained.

Chapters three, four, and five are the basis for manuscripts to be submitted for publication. The first of these, chapter three, is a manuscript written prior to analysing

data. The chapter outlines for the reader some stories from the program that inspired me to investigate the interplay of the landscape outlined in chapter one. I explore the potential impact these outreach experiences seem to have had on participants in the program.

In the fourth chapter, literature reviews are used to develop a framework of indicators of engagement. I used this framework to investigate the extent to which students were engaged during participation in the program. SotB is an example of a science outreach program that enables students to conduct authentic scientific inquiry, thus providing an opportunity to investigate if that has an effect on student engagement. Data provided insight into what contributed to student engagement, and specifically whether participation in authentic scientific inquiry contributed to engagement. Chapter four presents the deeper understanding that I developed from these investigations.

Chapter five explores the interplay between authentic scientific inquiry and student engagement and whether or not possibilities for transformative learning exist within this landscape. I relate the stories revealed in data of where these places might occur.

The final chapter, six, is a summary of discoveries and conclusions drawn from the study. I will present practical suggestions for outreach program developers, teachers, curriculum writers, and research facilities should they wish to develop programs or activities that include elements of authentic scientific inquiry. The chapter also includes a reflection on what I still wonder about regarding student engagement in science education, using authentic scientific inquiry techniques, and transformative learning within this landscape.

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## List Of Abbreviations

AAAS (American Association for the Advancement of Science): an international non-profit organization dedicated to advancing science around the world

CLS (Canadian Light Source): a national science research facility and the site of investigation for this work

CMEC (Council of Ministers of Education, Canada): provides leadership in education at the pan-Canadian and international levels and contributes to the fulfilment of the constitutional responsibility for education conferred on provinces and territories

NRC-A (National Research Council - American): The Research Council's independent, expert reports and other scientific activities inform policies and actions that have the power to improve the lives of people in the U.S. and around the world

NSERC (Natural Science and Engineering Council): NSERC's role is to make investments in people, discovery and innovation to increase Canada's scientific and technological capabilities for the benefit of all Canadians.

NSSE 2000 (National Survey of Student Engagement): an American report issued in 2000.

NSTA (National Science Teachers Association): is the largest organization in the world committed to promoting excellence and innovation in science teaching and learning for all.

SAC (Science Advisory Council): The mission of the SAC is to ensure that present and future scientific programs at the CLS are of the highest quality and relevant to the requirements of the Canadian scientific community, and that they support the mission of the CLS.

SotB (Students on the Beamlines): the educational outreach program developed at the CLS and part of the landscape for this investigation

## Abstract

Students on the Beamlines (SotB) is a unique program offering an opportunity for high school students and their teachers to collaborate with scientists to develop, execute, and share an authentic scientific inquiry using techniques offered by the Canadian Light Source (CLS). Canada's synchrotron is a national science research facility that generates intense beams of x-ray and infra-red light to probe the structure and function of matter. The nature of the SotB program, involving high school students in authentic scientific inquiry, and observation of engaged students provided an opportunity for investigation into these concepts. The purpose of this study was to provide insight into what engaged these students and in particular, to determine if, how and to what extent the authentically scientific nature of the program contributed to student engagement, as well as to determine if, how, and to what extent this unique situation nurtured the potential for a transformational learning experience. To address the research questions qualitative methods were employed to study field notes, correspondence, observations and feedback related to the program and interviews of the student, teacher, and researcher participants. This provided insight into the experiences of the participants that will be of interest to teachers, parents, students, curriculum writers, researchers, funding agencies, outreach program developers, scientific research facilities and others.

Through the analysis of literature, this work produced a list of indicators of engagement and attributes of authentic scientific inquiry. These indicators and attributes were used as a framework through which data were analysed resulting in the refinement of these frameworks. In addition, evidence supported a connection between participation

in authentic scientific inquiry and the engagement of students, although it also suggested other contributions to engagement. There is also evidence to support the presence of transformational learning for some students and teachers. This thesis presents the evidence in the form of a series of manuscripts drawing conclusions useful for those wishing to create similar science experiences for high school students and for science educators.



## Chapter One: Background/Landscape

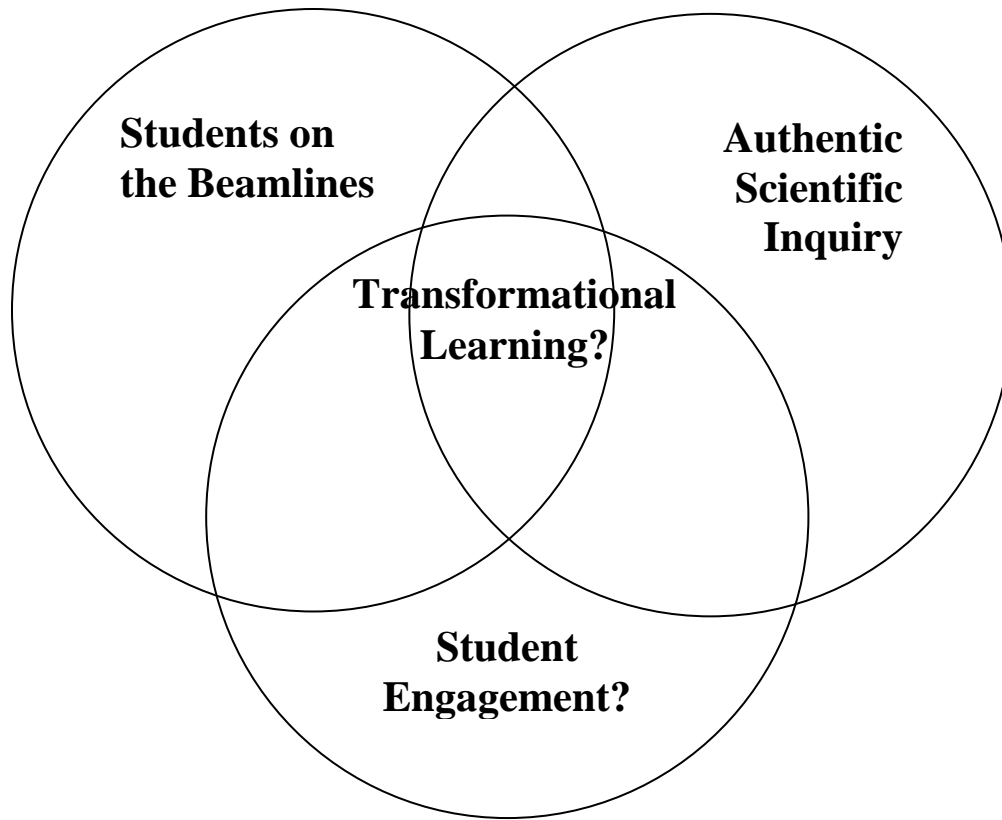
Much is made of the need for society to be scientifically literate in today's world. A quick Internet search for 'need for science education' reveals government, public, education documents, scholarly journal articles, media reports, blogs, and more, all espousing the need for reform in science education. Critics proposed that, "the content of the curriculum is not appropriate for meeting the individual and social needs of people living in the modern world. ... Much of what is taught is not needed in everyday life, and much of what is *not* taught *is* needed in everyday life" (emphasis in original, American Association for the Advancement of Science [AAAS], 2000, p. 3). I am an informal science educator employed at a national research facility. My role is to create educational outreach programs that contribute to the scientific literacy of Canadians, and to encourage young people to consider picking up the torch of science research currently carried by folks such as those who work at and use the facility where I work. I am a former classroom teacher. I have experience teaching every subject area except science and in every grade level except Kindergarten and grade twelve. I do not have any formal training in science or scientific research. My undergraduate degree is a Bachelor of Education with English as my major area of study and both History and Counselling as minor areas. I have always had a passion for sharing whatever knowledge I possess. My passion for teaching and learning stems from the love of watching people as they experience new things, as they grow and develop, as they learn. As a high school student, I was competent in all subject areas but the study of literature and history ignited my imagination and creativity. Science, for me, consisted of memorization and regurgitation of content not related to my life, though I understood its importance. Coming to work at a scientific research facility demonstrated that there was much

passion, creativity and excitement in science. Working with the students and teachers involved in the programs I developed fed my passion for creating learning situations and observing that growth. Graduate studies offered an opportunity to learn about, to investigate this process. This study developed from an opportunity to gain insight into the processes of learning I am inspired by and privileged to be part of.

As with everything, understanding the context of an event or activity helps in understanding that event or activity, therefore, I will paint the landscape within which this study takes place. There are four parts to this landscape: authentic scientific inquiry, student engagement in science learning, transformational learning, and an outreach program called Students on the Beamlines (SotB). Each of these pieces will be defined and explained following the explanation of my research questions.

### *Research Questions*

As these parts of the landscape come together, I wonder what the effects of the interplay between the parts of the landscape will be. I wonder if the intersection of these might result in a place where transformational learning can take place. One might view it in this way:



*Figure 1: Diagram showing intersections within which the study is situated.*

A later section of this chapter will establish SotB as an example of authentic scientific inquiry. Given that perspective, the focus of this study was to explore the nature of participation in such an experience. Specifically, I sought to gain insight into student engagement and transformational learning from the perspective of participation in an authentic scientific inquiry experience situated in an informal science outreach program. My research questions were:

1. Students, teachers, and scientists, that participated in this program were highly engaged.

Given this situation,

- a. How do we know they were engaged? Using indicators of engagement identified in the literature, do the participants (students in particular) demonstrate their engagement?
- b. What engages them (particularly the students)?

- c. Does participation in authentic scientific inquiry affect the engagement of the students?
2. Is there evidence that transformational learning is taking place for any of the student, teacher, or scientist participants?
  - a. If yes, what contributes to the transformational learning considering the landscape of authentic scientific inquiry and student engagement?

During the next few sections I will use literature reviews to define authentic scientific inquiry and student engagement. Following those I provide a description of the SotB program and establish how it is an example of authentic scientific inquiry and thus an appropriate site for this investigation.

### *Authentic Scientific Inquiry*

The criticisms of science education mentioned at the beginning of this thesis are not new. Over several decades professional education communities have encouraged science teaching practises to include a variety of teaching methods. Educational practices have been influenced by reformers including Joseph Schwab, Jean Piaget, and Jerome Bruner who pressed for the inclusion of learning processes in addition to content. There has been a growing demand for teachers to reform their teaching methods (Abbott, 1999; Anderson 2002; Smith, 2007; von Secker & Lissitz, 1999). As April Luehmann and Dina Markowitz (2007) put it:

Current science education reform urges that every student be frequently and actively involved in exploring the natural world in ways that resemble how scientists work (AAAS, 2001; National Research Council [NRC, American],

1996, 2000). The *National Science Education Standards* (NRC, 1996), as well as the American Association for the Advancement of Science's Project 2061 *Benchmarks for Science Literacy* (AAAS, 1993), place significant importance on the development of student's understanding of the process of scientific inquiry. (pp. 1133-1134).

Recently in Canada, the United States, and other countries, organizations and individuals involved with science education have proposed, developed and published various science curricula that identify inquiry as a core feature of school science learning (Abd-El-Khalick, 2004; Aikenhead, 2006; Council of Ministers of Education in Canada [CMEC], 1997; National Research Council [NRC-A], 1996). In this context inquiry is considered both a desirable learning outcome and a process for meaningful science learning (NRC-A, 1996; CMEC, 1997). The concept of inquiry in the science classroom is not a new one. As early as 1909 John Dewey presented to the American Association for the Advancement of Science (AAAS) that science teaching "gave too much emphasis to the accumulation of information ... there is a process or method to learn as well" (Olson & Loucks-Horsley, 2000, p. 14). In their guide to using inquiry in the context of the National Science Education Standards (for the US), Olson and Loucks-Horsley (2000) point out that this call for reform continued to build through the mid-twentieth century as influential educators such as Bruner, Schwab and Piaget added pressure to actively teach science through inquiry instead of having students learn about inquiry that resulted in a emphasis on having students experience inquiry as a learning process rather than focusing on the mastering of subject matter. Canada attempted to heed the calls for curriculum change. The Council of Ministers of Education Canada (CMEC) created a recommended framework for science curriculum development to guide provincial curriculum renewal work. Hart (2002, p.

1240) explained that “reasons for science curriculum change include ... a desire to make science and mathematics more authentic, that is, more genuine and pertinent to students and more like ‘real’ science, as practised by scientists.” An example of implementation of this framework is in Saskatchewan in the 1990/1, the year that a new elementary science curriculum following the CMEC recommendations was implemented. Birnie (1991) documented that the Science Curriculum Advisory Committee relied on the best research available when they formulated the underlying philosophy that “learning is superior if the learner is actively involved rather than sitting passively” (p. 9) and that “this approach leads to an inquiry-based program, in which students, under strong guidance and facilitation by the teacher, are given opportunity to find out some things for themselves.” (p. 9) Despite this, prompts for the inclusion of inquiry processes continued and we find teachers asked to regard themselves less as dispensers of knowledge, transmitting content to students but more like a coach or facilitator where students are active in directing their learning (Anderson, 2002).

The idea of inquiry as a critical component of science education and an important aspect in curriculum reform is echoed often in the science education research literature (Aikenhead, 1986; Bell, Blair, Crawford, & Lederman, 2003; Bencze & Hodson, 1999; Braund & Reiss, 2006; Eick, Ewald, Kling, & Shaw, 2005; Gengarelly & Abrams, 2009; Gibson & Chase, 2002; Hu, Kuh, & Li, 2008; Hume & Coll, 2008; Luehmann & Markowitz, 2007; Markowitz, 2004; McDonald & Songer, 2008; NSTA, 1998; O’Neill & Polman, 2004; Rahm, Miller, Hartley, & Moore, 2003; Robinson, 2004; Short, Lundsgaard, & Krajcik, 2008; Sikes & Schwartz-Bloom, 2009; Windschitl, 2004). In the American National Research Council (NRC) *Standards* document, “the term ‘inquiry’ refers to what students should *understand* about scientific inquiry as well as the *abilities* they acquire and develop in their experiences with scientific inquiry” (as

quoted in DiGuiseppe, 2007, p. 21, emphasis in original). In Canada, these emphases are echoed in the Common Framework of Science Learning Outcomes (CMEC, 1997) that states the need for:

- A science inquiry emphasis, in which students address questions about the nature of things, involving broad exploration as well as focused investigations
- A problem-solving emphasis, in which students seek answers to practical problems requiring the application of their science knowledge in new ways
- A decision-making emphasis, in which students identify questions or issues and pursue science knowledge that will inform the question or issues. (p 4)

Inclusion of inquiry-based practise is accepted and expected. What is difficult to define is what that inclusion might look like at the grass-roots level in the classroom. There is a multitude of ways to meet this expectation. One method is to enable students to experience authentic scientific inquiry. There is literature advocating that science inquiry in the classroom be authentic in nature, using phrases like ‘at the elbow of scientists’, ‘doing what scientists do’, and ‘thinking how scientists think’. Many acknowledge that accomplishing authentic scientific inquiry in classroom practise is much more complex than imitating activities and using similar equipment (Aikenhead 1986; Bell, Blair et al. 2003; Benze & Hodson, 1999; Braund & Reiss, 2006; Campbell, 2006; Carr, 2009; Duschl, 2008; Hume and Coll, 2008; Kalantzis, 2006; Luehmann & Markowitz, 2007; Markowitz, 2004; McDonald & Songer, 2008; O'Neill & Polman, 2004; Sarkar & Frazier, 2008; Schwartz & Lederman, 2008; Stiles, 2004; Windschitl, 2004).

The work of various researchers indicates that teachers have been trying to reform their practices in accordance with curricula that call for the use of inquiry in school science learning

(Aikenhead, 1986; Bencze & Hodson, 1999; Campbell, 2006; Gengarelly & Abrams, 2009; Gibson & Chase, 2002; Minner, Levy, et al., 2009; Osborne, Simon, et al, 2003; Smith, Desimone, et al., 2007; Stuckart & Glanz, 2007). However, achieving this reform remains elusive in classrooms across North America and elsewhere (Abbott & Ryan, 1999; Aikenhead, 1986, 2006; Barmby, Kind, et al., 2008; Bencze & Hodson, 1999; Campbell, 2006; Crawford, 2007; Duggan & Gott, 2002; Eick, Ewald, et al., 2005; Kaiser, 1996; Kalantzis, 2006; National Science Teachers Association [NSTA], 1998; Smith, Desimone, et al., 2007). Crawford (2007) identifies some of the challenges that teachers face, noting that:

Conflicting views of school-based cooperating teachers, school context, student population, subject matter, university teacher education requirements, parental pressures, high-stakes testing, self-confidence, and the nature of prior authentic scientific experiences – all may deflect a teacher’s success in teaching science as inquiry. Research does not provide a clear picture of just how difficult it is to teach science as inquiry. (p. 614)

In a similar vein, Anderson (2002) suggests that another reason for difficulty in implementing more inquiry experiences into school science learning may be that teachers, mired in everyday tasks and challenges, find it difficult to find the creativity required to change their practises. As a result, they are looking for practical ideas that enable them to put inquiry into practise. Rahm, Miller, Hartly, and Moore (2003) argue that there are too many definitions and perspectives of what authentic scientific inquiry is. For the purposes of this study, the term authentic scientific inquiry describes a process of inquiry in a science education setting that closely resembles inquiry conducted within a professional science setting. A review of the



literature cited above provided a list of five essential elements for a school-based activity to be considered authentic scientific inquiry:

1. Student involvement in formulating the question
2. Open-ended inquiry where the answer is unknown
3. Student involvement in gathering and analyzing data
4. Collaboration
5. Communication of outcomes

*Students are involved in formulating the question.*

Several studies indicated that involving students in the design of the inquiry is a key part of authentic scientific inquiry. Gengarelly and Abrams (2009) described science education as a “window on how scientific knowledge is constructed” (p 75). Their model, borrowed from Bell, Blair, et al.(2003), described four levels of authentic scientific inquiry dependent upon the amount of direction provided by the teacher in three key areas: determining the question, the methods to answer the question, and whether or not the solution to the question was known. The model established the lowest level of authentic scientific inquiry as a “cookbook” approach, where the teacher provided the question, instructions to gather information, and the answer to the inquiry. The highest level of authentic scientific inquiry was fully student directed with an unknown outcome. As the level of authentic scientific inquiry increased, the amount of teacher direction decreased. In Gengarelly and Abrams’ publication, development of the question was the last direction to be transferred from teacher to students and was included in only the highest levels of authentic scientific inquiry.

According to Short, Lundsgaard, and Krajcik (2008) inquiry had several features, but authentic scientific inquiry exhibited an over-arching question that drove the structure and content of the curriculum; where the question was meaningful to the students' lives; contextualized the content; allowed for sustained and deep exploration; and allowed for various investigations to find a solution so that the participants in the research could generate their own question or sub-questions. A study conducted by Hume and Coll (2008) identified various aspects of authentic inquiry including an open-ended question, data collection, collaboration, and communication. In their work the inquiry question was developed specifically for the study, not by the students. The purpose of their study was not focussed on the outcome of the inquiry students were conducting, nor to the processes of inquiry as a learning outcome, but to determine if the students were learning what the curriculum intended through an inquiry process called fair testing. The students understood that assessment was the key activity and this understanding "reduced students to following a set of rules and procedures which they learned in practice assessments" (p. 1218). As a result, Human and Coll reported, the inquiry conducted by the students was not meaningful to them. They connected part of the reason to the lack of contribution to the design of the question by the students and, in this regard, might not be considered authentic scientific inquiry. Sarkar and Frazier (2008) stated that, "When a question is formulated by students, the degree of engagement is greater and the learning is more authentic" (p. 30). They suggested that student involvement in the design of the inquiry question was essential for the participants to experience authentic scientific inquiry.

*Open-ended inquiry, where the answer is not known.*

Another key element in authentic scientific inquiry included conducting experiments or inquiries where the outcome is not known, where it is possible for the outcome of the inquiry to produce novel information. In the study conducted by Gengarelly and Abrams (2009), researchers raised the level of authentic scientific inquiry by removing the solution to the problem students were seeking to resolve. This indicated that open-ended inquiry is basic to authentic scientific inquiry. Stiles, in *I LOST the Answer Key*, (2004) provided an example of the effect that an open-ended inquiry could have. His story related how the motivation of students increased as a result of the answer key to their lab activity being lost. Determined to satisfy their desire to be confident they knew the correct answer, students devised additional tests, compared results with each other, and repeated tests, before announcing they knew the “right” answer. All of these activities are consistent with attributes of authentic inquiry.

With the similar goal of understanding how inquiry unfolds, O’Neill and Polman (2004) followed three classes through differing forms of inquiry-based instruction. They also noted that when students formulated their own inquiry questions, where the outcome or solution was not predetermined, students became more empowered and motivated. The work of these researchers suggested that the use of open-ended inquiry, where the answers to the questions are not known to the learners, is a necessary component of authentic inquiry.

While each of these article are examples of inquiry where the students did not know the answers, the students were not producing novel information. In a professional scientific inquiry the purpose is to produce novel information. In the SotB program, this is also the goal.

### *Student involvement in gathering and analysing data.*

Emulating the work of scientists by gathering scientific data using similar methods as well as making sense of data collected, is a cornerstone of science education curricula. Most of the literature reviewed in this thesis indicated gathering and analyzing data as an essential element to authentic scientific inquiry. Windschitl (2004) explained how some of the classroom-based practices differ from authentic scientific inquiry. His work pulled from several North American curriculum development documents that encourage students to participate in “activities that characterize the pursuits of scientists” (p 481). ‘What scientists do’ was connected to laboratory activities and equipment. An expectation was that students will gather and analyse data as well as become familiar with equipment and procedures. He proposed more to authentic scientific inquiry than a list of equipment and ‘things to do,’ however, habits of mind and thoughtful consideration of how to put these activities and equipment to use were considered important to the authenticity of the activities. As an example, consider Windschitl’s inclusion of the necessity of multiple data points and the possibility of altering the questions or design after the study begins in his list of activities congruent with authentic scientific inquiry. These are activities common in ‘what scientists do’ but less often in ‘what students do’ in the classroom as they are leaning science.

### *Collaboration.*

Engaging in authentic scientific inquiry is rarely done in complete isolation. Work conducted by Hume and Coll (2008) indicated that successful inquiry depends on the ability of researchers to draw on appropriate and relevant information, thus collaboration with subject or content experts is required. This does not change when students conduct authentic scientific

inquiry. Short, Lundsgaard and Krajcik (2008) proposed that teachers could “help create an authentic scientific atmosphere in the classroom as students have scientific discussions within smaller groups and between groups” (p. 39). Collaboration with peers, experts, and others who have necessary resources is an integral component to authentic scientific inquiry.

*Communication of the findings or results of the analysis.*

Knowledge is embedded culturally in how that knowledge is shared from generation to generation. If students are to engage in authentic scientific inquiry, their novel knowledge must be shared if it is to be considered part of an authentic scientific inquiry. Several articles identified the expectation of communicating the outcomes of inquiry activities as important (O’Neill & Polman, 2004; Slayton & Nelson, 2005; Short, Lundsgaard, et al., 2008; Sikes & Schwartz-Blum, 2009). Not only is this an essential part of an authentic scientific inquiry, but these researchers also identify it as important for keeping high school students focused and organized, particularly if the inquiry extends over a long period of time.

Considering suggestions derived from the literature reviewed above, I have identified five elements as essential for a school-based research activity or experiment to be considered authentic scientific inquiry. Students must be involved in each of the following activities

1. Involvement in development of the question
2. Open-ended inquiry, where the answers are unknown and there is potential to produce novel information
3. Gathering and analyzing data
4. Collaboration
5. Communication of outcomes

In a later section of this chapter I will establish how the SotB program, considering these five elements, is an example of an authentic scientific inquiry. This perspective provides the lens through which student engagement and transformational learning is viewed. Before that, I must define what student engagement is and ‘looks like’.

### *Student Engagement*

Student engagement is accepted as a fundamental part of learning (Peters, 2010; Pickens & Eick, 2009; Tytler, Symington et al., 2011; Zyngier, 2008) and there is interest in developing a richer understanding of when and in what ways engagement plays a part in learning (Butroyd, 2008; Cooper, Bronwen et al. 2010; Shernoff, Csikszentmihalyi et al., 2003). According to Kuh (2009), “The engagement premise is straightforward and easily understood: the more students study a subject, the more they know about it” (p. 5). The US National Report on Student Engagement stated that “engaged students were involved in their school work in more than a superficial way that signified some level of commitment (p. 5)” (as quoted in McMahon 2003, p. 259). Engagement as Zyngier (2008) noted, “is difficult to define operationally, but we know it when we see it, and we know it when it is missing” (p. 1765). Definitions in the literature can be very simplistic, very general, vague in some literature such as Libbey’s (2004) definition of engagement, “the extent to which students are motivated to learn and do well” (p. 278). But various scholars indicated that there are certain behavioural and emotional realities present with engagement that hint the definition is more complex (Fredricks, Blumenfeld et al., 2004; Hudley, Daoud et al., 2003; Kuh, 2001; Libbey, 2004; Nystrand and Gamoran, 1989; Patrick, Ryan et al., 2007; Robinson and Hullinger, 2008; Skinner, Kindermann et al., 2009), typified best perhaps by Schlechty (2002) who suggested, “engaged students see meaning in what they are doing ... When

students are ... engaged, the distinction between ends and means become blurred" (p. 10). This blurring of ends and means show, as Fredricks (2004) outlined, that engagement is a complex, multi-faceted metaconstruct that involves behavioural, emotional, and cognitive aspects, each of which could be subdivided and studied in relation to the other.

Given the range in how engagement is understood, for the purposes of this study, an engaged student is defined as one that demonstrates several or all of the complex behavioural, cognitive and physical indicators outlined in the literature review below.

*Indicators of engagement.*

Having offered a working definition of engagement, there is a need to identify more succinctly what is involved to allow for closer examination of the experience of participants in the SotB program and to determine to what extent participants might be engaged and in what manner. While observable behaviours of engagement might be the simplest to recognize, many of these authors attest that they are only part of what an engaged student is doing. Table 1 provides descriptions of engagement within the literature.

*Table 1: Indicators of Engagement: Students who are engaged ...*

<b>Author</b>	<b>Behavioural</b>	<b>Emotional</b>	<b>Cognitive</b>
<b>Nystrand (1989)</b>	<ul style="list-style-type: none"> <li>• ask questions</li> <li>• sustain rapt attention for a long period of time</li> </ul>		<ul style="list-style-type: none"> <li>• ask higher order questions</li> <li>• sustain commitment to the content</li> </ul>
<b>NSSE 2000 Report</b>	<ul style="list-style-type: none"> <li>• ask questions; contribute to discussions</li> <li>• preparing for class</li> <li>• work with classmates outside</li> </ul>		<ul style="list-style-type: none"> <li>• tutor or teach other students</li> <li>• use higher-order thinking skills</li> </ul>

	<ul style="list-style-type: none"> <li>of class</li> <li>discuss ideas with others</li> </ul>		
<b>Schlechty (2002)</b>	<ul style="list-style-type: none"> <li>are willing to do menial tasks</li> </ul>	<ul style="list-style-type: none"> <li>see meaning in what they are doing</li> <li>display either acceptance/resignation or enthusiasm/commitment</li> </ul>	<ul style="list-style-type: none"> <li>connect task-related behaviour to end of significant consequence</li> <li>value the activity</li> </ul>
<b>Hudley (2003)</b>	<ul style="list-style-type: none"> <li>persist</li> <li>have a high rate of task completion</li> <li>suffer few discipline problems</li> </ul>	<ul style="list-style-type: none"> <li>exhibit enjoyment of tasks</li> <li>are intrinsically motivated</li> <li>show a positive attitude towards activity and achievements</li> </ul>	<ul style="list-style-type: none"> <li>persist</li> </ul>
<b>Shernoff (2003)</b>	<ul style="list-style-type: none"> <li>display concentrated attention (Newman 1992)</li> </ul>	<ul style="list-style-type: none"> <li>display interest and enjoyment (Newman 1992)</li> <li>have a sense of commitment and belongingness (Christenson, 2001)</li> </ul>	
<b>Fredricks (2004)</b>	<ul style="list-style-type: none"> <li>do the work</li> <li>follow the rules</li> <li>demonstrate effort; persistence</li> <li>display concentration; attention</li> <li>ask questions; contribute to discussions</li> </ul>	<ul style="list-style-type: none"> <li>like or deeply value or identify with activity</li> <li>display affective reactions</li> <li>show an appreciation of success</li> </ul>	<ul style="list-style-type: none"> <li>use strategies that promote a deep understanding</li> <li>desire to go beyond requirements</li> <li>prefer a challenge (more than just behavioural engagement)</li> </ul>
<b>Libbey (2004)</b>	<ul style="list-style-type: none"> <li>sustain commitment</li> <li>follow rules &amp; regulations</li> </ul>	<ul style="list-style-type: none"> <li>take ownership</li> </ul>	<ul style="list-style-type: none"> <li>ask authentic questions</li> </ul>
<b>Patrick (2007)</b>	<ul style="list-style-type: none"> <li>display task-related interaction</li> </ul>	<ul style="list-style-type: none"> <li>are concerned with developing competence</li> <li>display academic efficacy</li> </ul>	<ul style="list-style-type: none"> <li>use self-regulation strategies</li> </ul>
<b>Robinson</b>	<ul style="list-style-type: none"> <li>practise, obtain feedback</li> </ul>	<ul style="list-style-type: none"> <li>display effort</li> </ul>	<ul style="list-style-type: none"> <li>expend time and physical</li> </ul>



<b>(2008)</b>			<ul style="list-style-type: none"> <li>energy</li> <li>analyse &amp; solve problems</li> </ul>
<b>Zyngier (2008)</b>	<ul style="list-style-type: none"> <li>do the work</li> <li>follow the rules</li> <li>persist, participate</li> <li>take the initiative (Finn, 1989)</li> </ul>	<ul style="list-style-type: none"> <li>show interest</li> <li>show positive feelings towards school, the class and teacher</li> <li>value outcomes (Finn, 1989)</li> </ul>	<ul style="list-style-type: none"> <li>display psychological investment</li> <li>are motivated</li> <li>exert effort</li> <li>display strategy use</li> </ul>
<b>Kuh (2009)</b>	<ul style="list-style-type: none"> <li>spend time on task on learning (Tyler, 1930)</li> <li>prepare for class</li> <li>Ask questions in class or contribute to class discussions</li> <li>Work with other students on projects during class</li> <li>Work with others outside class</li> <li>Discuss ideas from readings or classes with others outside class</li> </ul>	<ul style="list-style-type: none"> <li>interact with their peers and teachers about learning (Pace, 1990)</li> </ul>	<ul style="list-style-type: none"> <li>show quality of effort (Pace 1990)</li> <li>Work harder than anticipated to meet an instructor's standards or expectations</li> </ul>
<b>Skinner (2009)</b>	<ul style="list-style-type: none"> <li>display focused, on task behaviour</li> <li>show effort; persistence</li> </ul>	<ul style="list-style-type: none"> <li>display enthusiastic participation</li> <li>have enthusiasm, interest, enjoyment</li> </ul>	<ul style="list-style-type: none"> <li>are constructive</li> <li>exert mental effort (attention/concentration)</li> </ul>
<b>Wishart (2009)</b>	<ul style="list-style-type: none"> <li>have generic skills of learning</li> </ul>		<ul style="list-style-type: none"> <li>exhibit high metacognitive control</li> </ul>

Sifting through the literature summarized in the table above, I have distilled the common threads within the various descriptions to a list of specific behaviours that indicate a student is engaged. These indicators were used as the basis to identify the extent to which students were engaged for this study. Students who are highly engaged display the following attributes:

1. Persistence: the learner is persistent in seeking answers and overcoming challenges
2. Dedication: the learner provides a dedicated effort both physically and cognitively
3. Motivation: the learner establishes that the desire to participate is generated internally and not imposed upon from someone or somewhere else
4. Ownership: the learner demonstrates a sense of responsibility towards ensuring success
5. Participation: the learner displays enthusiasm during all or most aspects of the activity
6. Value: the learner indicates that the activity is worthwhile
7. Contribution: the learner asks high level questions or participates in discussions at a high cognitive level

These seven indicators of engaged behaviour form part of the landscape within which this study took place. These are the tools used to measure the level to which participants in SotB were engaged. The next sections provide two more pieces to the landscape of this study. I will define transformational learning experiences and then provide a description of the program, establishing how SotB can be considered authentic scientific inquiry.

### *Transformational Learning*

Since a focus of this study was to gain insight into transformational learning from the perspective of participation in an authentic scientific inquiry experience situated in an informal science outreach program one must explore what is in the literature to define transformational learning. It is worthy to note that current organizational change literature differentiates between transformative learning and transformational change as, “transformative learning, which focuses on change on the individual level, and transformational change, which focuses on organizational change” (Henderson, 2002, p. 186). The theory of transformative learning is a cornerstone in the

field of adult education. Foundational ideas and writing appear as early as 1978 with the work of Jack Mezirow (Imel, 1998). Mezirow (1997) defined transformative learning theory as:

the process of effecting change in a *frame of reference* ... associations, concepts, values, feelings, conditioned responses – frames of reference that define their life world ... When circumstances permit, transformative learners move toward a frame of reference that is more inclusive, discriminating, self-reflective, and integrative of experience. (p. 5, emphasis in original)

Imel (1998) subdivided transformation into two levels, “perspective transformation is the process of becoming critically aware of how and why our assumptions have come to constrain the way we perceive, understand, and feel about our world” (Mezirow, 1991, as quoted in Imel, 1998, p. 2). Imel pointed out that this happens in learning frequently and routinely but, “perspective transformation leading to transformative learning, however, occurs much less frequently” (Imel, 1998, p. 2). Mezirow (1997) also differentiated between a frame of reference (or habit of mind) and a point of view. One can consider slight changes in assumptions associated with a point of view or try on another’s point of view. If critical reflection of the experience reveals the originally held point of view to be inaccurate, that point of view is relatively easily changed. Repeated changes to similar points of view may lead to transformation. These repeated adjustments or a significant experience might make one aware of a habit of mind, and if critical reflection results in changing that habit of mind, a transformational learning experience may occur. “Such epochal transformations are less common and more difficult” (p. 7). Critical reflection on one’s assumptions, attitude, beliefs, habits of mind, and meaning schemes is necessary for a transformational learning experience to take place (Carson & Fisher, 2006; Cranton, 2002; Imel, 1998; Mezirow, 1997). Kreber (2006) uses a problem solving metaphor to

show a distinction between three types of reflection: (a) content or a description of a problem to reflect upon, (b) process or a method of problem solving, and (c) the premise upon which the problem is predicated.

While far from comprehensive, this review of some of the literature offers a definition of a transformative or transformational learning experience for the purposes of this study. A transformational learning experience is one where a participant's point of view, perspective, or habit of mind is challenged through their experience. If, upon reflection, that point of view, perspective or habit of mind shifts or changes, one can assume that the participant underwent a transformational learning experience. For the purposes of this study, two categories of transformational learning were considered, perspective transformation and epochal transformation. A perspective transformation was considered to have been present when assumptions were challenged and changed. Epochal transformation was considered to be present if a significant change was noted, similar to Mezirow's description mentioned above.

#### *Indicators of transformational experiences.*

Having provided a definition, to determine if and to what extent transformative learning might take place, indicators that help identify transformative learning would be useful.

According to Carson and Fisher (2006), an analysis of a person's writing can reveal transformative learning. There are three main features to this writing:

- Identification of values, beliefs or assumptions
- Changing and/or reassessing values, beliefs and assumptions
- Making connections with cultural, social, and political realities (p. 707)

Additionally, “an important indicator of transformative learning is the change that occurs in behaviours” (p. 711). Their study showed that acting differently from habituated responses and/or taking on new behaviours also indicated a transformative learning experience. Other indications of transformative learning were identified by Kreber (2006). While Kreber’s study focussed on university teachers, several indicators that, if modified, could be appropriate for teacher participants in this study. These indicators included: experimenting with alternative teaching approaches; writing critiques on “how-to teaching books”; writing an article on how to facilitate learning in the discipline and submit it to a scholarly journal; presenting findings from classroom teaching experiments at teaching-related sessions at conferences; and showing how goals of one’s teaching relate to what students need to live successful lives.

For this study, I needed to identify evidence of transformational learning. Therefore a list of indicators was developed based on the literature (outlined in Table 2).

*Table 2: Indicators of Transformational Experiences*

<b>Perspective Transformation</b>	<b>Epochal Transformation</b>
<ul style="list-style-type: none"> <li>• Participant becomes critically aware of assumptions</li> <li>• Participant reflects upon challenges to those assumptions</li> <li>• Participant changes assumptions and associated points of view</li> </ul>	<ul style="list-style-type: none"> <li>• Participant changes a frame of reference, or world view</li> <li>• Participant changes behaviour in accordance with either a perspective transformation or a change in world view</li> </ul>

A transformational experience, for this study, is considered to have occurred if data indicated that they had experienced a shift or change in assumptions or perspectives. In essence data would show that the participant was or became aware of their assumptions, reflected upon them and changed those assumptions or points of view as a result. This would be considered perspective transformation, identified earlier in this review by both Mezirow and Imel as what happens often and is a natural part of the learning experience. Epochal transformation as identified above by Mezirow, involves much more significant change and could be identified by the participant as change in a frame of reference or world view. This epochal transformation could also be identified through a change in the behaviour of the participants such as Kreber's example of a teacher participant experimenting with alternate teaching techniques.

Three parts of the landscape have now been brought into focus: authentic scientific inquiry, student engagement, and transformational experiences. These parts are the backdrop for the stage upon which the activity takes place. The next section provides the script for the play, a description of the informal science outreach program, *Students on the Beamlines*.

### *Students on the Beamlines Program Description*

In addition to being a graduate student of curriculum studies at the University of Saskatchewan, I am the Educational Outreach Coordinator for the Canadian Light Source (CLS) where *SotB* takes place. The CLS is Canada's only synchrotron research facility employing extremely brilliant infrared, ultra-violet, and x-ray light to probe the nature and structure of matter. As a national research facility, part of CLS' mandate is to participate actively in the educational development of our communities. My role is to create programs that support educational efforts, showcasing contributions that synchrotron techniques have made and are

capable of making to science research. As an educator, it is important to me that these programs are in keeping with current science curriculum trends and sound pedagogical practises.

The purpose of the SotB program is to provide an opportunity for high school students to experience authentic synchrotron scientific inquiry. For the CLS, the hope is that students become involved in science, to perhaps, consider scientific research as a career, or at least to come to a better understanding of scientific research. Educationally, I hope the program offers students and teachers the opportunity to experience authentic scientific inquiry so that they come to a better understanding of what science research entails which will, in turn, enrich their appreciation for scientific research when they interact with it on a daily basis. For the scientists that participate, I hope they come to a better understanding of what is involved to engage young people and support educational efforts.

As a first step to participating, teachers from across Canada are invited to attend a professional development workshop at the CLS. Those that attend have the opportunity to bring their students back to the facility to participate in SotB. At this workshop teachers are able to participate in synchrotron experiments similar to those their students might be able to conduct, as well as to become familiar with many aspects of synchrotron research such as safety protocols; physics concepts involved in manipulating high energy electrons to produce light; understanding techniques involved in several applications employing synchrotron radiation; exposure to research stories in environmental, materials, and life science research. The CLS hopes that these teachers will extend their enthusiasm and knowledge to their students whether or not they participate in SotB. There is a significant commitment on the part of the teacher to undertake the adventure of this program in terms of time, travel, and in helping students to experience something that the teacher is unlikely to have expertise in (synchrotron research).

The full process of participation takes place over the course of a school year. In the fall a topic is determined that is of interest to the students and that also has potential to generate novel information using synchrotron techniques. Students embark on their adventure by learning as much about the topic as possible so they are prepared to work with CLS staff in developing an experiment. In an ideal situation, the results of the student project would make a novel contribution to society's scientific knowledge. Later in the school year, students spend a minimum of three days at the CLS to conduct their experiment. The first day is spent in orientation including safety training. The facility is roughly the size of two football fields with multiple and varied experimental stations in operation and requires some getting used to before students are able to focus on their scientific pursuits. Students also need to become familiar with the equipment they will be using and finalize any sample preparation that could not be completed prior to their arrival. In most cases the students and the scientists assisting them will have had some contact prior to arrival but a trusting and collaborative relationship needs to be developed. The program is built on the assumption that the adults involved, including teachers, scientists and other supervisors, function as advisors and knowledge experts, but that the experiment belongs to the students. This means that students are responsible for making decisions (upon the advice of the experts) and providing direction for the experiment.

Beamtime at the CLS is distributed in eight hour shifts. SotB groups typically receive a single shift, though that number may vary with the technique they are using and the amount of time available in the schedule. During their shift, students set up the experiment and gather data to answer their questions. There is often a significant amount of time where the students are merely waiting for data to be recorded. This provides opportunities for students to learn more about their experiment, the synchrotron technique, and the possibilities for follow-up



experiments. As each data set becomes available, students try to make sense of the information and determine how to set up the next step. This initial data analysis is usually heavily supplemented by the scientist(s) at the beginning but less so as the students gain experience and confidence. Significant responsibility and authority is given to the students as they determine the direction of their experiment. Once their allotted beamtime is used, students spend a day reviewing their data to determine what conclusions they might be able to come to with this new information. At the end of this day students are asked to make a presentation to interested CLS staff explaining their findings and outlining what they've learned through their experience. During the remainder of the school year students are also expected to present their scientific findings to the CLS' synchrotron user community by preparing a short article and a poster to be presented at the Annual Users' Meeting in June. It is common for these groups of students to also be invited to make presentations in their communities to classmates, teachers, school student body, division personnel, and others. It is also quite common for there to be some media interest generated by the visits of these students.

There are several aspects of this program that make it unique and special for high school students. First, the CLS is the only synchrotron to allow high school students to conduct experiments alongside staff and users at the facility. While there are facilities that have robust outreach programs including collaborative work, no others allow students to work directly on the synchrotron experimental stations. Second, these are not demonstration experiments. A cornerstone of the program is the expectation that the experiments proposed must, if successful, provide novel information that has potential to be published in the scientific community. Third, while the process is collaborative between students, teachers, and researchers, and all participants own the novel information, it is the students who take the lead. Last, students

experience the full scientific process, including (a) narrow the focus of the experiment to something achievable through synchrotron techniques, in the very limited time allotted, (b) gather or prepare samples, (c) gather, and analyze their own data, (d) present conclusions drawn to the scientific community, their peers, and the society at large.

My interest in discovering the extent of the effect of this program began with the observation of the level to which these students, teachers, and researchers became involved in the experiments they were conducting and the rich experience that became apparent in their comments during the experience, “This experience taught me the real scientific method, not like the one we learn in school where you know the answer before you start” and “the project did not just foster knowledge about the synchrotron, electron-orbitals ... but many other practical skills that are needed in all fields of study and careers such as decision-making, preparation, time management and focus” (Walker, 2008). In some cases, students with years of investment in other extracurricular activities withdrew from those activities to pursue this experience. As a direct result of observing the experience that her SotB group had at the CLS, one teacher declared that she would change the way that she presented labs in her classroom to incorporate more opportunities for students to design their own experiences. In spite of the unexpected amount of time and effort involved in supporting these high school groups, several of the CLS staff agreed to work with students again. There must be reasons for this willingness as the time and effort required is above and beyond their regular workload. It seemed to me that this experience had a significant effect on those participating and merited further investigation and so embarked on my own adventure of inquiry resulting in this thesis.

Having laid out a third piece of the landscape of this study, the SotB science outreach program, it remains to tie two pieces together. The following table outlines how participating in SotB can be considered an authentic scientific inquiry experience:

*Table 3: Similarities between authentic scientific inquiry and requirements of SotB program development.*

<b>Authentic scientific inquiry (literature)</b>	<b>Students on the Beamlines program requirements (Walker, 2008; 2011)</b>
Involvement in the design of the inquiry or formulation of the question or hypothesis	<ul style="list-style-type: none"> <li>• Students must be involved in the design of the experiment</li> <li>• changed from CLS staff designed (2008)</li> </ul>
Open-ended inquiry, where the answer is not known	<ul style="list-style-type: none"> <li>• The experiment is not to be demonstration. The answers to the questions must be unknown (2007)</li> <li>• Program is open to all students curious about science; not restricted to specific academic skills (2009)</li> </ul>
Gathering and analyzing data	<ul style="list-style-type: none"> <li>• Analysis &amp; presentation of findings are added to sample preparation &amp; data collection (2009 )</li> <li>• Sample collection and/or preparation is to be completed by students whenever possible (2010)</li> </ul>

	<ul style="list-style-type: none"> <li>• Students shall operate beamline software, hardware is at the discretion of the beamline scientist. (2011 )</li> </ul>
<p>Communication of conclusions, findings or results of the analysis</p>	<ul style="list-style-type: none"> <li>• Students create a scientific poster for display (2007)</li> <li>• Students invited to make a presentation to CLS staff and encouragement to present at their school and/or in their local community (2008 )</li> <li>• Student written articles published where possible, peer-reviewed journals encouraged; CLS website and other documents where appropriate (2008 )</li> <li>• Results are owned and shared by both students and scientists (2010)</li> </ul>
<p>Collaboration</p>	<ul style="list-style-type: none"> <li>• Students must be interested in the results of the experiment (2008)</li> <li>• Results are expected to be novel and contribute to the scientific research community (2008)</li> </ul>

Having described the landscape of authentic scientific inquiry and student engagement where a science outreach program is situated, an investigation into what that experience has been for participants unfolds in the next few chapters. I will relate if students were engaged, if so,

what engaged them, and if experiencing authentic scientific inquiry had an effect on that. I will explore if the authentic scientific inquiry and student engagement pieces of the landscape created a place where it might be possible for a transformational experience. Finally, there will be a summary of discoveries and conclusions drawn from this investigation with practical suggestions for science educators, curriculum developers, and scientific research facilities hoping to design similar programs.

## Chapter Two: Methods

### *Introduction to methods used*

In choosing a methodology for research Annells (1997, as cited in Fassinger, 2005) advised researchers to consider (a) the philosophical underpinnings of the research, (b) epistemological and ontological assumptions of the researcher, and (c) the intended product of the research, as the choice of methodology should be closely linked to the researcher's philosophical underpinnings (Creswell, 2007, Denzin & Lincoln, 2003, Mabry, 2007). My epistemological foundations reside within constructivist philosophy. In agreement with Dewey and Piaget, my understanding is learning, in essence, is experiential. Each individual constructs his or her knowledge by making sense of each new experience and incorporating that into his or her personal knowledge (Posner, 2004). Mabry (2007) extended this concept and explained that perception is personally constructed by each individual as she or he absorbs the building blocks of each experience. I also agree with Armstrong's (2002) presentation of Vygotsky and Piaget's perspective that personally significant knowledge is socially constructed through shared understandings. Adding a dimension to these underpinnings, I am a story teller and as such find a connection with Clandinin, Pushor, and Murray Orr's (2007) perspective that we live storied lives and that we tell and retell those stories as we make meaning from our experiences and connect with others. So, with these philosophies as the foundation, I present the purpose and intended product of this study. I wished to explore the personal experiences of students, teachers, and scientists who participated in the SotB outreach program of which I am an integral part. I search for a rich understanding of stories, of experiences, and of the effect these may have had on the lives of those with this shared experience. The purpose of this work is to offer such

understanding of a specific experience to those who may find it useful as they develop other science education activities. Considering what I have outlined and explained above, it seemed to me that qualitative research was the natural choice.

Qualitative research is multimethod in its focus, involving an interpretive, naturalistic approach to its subject matter. This means that qualitative researchers study things in their natural settings, attempting to make sense of, or interpret, phenomena in terms of the meanings people bring to them. (Denzin & Lincoln, 2003, p. 31)

I employed a qualitative research approach involving the analysis of

- several text-based documents: program reports, non-peer reviewed articles, and media reports, among others;
- field notes: in the form of anecdotal notes I collected during the progress of each group's experience;
- my personal correspondence with students and teachers during the course of their participation in the program;
- feedback evaluation surveys that were routinely sent to all participants as part of the program; and
- ten semi-structured interviews of students, teachers, and scientists.

This section will describe the details of how this information was collected, how interview participants were selected, and how data were analyzed.

## *Data Collection*

### *Correspondence.*

Beginning with an intense three-day professional development workshop, teachers who brought their students to participate in SotB were in close contact with me for approximately a year. Correspondence included email, telephone, and video links such as video conference or Skype™. Once a project was started, a CLS scientist also joined the correspondence and eventually, depending on the culture and regulations of each school, students joined in as well. In some cases all correspondence with students was directed through the teacher. Through these conversations directly, through email or conference call, or indirectly, such as through notes or follow-up emails to telephone or video correspondence, we developed a strong personal relationship as well as plan for a scientific exploration. These conversations often revealed insights into the participants' experience.

### *Documents.*

Not unexpectedly administration of an outreach program generated a number of documents that provided insight into the participants' experience. Students were expected to collaborate to make presentations and to produce a poster communicating both the scientific findings of the inquiry as well as documenting their experience. Student presentations were also video recorded. In addition, each group was asked to write a short article for CLS' Annual Activity Report. A few of the student groups, as well as I, had the opportunity to publish in peer reviewed conference proceedings. Reviews or summaries of the program written by myself and others for the CLS management and other interested parties, such as the Board of Directors and CLS funding agencies, were generated periodically. These documents provided quotes from



participants, collaborators, and observers of the program. When used, these are cited as documents and included in the reference section.

*Media Accounts.*

Several SotB groups enjoyed attention from the media, both locally and nationally. Each newspaper clipping, documentary, and several of the television and radio interviews/reports were recorded and saved. These provide data that were cited appropriately and included in the reference section.

*Feedback surveys.*

A routine part of program development involved gathering feedback from participants. While these surveys focused on determining what elements of the program required revision for improvement, they were also designed to gather data necessary for CLS reports for funding agencies and stakeholders and thus asked some questions pertinent to this study. Not all participants received the same survey. Initially there was a single survey distributed at the end of the experience. Subsequently I developed a 'before' and 'after' survey to address questions asked in funding reports required by NSERC PromoScience. These surveys are included as Appendices 1, 2 and 3.

*Field Notes.*

Throughout my participation with each SotB group, I continually took field notes. I wrote down comments from the participants and observers that seemed relevant to their learning or understandings at the time. I made observations, comments, and reflections about the experience concerning myself and what I thought was happening for the participants.

### *Interviews.*

Ten participants were interviewed: three teachers, three scientists, and four students. Following protocols approved by the University of Saskatchewan, Board of Ethics, these interviews were recorded and transcribed. Transcriptions were reviewed by the interviewee for accuracy and edit prior to analysis. The interviews were semi-structured, beginning with the same set of questions (see Interview Protocol in Appendix 3), but allowing flexibility for me to probe where it seemed more insight and a richer explanation could be gained from further questioning.

The pool of potential participants for this study included volunteers from the participants of SotB from 2007-2010, a total of 119 high school students, 23 teachers or informal science educators, 11 CLS scientific staff, and seven subject expert scientists, totalling 18 scientists. I narrowed the list of possible student participants to those who had agreed to participate in their feedback survey and who had graduated from high school. This allowed me to contact them directly to request their participation. I narrowed the pool of potential participants in this manner believing that students who had completed high school might be better able to provide a sense of how the experience affected them against the background of additional life experience and the distancing of time and place from their cooperating teacher, and that this might allow them to talk more freely about their experience. I further narrowed the pool of possibilities by eliminating those students employed at CLS with whom I had a supervisory relationship. In my search for participants I considered a balance of males and females; those living near to and far from CLS; those who had recently participated and those who would have participated several

years ago. Of 14 students who provided contact information on their surveys, six met the aforementioned considerations, and four agreed to be interviewed either in person or via Skype.

I contacted five scientists with a request to be interviewed. My selection was based on choosing scientists who had participated with more than one group of students and who had not been part of the development of the program including both CLS staff and scientists that collaborated as subject experts. I felt that scientists involved with more than one student group could offer a richer explanation of their perspectives as they compared one experience with another. Scientists involved in program development would have different experiences than those participating purely for inquiry collaboration, and while valuable, for this study, I was interested in the experience of the collaborator. The first three of these to agree were interviewed.

Similarly, I selected four teachers taking care to balance distance, time, and gender from those who had expressed a willingness to participate. I did this because I hoped they would be free, open, and reflective in their responses to the interview questions and so provide a rich source of insight into the experience. Three were interviewed.

To simplify the citation of quotations from several of these sources and to aid in the location of the quotes within the original documents, if necessary, a code was developed. First the speaker is identified as a teacher, the abbreviation is T; if a student then, ST; scientist, SC; and if the comments are mine, my initials TW indicate that. Interview quotations are abbreviated as I with a number indicating which interview the quotation is taken from. So a citation of ST-I-5 indicates that it is the fifth interview and that a student is the speaker. Personal correspondence would be similarly cited with the speaker and number with the abbreviation of PC. Feedback

surveys were abbreviated to FS with a number indicating which group the surveys were completed by and the page number indicating the individual survey. Anecdotes recorded in field notes were abbreviated to AN with the number indicating which group the notes are associated with similarly to the feedback survey. Only I and my supervisor have access to the code connecting numbers to documents. Other documents are cited appropriately and included in the reference listing.

### *Data Analysis*

Qualitative research is a situated activity. As the researcher and program coordinator, I am in the landscape of both the phenomenon and the study (Denzin & Lincoln, 2003). I am a participant-observer. I was in many cases, the tool to gather data such as in the form of field notes and personal correspondence. I am also the tool for data analysis. Analysis followed an interpretivist, emergent design similar to that described by Mabry (2007). In her case study work, she gathered data through direct observation, semi-structured interview and site-generated documents. Her goal was not to confirm or disconfirm a priori theory, but to develop a rich understanding of the case. There were many similarities in this study including methods to gather data and in analysis. My analysis, generally, was to review multiple sources of data and to “progressively focus the study based on the features of the case which gradually appear to be most significant” (p. 3). I employed a constant-comparative method involving “continuous comparison of incoming data with emerging interpretation (Glaser & Strauss, 1967; Strauss & Corbin, 1990), new data igniting new realizations and new interpretive possibilities provoking more sensitive data collection” (p. 6) to identify themes emerging from the words of participants in the program for thematic analysis. I use the phrase, “only somewhat” to describe how

constant comparison informed the emergent themes as I reviewed data and each interpretive document to refine and consolidate emergent themes. It did not inform further data collection. I also used a criteria strategy (Mabry, 1998) in that there were standards against which data were measured. The level of student engagement rubric (see Table 4), developed using the attributes identified through literature review, compared against the level of authentic scientific inquiry (see Table 5) is an example of the criteria strategy. These processes will be more specifically outlined in the following sections.

Recognizing that, like all scholarly research, this study is subject to critical review, I offer these explanations. First, data generated are the words of the participants. My assumption is that their words are an accurate representation of their experience, perceptions, and perspectives at the time data were gathered. For example, field notes were recorded during informal conversations, some that I was involved in and some were I was merely another person present in the room. Surveys were completed anonymously and interviews were conducted with students who had already completed their participation in the program. I no longer held any power over these former high school students. Further, these interviews were transcribed and returned to the interviewee for approval of accuracy prior to analysis. Findings are offered as direct quotations of data. Analysis resulted in emergent themes that were then represented through the words of the quotes. Emergent themes were derived with a care for triangulation and included data from different sources: interview, survey, and document, as well as from different participants: students, teachers, scientists, or the field notes containing my reflections; and across time: participants in the program in different years. What follows is a specific description of the process followed for data analysis.

As I reviewed and reflected on the information collected from each source, I recorded quotes from students, teachers, scientists, and from my own notes that indicated participants were engaged or that there was a change in perspective of a participant. With each quote I identified who the speaker was (student, teacher, scientist, or me), who the speaker was referring to (student, teacher, or scientist), what the source was, and in the case of engagement, which indicator of engagement the quote demonstrated. All of this information was recorded into a spreadsheet for easy comparison. Analysis followed an emergent design where themes and patterns that emerged formed the basis for conclusions.

To investigate the question, “What engaged the student participants?” quotes identified as demonstrating engagement were grouped according to the attribute of engagement they demonstrated and further categorized into themes that emerged revealing if, why and how they were engaged. I noted if each theme was observed and/or demonstrated by each type of participant (student, teacher, scientist) as well as which source of data the quote came from to see if patterns emerged that might contribute to a richer understanding.

To investigate if authentic scientific inquiry contributes to student engagement, I developed a rubric to assess the level of authentic scientific inquiry (Table 4) and one to assess the level of engagement (Table 5).

*Table 4: Rubric for Assessing Authentic Scientific Inquiry*

	<b>High authenticity</b>	<b>Medium authenticity</b>	<b>Low authenticity</b>
<b>Student involvement in the design of the inquiry</b>	Students generate ideas for experimental design which are modified by the students as they collaborate with scientists to determine the best course of action.	Experiment is primarily designed by others. Students agree to the design but did not generate ideas themselves.	Experiment is designed by others and the students are provided with information and instructions.
<b>Open-ended inquiry (where the answer is not known)</b>	Results of the experiment are of interest to the scientific community and the results are unknown	Experiment is highly predictive but the results are of interest to the scientific community.	Experiment is highly predictive and results provide little or no new information to the

	or difficult to predict.		scientific community.
<b>Student involvement in sample collection and preparation</b>	Students actively participate in collecting and preparing the materials to be tested in the experiment.	Students actively participate in either the collection of materials or the preparations of the sample but not both.	People other than the students acquire and prepare the samples for experimentation.
<b>Student involvement in data collection and analysis</b>	Students run the beamline computers (under the direction of beamline staff), record information in the log book, make sense of the data (with assistance as required from scientists), and draw their own conclusions.	Students are able to conduct only parts of the experiment and data analysis requires that scientists explain it and provide detailed instructions for students to draw conclusions from.	Students observe while the beamline staff collect data. Analysis is explained to the students by the beamline staff and students are lead to conclusions.
<b>Communication of findings or results</b>	Students generate their own talking points; organize their own material for presentations to several audiences, a poster and an article written by them.	Students require direction to generate talking points and organize their material for a presentation, poster and article. Article requires significant editing	Students are presenting material generated by others. Poster and article are substantially written by others, they are merely arranging the information.
<b>Collaboration (equal contribution and ownership)</b>	Students, teacher, and scientist(s) worked together to develop, conduct, and make sense of the project.	Group worked as a team but the students were following the lead of the experts.	Students essentially followed instructions of the experts.

Table 5: Rubric for Assessing Engagement

	<b>High engagement</b>	<b>Medium engagement</b>	<b>Low engagement</b>
<b>Persistence when challenged</b>	Effort (behavioural and cognitive) persists despite continued failures. Alternate solutions are actively sought. Overcoming obstacles is the goal with little regard for the amount of time or effort required. Exceeds expectations.	Effort (behavioural and cognitive) persists when success seems possible. Alternate solutions are considered as is level of effort required for success. Fully meets expectations.	Effort (behavioural and cognitive) is evident when success seems likely. Waits for others to determine alternate solutions. Meets the minimum expectations.
<b>Dedicated effort</b>	Personal time is committed. Project is given high priority.	Time is committed during specific project related activity, but not personal time. Project is given a medium priority.	Commitment to the project is restricted to within time allotted for specific activities. Project is given a low priority.
<b>Intrinsically motivated</b>	Can articulate reasons for participation and those reasons are not provided by others (self-fulfilment). Prepares for tasks without	Looks for others to provide reasons for the activity (marks, promotion). Requires prompting to prepare for tasks.	Is willing to do the tasks but requires specifically stated rewards for activity. Requires reminding to prepare for tasks.

	prompting.		
<b>Sense of ownership</b>	Expresses ownership and takes personal pride in the results of the project. Is willing to put time and effort into success.	Sees ownership as a group not personal. Compares time and effort to others. Is more concerned with equity than success.	Sees personal efforts as completing assignments, ownership belongs elsewhere.
<b>Enthusiastic participation</b>	Expresses obvious enjoyment and interest in the project, including for menial tasks. Prepares for tasks ahead of time. Seeks to participate.	Obvious enjoyment and interest is present for some tasks but not for others, such as menial tasks. Preparation begins when prompted, at beginning of task. Waits to be invited to participate.	Interest and enjoyment is not obvious or appears to be resigned to participate. Requires cajoling or convincing to participate.
<b>Value the activity</b>	Sees meaning in the project and connects that to significant returns either personal or on a larger scale.	Sees meaning in the project but needs assistance to connect to significant returns.	Has difficulty connecting specific tasks to a significant end result.
<b>Asking high level questions or discussions</b>	Questions and discussion indicate consideration of project beyond immediate completion (societal implications). Seeks to extend knowledge beyond what is immediately required.	Questions and discussion indicate consideration of the project but lack extension from immediate completion. Seeks to fully understand the project but not what that might extend into.	Questions and discussion is directly related to the tasks at hand in the project. Understanding of the project seems limited to procedural or factual knowledge.

These rubrics were developed using descriptions gathered during the literature reviews for the subject of the rubric. The rubrics employed a high/medium/low scale for each attribute identified in the literature and included additional attributes that emerged during data analysis as appropriate for constant-comparative methods (Mabry, 2007). The experiment conducted by every group of students was assessed using the rubrics for authentic scientific inquiry. Each group of students was then assessed using the rubric for engagement. The scores (expressed as percent) obtained were compared to see if there was a relation between authentic scientific inquiry and level of engagement. While this method of investigation was interesting, generalizations should not be drawn based on these data as I developed them as a tool to investigate a study where I am an integral part and have been the only researcher to make use of them and really are only applicable in this particular case. Rather than being a tool for this study,



these rubrics may open possibilities for future research to determine if such a tool might be useful.

### *Reporting Results*

There is a need in science education for students to experience scientific inquiry (Abbott & Ryan, 1999; Council of Ministers of Education, 1997; Duggan & Gott, 2002; Gengarelly & Abrams, 2009; Gibson & Chase, 2002; Luehmann & Markowitz, 2007; Markowitz, 2004; NSTA, 1998; Osborne, 2003; Ryder, 2002; Sikes & Schwartz-Bloom, 2009). This creates opportunities for collaboration and mutual support between the education and research communities. Research could inform science educators' attempts to include inquiry in their practises. Agencies that fund scientific research are placing a growing emphasis on educational or outreach programs in their grant application reviews (Ara'ugo-Jorge, 2004; Banner, Guda, James, Stern, Zavala, et al, 2008; Penn, Flynn, & Johnson, 2007). Examples of these collaborations are extremely varied and include classroom-based programs, after school programs, summer programs, and combinations of these. Some focus on the teachers' involvement and/or training and others place students at the center of the program. There are also several differences in the focus of learning such as laboratory skills, versus science content, or experience. Areas of investigation include content or process knowledge gained through experience (Bell, Blair, Crawford & Lederman, 2003; Knox, Moynihan, & Markowitz, 2003; Laursen, Liston, Thiry & Graf, 2007); student attitudinal changes (Short, Lundsgaard & Krajcik, 2008); improvement to retention and engagement (Marcus, Hughes, McElroy, & Wyatt, 2010; Slayton & Nelson, 2005). Some include aspects of authentic scientific inquiry, as SotB does, but few meet the criteria as outlined in the literature review earlier in this thesis (Ara'ugo-Jorge,

2004; O'Neill & Polman, 2004; Marshall, Taylor, Pine & Green, 2004; Penn, Flynn, & Johnson, 2007; Rahm, Miller, Hartley, & Moore, 2003; Sikes & Schwartz-Bloom, 2009; Snyder, 2008). Each article outlining a program, or the outcomes of a program, provides insight for teachers, formal and informal science curriculum or program developers, science research facilities, and possibly policy makers or funding agencies. This study is unique in that it investigates a combination of student engagement and transformational experiences in a program offering high school students an experience in authentic scientific inquiry, SotB, providing a rich description of the experience from a students' perspective. The study addresses some of the research called for by Anderson and Helms (2001) in that this investigation is conducted from multiple perspectives, is conducted in the "real world", is interpretive in nature, focuses on student roles and student work, as well as attending to teacher learning.

In an attempt to serve the various education and scientific communities' interests, the results of this study are presented as a series of thesis chapters derived from articles written for publication in peer reviewed journals. As a result, there is a necessity for repetition of some of the information in chapters one and two, to provide context for the readers of the article. Wherever possible, references are made to earlier chapters rather than repeating sections. The first article, *Students on the Beamline: Meaningful learning through inquiry*, identifies how SotB is a program that provides a context for meaningful engagement and learning that is potentially a transformational experience for students. This article will be submitted to a pertinent journal focusing on the area of inquiry, for example "Learning Landscapes." The second article, *How do you know if they're engaged? Reflections on student participation in authentic scientific inquiry*, is intended for a journal such as the Canadian Journal of Math, Science, and Technology Education, where there is a focus on student engagement. A third article *Can authentic scientific*

*inquiry result in transformational learning?* outlines places where a transformational experience arose from the SotB program.

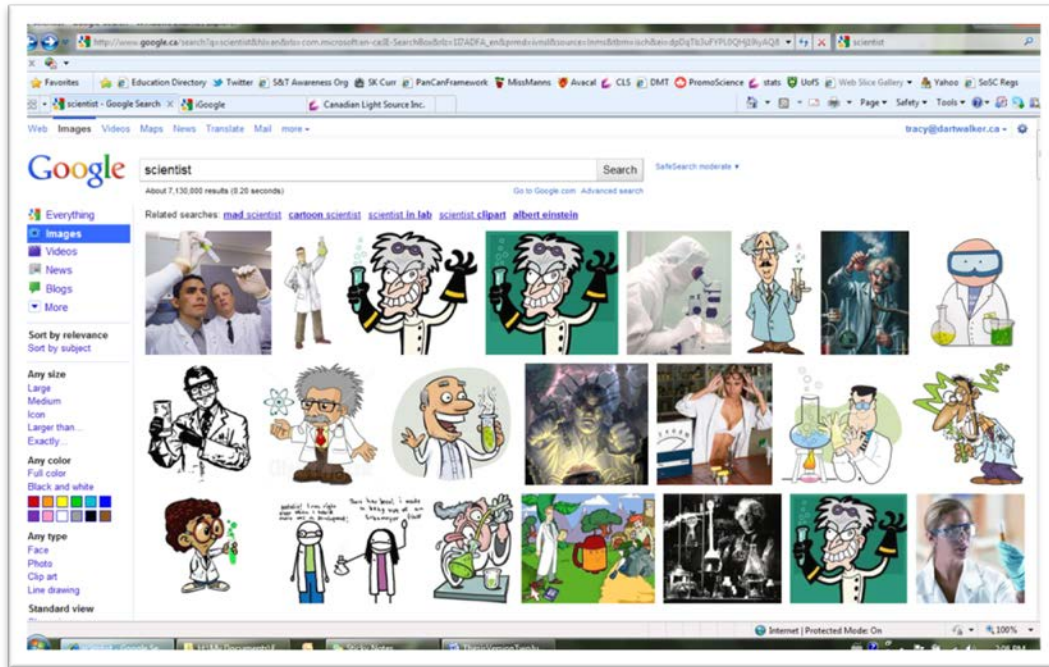
## Chapter Three: Students On The Beamline – Meaningful Learning Through Inquiry

### *Science learning: An Introduction and Background to Inquiry*

The process of inquiry is a central feature of science. However, scientific inquiry as part of science learning in school remains elusive even as calls for the use of inquiry in science education have been persistent and strident. Despite the acknowledged desire for inclusion of inquiry practices to school science, teachers struggle with implementation. However, there are examples of how inquiry as an engaging and possibly transformative learning experience may play out. In this chapter I outline some initial understandings of such an experience occurring at the CLS within the SotB program. I will provide a sense of the meaningful impact inquiry can have for students and their teachers and how this fits with thought concerning inquiry in science education. Some of the outcomes of this experience are shared and a discussion of what is believed to be crucial and fundamental underpinnings of such inquiry where participants have the opportunity for meaningful science learning experiences is provided.

When science and particularly science teaching or learning is depicted, one image that is often used is a stereotypical and narrow representation of who does science. Scholars point out the misleading and misguided employment of such representation (Schaefer & Farber, 2004), which often presents a be-spectacled, frizzy haired and dishevelled white male, clad in a white lab coat, enthusiastically “experimenting”, while holding a test-tube replete with bubbles and gases pouring forth (see figure 2 for examples generated by a simple Internet search for images of ‘scientist’).

Figure 2 Screen shot showing results of a Google Images™ search for ‘scientist’.



Perhaps, what is intended with such renditions is a desire to portray the sense of excitement and discovery that can emerge with inquiry, where there is a “finding out or bringing to light of that which was previously unknown ... the action of uncovering or fact of becoming uncovered” that is “the action of seeking for truth, knowledge, or information concerning something” (Canadian Oxford English Dictionary, 2004). Despite the good intentions intended by the use of such imagery, an argument might be made such representations have had little effect in encouraging any deep understanding or motivation for engaging in science inquiry, for if they did society would likely be awash in budding scientists, which we are not (Marcus, Hughes, McElroy, & Wyatt, 2010; Knox, Moynihan, & Markowitz, 2003). The need for inquiry experiences that is identified in documents such as the Common Framework of Science Learning Outcomes (1997), while still hoped for in current curricula, exist in stark contrast to the reality of science learning in classrooms across North America and elsewhere (Aikenhead, 2006) where inquiry is still a foreign if not misunderstood pedagogical approach (Anderson & Helms, 2001). Given the

discrepancy between what is called for, what occurs, as well as misguided ideas about science and who undertakes science, an inquiring mind might ask, “So what might promote a positive attitude and appreciation of science, science knowledge, and involve children in meaningful science learning?” and “What might this experience be like for those involved?”

This study attempts to address such questions for there has been a general failure with school science to be meaningful and engaging for the majority of students, and to prepare critically engaged science literate citizens (Aikenhead, 2006; Anderson & Helms, 2001), even as there have been continued calls for change involving inquiry as part of how students and teachers should engage in learning science and technology (Abbott, 1999; Council of Ministers of Education [CMEC], 1997; Comley, 2009; Duggan and Gott, 1994; National Science Teachers Association [NSTA], 1998; Osborn, 2003; Ryder, 2002). Science teachers have been asked to use less transmission-like teaching styles and to enact a teaching-learning process with “less emphasis on presenting scientific knowledge through lecture, text, and demonstration, and more emphasis on guiding students in active and extended scientific inquiry” (National Research Council, 1996 as quoted in Campbell, 2006, p. 61).

An irony exists here, for exploring the nature of the world through scientific inquiry is a powerful way of knowing that calls upon the creative and interpretive capacities of the human mind (Bruner, 1986), and presents the opportunity for better understanding the nature of, and procurement of, human knowledge. Yet ‘inquiry’ in school science settings is often limited to such activities as searching texts and online resources for information and reporting on that information, or confirming existing science knowledge through pre-scripted ‘experiments’ or ‘demonstrations’. Science inquiry as practiced by scientists, however, remains outside the experience of almost all students (Aikenhead, 1986; Hume & Coll, 2008). In other subject areas,

such as the arts and humanities, inquiry comes in other forms (Bruner, 1986). Inquiry seems alive and a natural feature of the learning process, often identified as a major learning outcome. It is not uncommon for art teachers to be artists, language arts teachers to be writers, and music teachers to be musicians, modeling these endeavours for their students, but rarely, it seems, are science teachers engaged in what some would call authentic science inquiry (Rahm, Miller, Hartley, & Moore, 2003), and similarly, science students rarely engage in such inquiry. As noted earlier, inquiry is suggested as an important and crucial critical component of science learning in school science contexts (Aikenhead, 1986; Bell, Blair, Crawford, & Lederman, 2003; Bencze & Hodson, 1999; Braund & Reiss, 2006; Eick, Ewald, Kling, & Shaw, 2005; Gengarelly & Abrams, 2009; Gibson & Chase, 2002; Hu, Kuh, & Li, 2008; Hume & Coll, 2008; Luehmann & Markowitz, 2007; Markowitz, 2004; McDonald & Songer, 2008; NSTA, 1998; O'Neill & Polman, 2004; Robinson, 2004; Short, Lundsgaard, & Krajcik, 2008; Sikes & Schwartz-Bloom, 2009; Windschitl, 2004).

Likewise, there is no shortage of policy documents and curricula that establish the need for inquiry based methods of teaching (American Association for the Advancement of Science [AAAS], 2000, Dugan & Gott, 2002; 1995; NSTA, 1998). Canada's Common Framework of Science Learning Outcomes (Council of Ministers of Education, 1997) states the need for "a science inquiry emphasis, in which students address questions about the nature of things, involving broad exploration as well as focused investigations" (p 4), yet despite acknowledgment for the inclusion of inquiry practices in the classroom pedagogy, teachers struggle with implementation (Anderson & Helms, 2001; Campbell, 2006; Comley, 2009). However, there are places this challenge is being taken up (Ara'ugo-Jorge, 2004; Bell, Blair, Crawford, & Lederman, 2003; Marshall, Taylor, Pine & Green, 2004; Penn, Flynn, & Johnson, 2007; Rahm,

Miller, Hartley, & Moore, 2003; Marcus, Hughes, McElroy, & Wyatt, 2010; Sikes & Schwartz-Bloom, 2009; Snyder, 2008; Walker et al. 2008), where learning through inquiry is undertaken by students and their teachers in cooperation with research scientists. These are experiences where students inquire in to the nature of the world through empirical methodologies, but also inquire into the nature of knowing, the validity and reliability of the knowledge they produce, their relationship with this knowledge in light of other ways of knowing, and who they wish to become.

The purpose of what follows is to provide some insight into peoples' experience of inquiry in a unique venue, what the outcomes of this type of inquiry involve, and what this may mean for teachers or other educators who are seeking to engage students in meaningful learning. I do this by describing the context of inquiry, what could be considered some initial successes or outcomes of inquiry in this context, and three brief stories illustrative of the SotB experience. I end with a discussion concerning the meaningfulness of science learning through inquiry experiences such as SotB and some suggestions for educators.

### *A Site Of Inquiry And Learning*

For several years I have been intimately involved with establishing and developing learning opportunities involving science research for students and their teachers. Through my work and that of others at the Canadian Light Source (CLS) an inquiry-based high school educational outreach program has been developed. The CLS is Canada's national synchrotron research facility that generates intense beams of infrared through x-ray light to probe the nature and structure of matter. Since inception in 2006, this program has grown from a single high school class allowed to access a single beamline in the facility as a special case, to a continuing

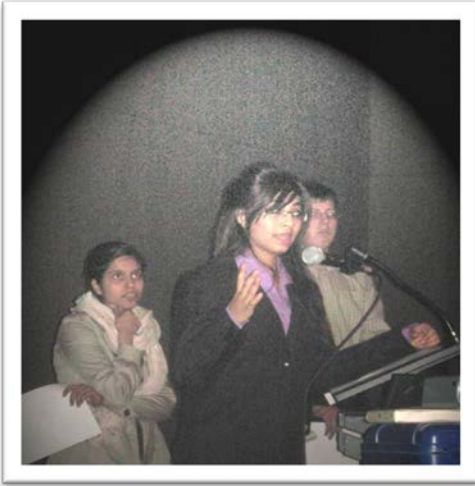


program that has connected nineteen groups of high school students. To Date, 177 students in total, and 32 educators from across Canada to 28 scientific researchers in a multitude of disciplines using half a dozen different beamlines as of the writing of this thesis.

The Students on the Beamlines (SotB) program facilitates inquiry-based research as a collaboration between students fourteen years of age and older, their teachers, and scientists. Each student/teacher/scientist team is involved in a scientific inquiry into the natural world. The range of projects varies significantly and includes investigations into rod cells of the retina of a toad, nano-particles in soil taken in by plants, effects of acid rain on boreal forest soils, and looking for indications of diabetes in human fingerprints to name a few.

Considering this undertaking one might ask, “What has been the outcome of such efforts and why bother examining these efforts?” In other words, what markers or signs of success exist that warrant examining participants’ experience of the SotB program as an example of meaningful learning? Some of the more tangible outcomes of this inquiry oriented program that we suggest are signs of success include:

- articles accepted for peer-reviewed publication in science journals written by students, teachers, and researchers
- well received student presentations of research findings to public audiences, scientific funding council meetings, university departments, and government agency workshops



*Figure 3: Students present scientific findings to government audience.*

- generation of scientific results that are of publishable quality in peer reviewed journals (written by scientist but contributed to by students)
- successful competition in Canadian Science Fairs (regional, provincial and national levels)
- student-created artwork based on scientific data, designed and created by students to celebrate their experience



*Figure 4: Collaboration team with their sculpture representing the scientific results of their research*

- SotB has captured interest from the media and been included in documentaries featuring successful twenty-first century education practices



*Figure: 5 Student being interviewed for the evening news*

- teachers returning to participate year after year with new students
- scientists offering their laboratory and personal time year after year to facilitate inquiry and learning
- frequent invitations to present the SotB program at both education and scientific conferences
- Students continuing their involvement with CLS outreach activities when possible

We offer the above evidence as an indication that, through the pursuit of an inquiry approach, meaningful science learning is occurring. The CLS' Scientific Advisory Committee seems to support our contentions of success:

The CLS has managed to build a vibrant outreach effort that has had an impact across Canada. The involvement of high-school students in both the design and execution of significant experiments is commendable, and should serve as a model for synchrotrons around the world. (SAC Report Spring 2010, p 8.2)

Given the apparent success of the inquiry based SotB program other synchrotrons such as the MAX-Lab (the national synchrotron laboratory in Lund Sweden), the Australian Synchrotron and Brookhaven National Laboratory (in New York) are developing similar educational programs, inspired at least in part by SotB experience.

Our interest in what constitutes meaningful science learning prompted our inquiry to better understand what this experience meant for participants and how this fits with notions of inquiry. To provide a better sense of participants' involvement we provide several short stories or vignettes, for the use of stories is a legitimate way of sharing human understanding and experience (Carter, 1993; Clandinin & Connelly, 1990). In what follows we offer a few examples of people's experience with the hope they will provide some further insight into the meaningfulness and impact of what we consider a meaningful inquiry experience.

*Story one: A turnaround.*

A small group of grade 11 students (15 and 16 years of age) from a Canadian rural farming community were invited to participate in an on-going synchrotron research project conducted at the CLS. Expecting only to watch while samples were prepared and data were collected, they were ecstatic at their level of involvement in the project. The team chose their own experiment for the day, selected their particular samples for exposure to synchrotron light, employed a more sophisticated optical microscope than what they had experienced previously, operated the beamline to collect data, and assisted the scientist in making sense of the complicated data sets collected. Afterward the students created a poster for a scientific meeting displaying their results and explaining their findings.

For one student, named "Jane", who was struggling to maintain passing grades in a Physics 20 course, the experience of inquiry was transformational. Throughout the experience Jane appeared quiet, shy, and refrained from saying very much, even after repeated attempts to draw her into conversation. However, she diligently participated in all the activities while appearing to remain somewhat detached during conversations (T-I-7, p. 3). A later conversation

with Jane's teacher revealed that not only had Jane diligently applied herself during the few weeks remaining in the semester to pass Physics 20, she had enrolled in Physics 30 after the summer break, a surprise to many who knew her. During the parent orientation night that fall, Jane's parents sought out Jane's Physics teacher to share changes they had observed in their daughter since her involvement in the inquiry-based program at the CLS. Jane's parents related that Jane had shown a greater interest in science. For example, she began to watch science related television programming such as the Discovery Channel and other science-based television shows. Jane went on to complete Physics 30 and has also successfully completed her first year of university including Physics course work. Jane has stated to various people that she plans to enter a science related career.

*Story two: Life lessons.*

Like any program, SotB changed over the years. Initially students were invited to participate in existing research projects that were designed by scientists (adapted and simplified). The very first group involved in a more authentic inquiry experience displayed some interesting behaviours. The dedication these students showed to this project was significant. They spent evenings and weekends in their school laboratory, at the library, and in front of their computers trying to find the information they needed to prepare their samples, plan for the experiment, and prepare for their presentations. This was on top of other academic responsibilities and involvement with other extra-curricular activities such as athletics, music, drama, and part-time employment. The SotB program organizers assumed that students would have a 'good' experience where students would learn a great deal about the synchrotron, basic science content concepts, and about the topic of their research. What organizers did not realize was the degree to

which students gained proficiency in a variety of other skills. Students had to come to consensus decisions based on information they uncovered and the guidance provided by the scientists involved, and quickly, since they had only a single eight hour shift of beamline time, whereas many scientists work with four or five times that. These young researchers acted expeditiously, gathering their thoughts to put aside preconceptions about their hypothesis and then embarked on new directions in their research. At times they proceeded against the advice of the scientist, which, contrary to the scientist's expectations, resulted in surprising and excellent scientific data. According to their teacher:

During this project, the students worked their way through the process of finding a problem to research, submitting a proposal, preparing and testing samples, performing data analysis, writing a paper, and presenting their findings. ... From the very beginning of this process, the students learned how different "real science" is from "classroom science". (Belsey, 2008)

The level of confidence these students displayed during their presentation at a scientific conference was remarkable. When, at the end of their presentation, students were questioned about some of their data, they enthusiastically replied, "Yeah! We were surprised too!" (TW-AN-4, p. 1). The ease and confidence with which the students engaged in discussion concerning their work brought a rousing chuckle from the audience and newfound respect from the scientific community members. One direct result of this interaction was that the number of student groups accepted for placement with scientists doubled the following year.

*Story three: A “eureka” moment.*

Students from the Maritimes travelled more than 4000 km to participate in this program. These grade 11 and 12 (15-18 years of age) students were interested in space, specifically meteorites, and were looking forward to learning a great deal more about this area of study. However, there were challenges to overcome. The beamline used has exacting sample preparation requirements and intricate energy beam alignments to produce the extremely precise and high resolution data. Students struggled to relate the precision of the data they were collecting with their curiosity about the origin of asteroids. To address this scientists helped students make connections between their very general question, “Where do asteroids, and thus meteorites come from?” and to layer more complex questions, ultimately asking “Can we identify, chemically, where this meteorite originated?” The process evolved as students participated in an exchange between geologists and spectro-microscopists, the experts in using the techniques available on that beamline, as each learned more about the others’ field of research.

Their experiment involved exposing a small piece of meteorite to x-rays in different ways at different energies. They were attempting to match the characteristic chemical fingerprint of the meteorite in question to those with known origins. During one of the last scans a very clear image appeared on the computer screen that caused a great deal of excitement. The image revealed a clear and distinct pattern of black and white tracks, much like a tire tread.

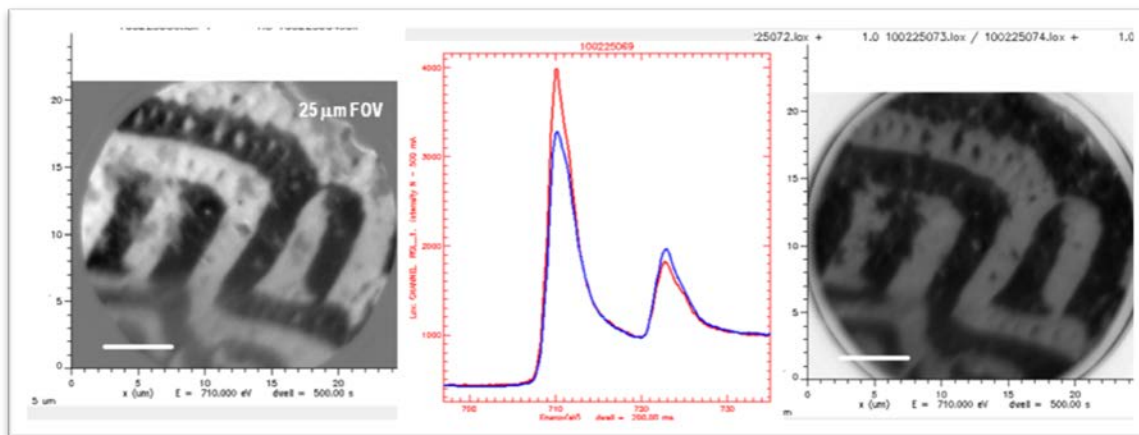


Figure 6: Images of magnetic domains of a meteorite collected by students using polarized x-rays first in one direction then another. Image in center indicates differences in light absorption.<sup>1</sup>

There were several scientists present, all whom became very excited, so much so that they started phoning others to join them. Students, teachers, and I were confused. The scientists explained the image created was that of the magnetic domains within the meteorite. The level of excitement among the scientists was high, correlating closely to the level of confusion experienced by students and teachers. When asked about the meaning of the image and the information the image conveyed, the scientists' exclamation "We don't know!" was delivered with a great deal of excitement and enthusiasm. This further added to our confusion. The students and I gathered together, in an attempt to try and connect what was on the screen to the questions formulated at the beginning and throughout the experiment. We were trying to find a question to ask that would elicit an answer which would help us to understand what was happening. Eventually the right question was posed, "Why does this image cause so much

<sup>1</sup> Difference in x-ray absorption between left and right circularly polarized light has been exploited to get magnetic domain imaging or x-ray magnetic circular dichroism (XMCD) (Lanke, 2010). The Spectromicroscopy Beamline with the x-ray photoemission electron microscopy (XPEEM) technique is capable of capturing images generated as electrons are emitted from the sample at very high resolutions with polarized light. The center graph is the absorption spectroscopy spectra of iron indicating differing absorbance for each polarization, supporting the mirrored images of the magnetic domains.



excitement?” The answer, to the best of the knowledge of the experts present: this was the first time that magnetic domains had been imaged in a substance that was not man-made using lower energy x-rays.

Excitement was now understandable, though comprehending what magnetic domains were and how the polarized x-rays in the beamline had been able to visually capture them was still challenging. When the time came for students to share their findings in presentation, poster, and article formats, they were unsure how to proceed. To their minds an experiment write-up always had the same structure: present your hypothesis or question, explain how you tested it, and present how your results answer the question or prove/disprove the hypothesis. This was a ‘eureka’ moment. A perception of what constitutes the “scientific method” is different for students than it can be for scientists. From the scientists’ perspective, a piece of meteorite and a state-of-the-art tool were brought together in a unique situation. Meteorites had never been studied using the method available and so the question was “What could we find out?” Students understood research as a test of hypothesis, while scientists’ sensibilities to the activity was more one of exploration. Understanding others’ perspectives made communication easier among participants as well easing the preparation and sharing of findings.

*Story four: Changing practise.*

Teaching is a personal and social activity. Actions and interactions between teacher and student are affected by the personal experiences of the individuals involved. To determine the specific effects of any given experience for any given individual is impossible, in my opinion. That being said, reflection upon possible effects may perhaps provide insight or limited understanding of such effects. I provide this as context for this story. A teacher’s personal

experiences cannot help but affect their teaching practise. The following is a short excerpt from an interview with a teacher who was reflecting on their experience in SotB and the effects it might have had on classroom practises (T-I-6):

Interviewer: Describe your experience.

Teacher: From a teacher's perspective, the experience to be able to open the doors and show the scientific community at work, and living breathing scientists, to students who rarely get a chance to see them. And those students get a chance to share them with fellow students and parents and the community. And really it's a sum. The sum the whole is greater than the sum of its parts for this kind of experiment. And personally I greatly enjoyed it just because I'm always passionate about science. I want to bring that on to my family, community, and students where I work.

Interviewer: Was the experience what you thought it would be?

Teacher: I knew it was going to be exactly the way that it was just from having a lot of experience with research ... . I didn't exactly foresee how the students were going to react to it. I knew they would be pretty overwhelmed in general, and the students we brought were able to overcome that. In general I got what I expected.

Interviewer: How did it make you feel to have this challenge for your students?

Teacher: As someone with a scientific background taking a job as a high school teacher, something that I've always wanted to do is get my students into that scientific field, the scientific lab, the academics as much as possible so I felt relieved that I was finally able to do that.

Interviewer: Has your experience affected the way that you teach in any way?

Teacher: My teaching is now kind of a little bit more focussed on a driving question. So rather than just teaching a specific concept because that's how it follows the curriculum, I might put forth a question to the students and and build the concept around that question, implement all the preciseness and precisions of that concept as we go throughout the unit.

### *Inquiry*

The information and stories above convey a limited sense of what occurred during participants' experience of inquiry during the SotB program. Despite the unique nature of this situation, which involved the use of a synchrotron, we believe this experience of inquiry possessed several important features that provided for meaningful learning in several contexts. Learning identified under other designations such as: discovery learning (Bruner, 1990), open inquiry (Roth, 1995), authentic science experience (Eick et al., 2005; Eijck & Roth, 2009), authentic science curricula (Braund & Reiss, 2006), and transformative learning (Kalantzis, 2006; O'Neill & Polman, 2004).

In each SotB experience, students and their teachers were directly involved in guiding their inquiry and were involved at all stages from the development of the research questions and hypothesis, through the collection and analysis of data, and reporting the results in presentations, posters, and articles. In these moments participants were not simply doing a form of demonstration of science concepts, where they were merely confirming existing scientific knowledge, but were engaged in the act of producing unique and novel knowledge, where the results were previously unknown. Participants had significant input in making sense of and sharing the emerging information. In the case of some participants with SotB, this information

was of interest to the local scientific community, but also a more global audience. High levels of engagement were indicated by the amount of time, effort and energy contributed from students, teachers and scientists throughout the duration of their participation in SotB. In most cases participation was extracurricular so students, their teachers and scientists contributed many hours in the evening and on weekends to ensure success.

With so much time, effort and energy going into the experience, I feel I must return to a question posed earlier in this chapter, “What are the outcomes of these efforts?” Informal observations and feedback from participants prior to the study presented in this thesis indicated that student perspectives towards scientists changed. Student comments showed a shift away from the fantastical image presented at the beginning of this chapter towards something they referred to as “real” and “normal”. In addition, student aspirations for future involvement in science and technology careers appeared to be enhanced. Teachers reported that the experience was professionally fulfilling, and that this invigorated their practice. When asked, informally, why they chose to participate, scientists responded that working with the students was rewarding and motivating.

Generally, the response of participants to this experience of inquiry seemed to indicate students and teachers became motivated to further develop their understanding of science knowledge and processes and that this was empowering and generative for them. Consider this against the “infantilizing” experience described by Botstein (1997) where secondary school students were often presumed deficient in their knowledge and abilities, unchallenged, less capable. Programs like SotB acknowledge that students’ abilities “are actually far superior to adults in some areas: memory, reasoning ability, reaction time, and sensory abilities in particular” (Epstein, 2007, p. 660). Inquiry in this situation allowed for more open ended

outcomes where personal meaning and involvement were encouraged as well as creative thinking and cooperation. Challenging tasks were proffered and sometimes upgraded, but also supported which are hallmarks of meaningful learning (Bruner, 1970; 1986; 1990; Caine & Caine, 1994; Tokuhama-Espinosa, 2009) and help to create a place where transformational learning is possible.

Inquiry in this context did seem transformational for students, and was not limited to only increasing their science content and procedural knowledge but also, as Roth noted of such circumstances, likely contributed “in crucial ways to the construction of identities and careers” (2004, p. 257). We can perhaps witness the beginning of such transformation with Jane, but she was not the only person who experienced a change of perspective in relation to science and identity. The image of the frizzy haired scientist, white lab-coated, arms splayed as flasks bubble was not the experience of students. Like the scientists of different nationalities, genders, cultural heritage and life experience they were working with, these students were also researchers and investigators in their own right, if only for a short time and despite their novice status, still themselves, non stereotypical.

Despite this being a new experience for students, teachers and scientists, perhaps the most fundamental realization from informal examination of the SotB program is that secondary students, having been given the opportunity, were quite capable of undertaking inquiry, scientific or otherwise, with a high degree of sophistication, dedication and productivity. Lave’s (1988) words in the context of SotB and inquiry comes close perhaps in offering a plausible rationale, both for why students’ experience of inquiry was meaningful to them, but also desirable as an experience for learning, because as he said:

They [students] chose to study realistic phenomena of their own interest, and made all decisions with respect to resources and materials to be used. Thus, our students, experience themselves as in control of their activities, interacting with their setting, generating problems in relation with the setting and controlling problem-solving processes.” (p. 69)

### *Final Thoughts On SotB And Inquiry*

Participants’ experience in the SotB program, the information and stories shared here, the literature concerning meaningful and engaging learning contexts we have reviewed, the data we have begun to collect on participants’ experience and our observations lead to the belief that significant transformational experiences can occur for students through inquiry such as the SotB program. Acknowledging that “learning in a rich setting allows knowledge to be anchored in, or indexed to a setting. The learning process, then, is scaffolded by the setting, and knowing is meaningfully linked to the experiences of the student in that setting” (Roth, 1995, p. 48). The SotB program, as an example of actual scientific inquiry, seemed to engage students and their teachers with scientists in a deeply involved manner. This setting provided an opportunity to develop a richer understanding of the experience and the potential effects of the experience for participants through formal research. The successful pursuit of inquiry and meaningful learning rests with access to the expertise of practitioners. Involvement with such people is crucial not only in pursuing scientific inquiry but in aiding students to fully experience inquiry, and to possibly see themselves as fully involved in the pursuit of science.

At this point I have come to believe that inquiry activities, as evidenced by participants’ responses to the program SotB are transformative for all participants because students and

teachers were engaged in an inquiry opportunity that activated and encouraged their creative problem solving abilities and that provided a meaningful challenge in a supportive learning community. Such work provided an experience that was potentially transformational, and offered an exciting option to make science learning meaningful and to meet various science education curricula. While the venue of interest and activity relates to science teaching and learning, from what has been investigated in this context, teachers and students, whether in science or humanities, are encouraged to network with universities, centers of excellence or other agencies, and to go beyond the confines of their classrooms if necessary, in seeking out learning opportunities that involve inquiry. If this can be accomplished I suspect students will have learning experiences that will challenge and extend their knowledge about the world, others and themselves in ways that in the end enriches learning.

From this description of the place wherein an experience with authentic scientific inquiry happens, and some of the outcomes evident from that experience, I turn, in the next chapter, to a reflection on the experience through a lens developed to identify engagement.

## Chapter Four: How Do You Know If They're Engaged? Reflections On Student Participation In Authentic Scientific Inquiry

### *Introduction*

Thus far, the reader has been made familiar with the concepts of authentic scientific inquiry, student engagement, and transformative experiences as well as the SotB program. The article under development from which this chapter is derived includes these contexts, definitions, and explanations provided previously in the literature reviews and methods descriptions. To avoid redundancy, I summarize and refer to those reviews in chapter one and to the methods I used in this study, outlined in chapter two, but endeavour to avoid lengthy repetition.

The landscape for this study was described in the first chapter of this thesis: SotB, as an example of authentic scientific inquiry, provided an opportunity to investigate how that context might affect the experience of those who participated in the program. Chapter three provided a more robust explanation of the context that inspired me to investigate more fully. I was convinced by my own experiences and observations while developing the program, as well as through conversations with other participants, that this landscape provided a place where exciting and meaningful learning had occurred. As was pointed out, engagement is considered by many educators to be an essential part of meaningful learning. In this chapter I will explain what my investigation of student engagement within the context of SotB revealed. In effect, I speak to my research question, “Are the participants in the program, including students, teachers, and scientists engaged during participation in the outreach program?” and sub-questions, “Do the students in particular exhibit the indicators of engagement identified in the literature? If yes, what engages them?”



### *Context Summary*

A topic of interest for this study was to develop a richer understanding of student engagement in relation to the unique and successful science research outreach program, SotB, at the CLS synchrotron. A review of literature provided a framework for indentifying when participants might be engaged. For the purposes of this study, the following indicators were used to identify when participants were engaged during the program:

1. Persistence: the learner is persistent in seeking answers and overcoming challenges
2. Dedication: the learner provides a dedicated effort both physically and cognitively
3. Motivation: the learner establishes that the desire to participate is generated internally and not imposed upon from someone or somewhere else
4. Ownership: the learner demonstrates a sense of responsibility towards ensuring success
5. Participation: the learner displays enthusiasm during all or most aspects of the activity
6. Value: the learner indicates that the activity is worthwhile
7. Contribution: the learner asks high level questions or participates in discussions at a high cognitive level

For a description of how this list was developed please refer to the Student Engagement section of Chapter one, particularly Table 1: Indicators of Engagement on page 25.

Using this framework as a lens, data collected through methods explained in chapter two, were investigated to determine if students demonstrated any of these indicators and if so, to determine what might have contributed to that engagement demonstrated. I hope that the framework developed for this study might prove useful for others interested in indentifying or investigating student engagement. It is also my hope that this study will have provided some practical suggestions for science education project or program development encouraging high

school student engagement with scientific research useful for high school and post secondary curriculum developers and also by the informal science education community developing outreach programs.

To review quickly, participants of the SotB program include high school students aged 14 and older, their teachers, staff and scientists from the CLS and sometimes other institutions. This is an intensive program that immerses the collaboration team in authentic scientific inquiry over most of a school year. Part of the unique nature of this program is that students lead the collaboration in the development of a project of their own interest, that is also of interest to the scientific community, and that requires synchrotron research techniques to address the research question(s). These are not demonstration experiments, but ones where the answer is not known and that will potentially contribute novel information to society's collective scientific knowledge. This is one part of what makes SotB considered to be an example of authentic scientific inquiry. For further information on what I mean by authentic scientific inquiry and how SotB fits that definition, please refer to the section Authentic Scientific Inquiry on pages 16-22. It is from within this context that I asked the research question, "Are the participants engaged" using the framework above to determine that.

In seeking to examine engagement I relied upon several sources of data which included: program development reports, personal correspondence and anecdotal records of the program coordinator, student notes in project lab books, program feedback evaluation surveys, and media reports. To probe more deeply into what engages the participants, three teachers, three scientists, and four students agreed to a semi-structured interview. As each data source was reviewed, quotes demonstrating engagement were noted that aligned with the indicator(s) of engagement.

These quotes were then reviewed and categorized and patterns emerged to reveal why or how they were engaged.

### *Evidence of Engagement in SotB*

In this section I have defined each of the indicators of engagement from the framework developed through the literature and provided evidence that the students who participated in the SotB program displayed each of those indicators. Afterward, I discuss what contributed to student engagement.

#### *Persistence.*

Persistence is a concept referred to frequently when describing engagement (Fredricks, et al., 2004; Hudley, et al. 2003; Skinner, et al., 2009; Zyngier, 2008). Fredricks, Blumenfeld, et al.'s (2004) review of studies focusing on measuring engagement showed that persistence is important in behavioural, emotional, and cognitive aspects of engagement, though no specific definition of the word was mentioned. Canadian Oxford Dictionary defined persistence as, "the fact of continuing in an opinion or course of action in spite of difficulty or opposition" (2004). This was the definition used for the purposes of this study.

Each SotB group faced challenges unique to their project. In each case, persistent effort from the students was required to address the challenge. There were some challenges that seemed to be common to several groups. A challenge, voiced by many participants, was a struggle with understanding how the synchrotron and the beamline(s) worked as well as the depth of science concepts involved in conducting experiments:

I was surprised by how much of the science my students were able to pick up in such a short time. ... I think my opinion of what students could take away from this experience has changed. I underestimated just how much students who are keen to learn stand to gain from this experience. (T-FS-3, p. 10)

The above quote from a teacher demonstrated that student persistence, identified by the words “keen to learn”, contributed to their learning.

A number of groups experienced difficulties with sample preparation but persevered until an acceptable procedure was developed:

I remember blending all those [raw materials] and trying samples and growing mould and having to redo them. [Laughs] So and at the end, writing that report, and we did like the project we had to submit, I felt like we put in a lot of work, yeah. ... I knew there would be work involved, I just...I had no clue what it was like to develop, like samples to test. Like, I'd never done anything like that before so no I didn't expect it to be that, that intensive and like, stuff would go wrong and you have to redo something all over again. I didn't expect that side of it I guess. (ST-I-8, p. 2)

Doing something over again repeatedly demonstrates the kind of persistence that is indicative of very high levels of engagement as defined in the Canadian Oxford Dictionary and referred to by other scholars (Fredricks, et al., 2004; Hudley, et al. 2003).

A third theme that emerged from the data centered on the open-ended nature of the student research. It is worthy to note, however, that as the program was developed, we anticipated that students would struggle with a situation where the outcome of the experiment was unknown. In our experience, this is not a common situation in high school science where

many courses are based on, “unimaginative, cookbook-style laboratory exercises.” (Marcus, Hughes, McElroy, & Wyatt, 2010) As a result, specific questions in the surveys and interviews related to this. I wanted to understand if and how this open-ended inquiry situation affected the participants. Results indicated that if the question had not been asked, it is likely that this would not have emerged as a challenge. Students and teachers both expressed that rather than being a challenge, this was more of motivator, “I enjoyed being able to experience the frustrations and triumphs throughout the researching process. I also learned how to be resourceful when faced with challenges such as broken equipment” (ST-FS-12, p. 6) writes a student on their feedback survey demonstrating both motivation and persistence.

Other challenges were mentioned or referred to by participants, but did not appear to emerge as a theme. It is also important to distinguish between persistence and dedicated effort, which is explained in the next section.

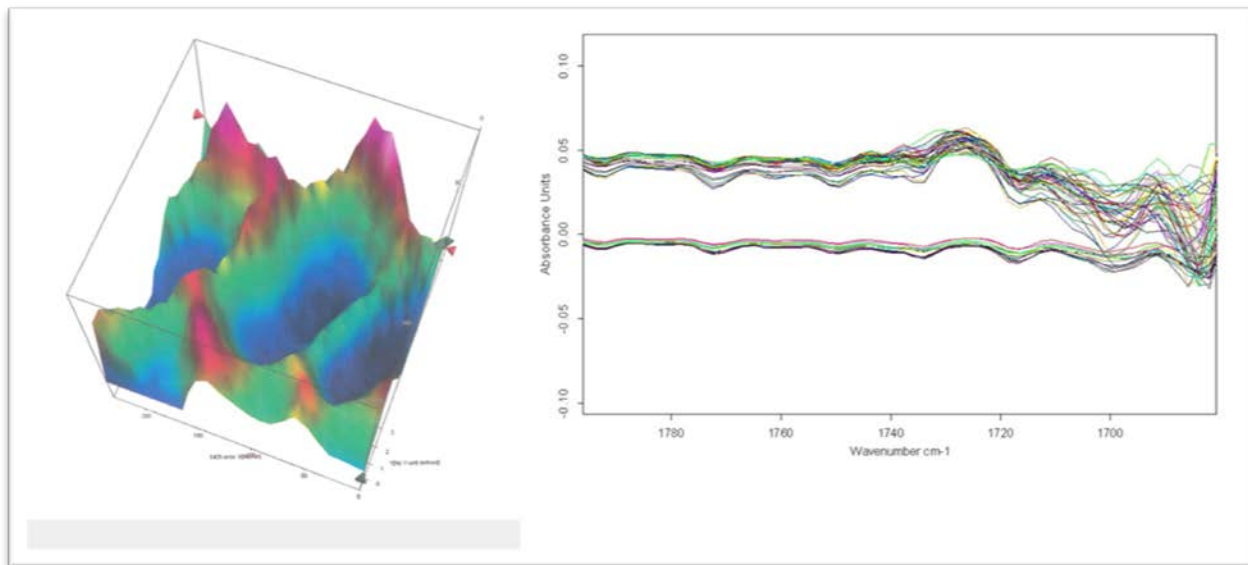
### *Dedication.*

Some examples of persistence when challenged might also serve as examples of dedicated effort, but they are independent indicators of engagement. A student may demonstrate both persistence and dedicated effort when working to overcome a challenge, however, it is also possible to demonstrate dedicated effort without facing a challenge, but merely because the work needs to be completed. The work might be easy and monotonous rather than challenging, still requiring dedicated effort, and thus indicates engagement. Schlechty (2002) described dedicated effort well, “engaged students see meaning in what they are doing, and that meaning is connected to ends or results that truly matter to the students” (p. 10) when he associated

practising an instrument with dedicated effort. Repeatedly playing a scale, for example, is not challenging for a gifted musician, but it is necessary and requires dedicated effort.

An example of this within the context of SotB is the story of a student who, at the beginning of the project, self-identified as taking science only because of the required credit to graduate, not because of an interest in science, and further volunteered the self-identification of being “dumb.” However, later this student put three hours of dedicated effort into analyzing hundreds of spectra (data produced in the form of graphs) to produce a chemical ‘image’ of their sample to use on their poster and in presentations (TW-AN-15, p. 6), demonstrating both engagement and the mis-identification of being ‘dumb’.

*Figure 7: Image of plant cell (left) generated from mid-infrared chemical spectra (right) data.*



Participants’ dedication to their projects was obvious, as revealed in the following quotes from an interview with a teacher who reflected upon the reaction of students when told their ongoing sample issues may result in an inability to conduct their experiment and then described how engagement was obvious (T-I-3):

I remember telling the kids, “We're still going to get the trip and we're still going to get to go to the synchrotron but, you know, it's looking like we won't be able to do the thing with the [sample].” I was surprised by how horribly disappointed they were when I said that to them because I thought, to them the thing was the trip and going and coming to see [the synchrotron] and everything, but they had become so committed to that project at that point that doing something else just wasn't even on the books for them. ... They desperately wanted to do their [experiment]. (p. 19)

They were willing to come nights and weekends to work on it. They were willing to come in Saturday morning, Sunday morning. You know if you've got a teenager that's willing to do that, they are pretty committed to something. ... They came up to me outside of class time wanting to talk about it. They clearly put time in at home. They got their parents involved. You know if a kid talks about it over the dinner table, you know at that age, that's an unusual thing. (p. 22)

This dedicated behaviour of students revealed through both the story and the quotes above were very common in data collected during participation in SotB. Many comments were made concerning the amount of work required to succeed in this endeavour. It made sense to ask, what motivated these students to complete this work with such dedication and persistence?

### *Motivation.*

When asked why they wanted to get involved in a SotB project, the overwhelming response from students (and teachers) was because they thought it would be fun or interesting. With a little probing, underlying, intrinsic motivations were revealed. Hudley (2003) explained that “an intrinsically motivated student will perceive the learning task to be a source of

enjoyment” (p. 4) and associated this with engaged behaviour. The SotB program did not have the typical school-based external motivator of evaluation for students, and so begs the question, what motivated the students? Several motivators were mentioned by students. Although the most common motivator, an anticipated boost to their resume, was also extrinsic, other, more intrinsic motivators, also emerged: that participation was ‘fun’, it was an opportunity to ‘test’ their anticipated career, and a desire to do something different from school science. One group of students articulated part of what made it ‘fun’ while answering questions after their presentation, “It's boring at school. Here it's more real, unpredictable. We could ask and direct our own learning.” (ST-AN-4, p. 7) These sentiments were echoed during an interview with a student:

We didn't really know what we were getting ourselves into at first, I don't think. We started off getting the research proposal and all that, but we never realized how far it would go. We were invited to the conference and stuff, it was just really fun and surprising the whole time and it kept us on our toes and gave us something, you know, something to look forward to every week to work on and something a little more engaging than what most of high school is so it was fun. (ST-I-2, p. 1)

I liked the atmosphere and the group work and that sort of thing. And it's fun because it didn't matter to our grades or anything. It was just something we chose to do. (ST-I-2, p. 7)

The students could certainly see potential rewards, but those seemed to be intrinsic, “We wanted to contribute something to scientific knowledge,” (ST-AN-9) said one student during



discussions on the beamline. A desire to complete what they had started was expressed by all of the students interviewed, such as this example:

Seeing the project through to the end. It would have felt weird if we had just left it. We had just did the research, we had found kind of some conclusions and then if we just left it. I mean that would be really kind of disappointing. It wouldn't value the effort we'd put in before. So it was kind of nice to see the project through to the end because you have something presentable and you can show something for it. You can show we wrote up this report. (ST-I-8, p. 12)

Coupled with internal motivators to complete work with dedication and persistence, students also demonstrated they felt both the work and the results were theirs. Students displayed a sense of ownership.

#### *Ownership.*

The indicator of ownership refers to a sense of responsibility a learner feels towards ensuring success of the activity they participate in. It is a term that encompasses behavioural, emotional and cognitive domains of engagement (Libbey, 2004; Kuh, 2009; Patrick, 2007; Shernoff; 2003). In this study, students felt that the work required to complete their SotB project was their responsibility. One of the students explained:

I think everyone kind of got way more involved as we went on and people started to show what they were good at. ... People got the opportunity to work on their strengths because we started splitting up the responsibilities.” (ST-I-2, p. 8)

When asked, “Who owned the project?” the response from this teacher demonstrated how important a sense of ownership was:

I think if you asked the kids they would say they did and if you said to me, “You have to pick one person.” I would say they did, but of course [the scientist] was always there ... doing 75% of it but letting the kids feel like they were doing 75% of it. ... They had a real sense of ownership there. You know they felt it was their project and as the teacher I could see the things going on in the background that I think they were largely oblivious to. (T-I-3, p. 8-9)

Later in the interview, the topic resurfaced. When I was reviewing the quote, “The two girls who had taken on the challenge of writing the article were very proud of it,” (T-I-3, p 12) I had noted my own observation as well which read:

They had a very strong sense of ownership of that article. So much so that they did not want their teacher to have input. Although they were not put off by the heavy editing their scientist did. These students felt that the work required to complete the project was their responsibility. (TW-I-3, p 12)

When one accepts a responsibility for the success of an activity, that sense of ownership may translate to enthusiastic participation, which appeared to be evident in SotB.

### *Participation.*

Behaviour consistent with the enthusiastic participation of an engaged student was described in many different ways in the literature including rapt attention for a long period of time (Nystrand, 1989), a positive attitude towards activities and achievements (Hudley, 2003),

interest and enjoyment (Shernoff, 2003), and initiative taking (Zyngier, 2008). In SotB the enthusiastic participation of the students was not only readily evident, it was contagious. One CLS scientist commented on this during an interview by the media and was quoted, “The work he does with young students is the best part of (his) job” (Simcoe, 2009). Enthusiasm was also evident in this quote taken from a student’s feedback survey:

I felt that this experience was very valuable to me, because it was an unbelievable experience. It was remarkable actually being able to work on an experiment that has not had an answer created was awesome and being able to work with the SCIENTISTS [names omitted, emphasis in original] were unforgettable moments. (ST-FS-6, p. 3)

Signs of student enthusiasm emerged in other ways, where for example, one student wrote on an impromptu autograph sheet given to me as a keepsake, “Thank You! It was the highlight of our academic year!”

Indications of enthusiastic participation in behaviour of the students were described by teachers, scientists, and the program coordinator in various sources including interviews, anecdotal notes, program reports, etc. These descriptions included the relation of animated discussion about results *among* students as well as between students *and* teachers or researchers; active involvement in the activities related to the project such as sample preparation, operated computers to collect data, record information, prepared for communication, all without having to be prodded or reminded; lack of off task or distracted behaviour; asked for more time to correct mistakes or find additional information; refused to take breaks for meals; arrived early for scheduled beamtime; and worked early mornings, after school and weekends in preparation for the synchrotron experiment. This description provided a sense of the level of enthusiasm during beamtime,

The five students were gathered so tightly around the computers that no one else could see anything. They had zoomed in on the graph so it was BIG [emphasis in original] on the screen and they exclaimed excitedly every time the graph raised a point and groaned when it dropped. It was like watching a tennis match. One student even joked about their "cheering" for a line. (TW-AN-3, p. 12)

While enthusiastic participation is the hallmark of an engaged student, once the lustre of a new and exciting activity wears off, some seemingly engaged students might also lose engagement. One might consider those who continue to diligently persist in efforts towards their own project as a student who can see value in the activity at hand.

*Value.*

Schlechty (2002), Fredricks (2004) and Zyngier (2008) are scholars that specifically mention valuing the activity as they described an engaged student. Several student comments from SotB readily demonstrated the value they placed on the experience. During the interview, in response to a query about why continue with the experiment despite problems with sample preparation, a student explained:

I knew it would be worthwhile in the end. And it would be worth the effort and it would be a fun experience going on this trip and being able to test our ideas. I was interested in finding out about our idea about the content in [the samples]." (ST-I-8, p. 3)

Another student described the experience in this way:

I felt that the experience at the Synchrotron, and all the preparation and analysis/follow-up work that went into this project was a great one and a very positive one as well. I had

a lot of fun with the project, but I also discovered how much tedious work goes into an actual experiment, before, during and after the excitement of both gathering the data (especially the first graph) and finding a possible match for it were well worth the work, though. I also learned how difficult decision making can be when a consensus is needed. (ST-FS-4, p. 2)

The following two quotes show the value that teachers perceived for their students:

I enjoyed seeing my students engaged in real science. Although experiments in class are valuable for their education, they're no substitute for real experience in a lab doing real experiments. They are more engaged and they take far more away from the experience. (T-FS-3, p. 10)

I feel that the experience enriched the study of science for the students. It allowed me to make the study of science more relevant and therefore more interesting. The students were able to take school learning and apply it to real life. The fact that the student results had meaning and were real made the whole experience more meaningful and real. (T-PS-11)

One of the questions on the feedback evaluation surveys asked participants if they found anything of value in the experience. The most common response to this included a reference to choosing a career. Generally students expressed an appreciation for the opportunity to experience and gain insight into a scientific career as this quote does, "I feel that I have gained insight into the research field by experiencing it first hand at the CLS." (ST-S-11, p. 3) Having presented evidence of engagement for most of the seven indicators in the framework, there remains only one left to demonstrate, contribution.

*Contribution.*

Contribution, as an indicator within a student engagement framework developed from a review of the literature, is in the context of asking questions or contributing to a discussion. The nature of the questions asked by students who are engaged are typically high level questions. Similarly, the discussions they hold are at very high levels. These are outcomes specifically referenced in the US-based NSSE 2000 Report and are a focus of the work of Kuh (2009) and Wishart (2009), who spoke of high metacognitive control exhibited by the engaged learner.

An example that demonstrated contribution within SotB was this observation by a scientist when asked “What was obvious [engagement] to you?”:

The fact that they would actually, I mean they were interested, and talking, and thinking, and working collaboratively at the points where we set them up with the samples. And they were scanning the samples and all that kind of good stuff. When they had to make a decision or talk about what data meant, they were doing that spontaneously without, minimal prompting. (SC-I-5, p. 3)

There were several examples where students developed an extremely good comprehension of science concepts and processes related to their project as evidenced by this anecdotal note:

Questions asked by one group of students displayed a very high level of understanding of physics concepts. They stumped me quickly. They stumped the technician on duty in the control room that day as well as the scientists who ventured in and agreed to try to answer their questions. Eventually we found the head of accelerator physics at CLS who could help them understand. (TW-AN-1, p. 2)

Some of the students' comments I noted during their participation revealed high level thinking such as, "We learn exactly what happens and not what we *think* goes on" (emphasis in original, ST-AN-14). This quote revealed that this student made connections between what they were learning about their natural world directly rather than knowledge interpreted by someone else and presented to them. A comment during questions following a presentation to CLS staff, "This is real work. At school we know the answers. Here you could succeed or fail" (ST-AN-4, p. 1) indicated a growing understanding of the difference between school science and authentic scientific inquiry on the part of the students. Seemingly small yet profound lessons, and thus examples of high level thinking, were demonstrated poignantly by this student's statement, "What I've learned that sticks out is that, eventually you just have to try it and see what happens, no matter how much preparation is involved. However, it is extremely important that you are highly prepared, and that comes from planning, research and hard work." (ST-FS-4, p. 2) A similar point is made by another group of students who spent a great deal of time and energy preparing for their experiment. In their opinion, they had a plan for every possible outcome so that they knew what to do next. They were forced, with considerable disappointment, to discard their plan after their initial data set. They realized that while they were well prepared, they also had to be flexible because they could not predict all possible outcomes. They understood, however, that had they not done all of the work, they would not have been prepared to go into uncharted territory. They determined that it wasn't the 'doing' of science that was difficult, it was the 'deciding what to do' that was the hardest part of their project (TW-AN-14). While these revelations are not included specifically in the description of attributes of authentic scientific inquiry, they are part of the culture of professional science research that is sometimes missed in school-based science (Gengarely & Abrams, 2009). In fact, what they had learned was

“that shows we had expectations and that's not science. ... It would actually be really cool if it didn't take up [the element in question]. That's a cool result!” (ST-AN-13, p. 3) Concerned with the rise in use of nano-particles these students hypothesized that plants growing in contaminated soil would take up the particles to the detriment of the plant, and thus the ecosystem. Despite being disappointed in data that disproved their hypothesis, they considered a positive view from a larger societal perspective, demonstrating the depth of their understanding of their project.

The comments and behaviour of these learners have contributed significantly to a rich description of an engaged learner as seen through a framework of attributes indicating engagement within the landscape of an authentic scientific inquiry experience. Evidence of that engagement has been provided through quotes and descriptions arranged in themes that emerged from data. Part of the research question, “What engaged these students?” includes the sub question, “Did an experience in authentic scientific inquiry affect student engagement? To address this sub question one must examine data as it relates to the attributes of authentic scientific inquiry.

### *Authentic Scientific Inquiry and Student Engagement?*

To provide a richer understanding of how each of the attributes of authentic scientific inquiry relates to high levels of engagement, the text that follows provides a selection of evidence that aligns with and expresses the five attributes that were identified as necessary for an inquiry to be considered authentic scientific inquiry, these are: involvement in the design, open-ended format, gathering/analyzing data, communication of results, and collaboration.



*Involvement in the formulation of the question.*

Authentic scientific inquiry is a complex activity. Designing the experiment so that it was of interest to both the students and the scientific community was not a trivial task. Several of the participants expressed that this was the most difficult part of the process. When students were involved in determining what was to be studied and how, more indicators of engagement were noted. The following quotes provide a window into what happens when this attribute was missing. This reflection was recorded in an anecdotal note by the program coordinator, “Some of the struggle seems to come from the lack of understanding of what scan to do and why”.

Later, during analysis of the data, the researcher added:

This speaks to the necessity of students being involved in the design. They didn’t have a complete grasp of the exploration paradigm of research and therefore were unable to contribute meaningfully to the design, and this affected their further understanding and engagement (less enthusiasm, lack of a sense of ownership). (TW-AN-8, p 2)

There were many similar sentiments expressed by students and remarked upon by their teachers.

*Open-ended inquiry.*

As a research facility, the purpose of CLS is to provide synchrotron light for techniques to discover information about the structure and function of matter. This purpose must also be respected in SotB. The students’ projects cannot be demonstrations of known concepts and maintain expectations of a research facility. The CLS staff developing the program anticipated that students would struggle with this concept. Thus a question was included in the feedback surveys and in semi-structured interviews asking if ‘not knowing the outcome’ presented a challenge for them. Students and teachers expressed that not knowing the outcome for their

experiments was a motivator for them rather than a challenge to be overcome. The idea of finding something that was unknown seemed to make the experience more “real” and exciting for students. “We wanted to contribute something to scientific knowledge” (ST-AN-9, p 1) explained one student. This was the scene noted during one group’s experiment:

During the wide scan students recorded a double peak that did not match references. This created a great deal of excitement and confusion. It was interesting to see the students grapple with the concept of not having an answer. They would scan their info and determine [which element] was closest or most likely and confirm with [the scientist]. The idea that [the scientist] didn't know or couldn't confirm was evident in the incredulous expressions and repeated questions. (TW-AN-3, p 11)

This situation motivated the group. Their engagement was obvious and noted when they started a similar scan on a new sample:

The five students were gathered so tightly around the computers that no one else could see anything. They had zoomed in on the graph so it was BIG on the screen and they exclaimed excitedly every time the graph raised a point and groaned when it dropped. It was like watching a tennis match. One student even joked about their "cheering" for a line. (emphasis in original, TW-AN-3, p 12)

The comments of students following their presentation to CLS staff illustrated how important open-ended inquiry was to their experience, “This is real work. At school we know the answers. Here you could succeed or fail,” and “It's boring at school. Here it's more real, unpredictable. We could ask and direct our own learning” (ST-AN-4, p 7).

*Gathering and analyzing data.*

Using synchrotron techniques to gather data was part of what made this experience unique and was part of what appeared to spark students' initial engagement. A teacher commented that the multidisciplinary nature of research at a synchrotron was part of the attraction of this program:

I like the fact that it moves kids out of thinking of subjects in three boxes and starts to bring it all to bear. It's all there, I mean we're doing [a biological sample] but we're using physics to look at it right? And we're looking for proteins which are chemistry, you know what I mean? It starts to show the kids, and the kids start to think that way themselves. Ok, so once you're done with the introductory stuff here, everything rams together now no matter which direction you go. And they start to get excited about science as a big field not 'well I like bio but not physics', and they start to realize that it's an artificial construct. So one of the reasons I like to get kids here is because it's a different way of teaching kids. This is like French Immersion. This is Science Immersion, and we need more of that. (T-I-7, p 25)

Notes from debriefing meetings of CLS staff indicated that those groups able to be more actively involved in the preparation of their own samples appeared also to be more involved in other aspects of authentic scientific inquiry such as data analysis and communication of findings (TW-AN-12, p 3; Walker, 2008).

### *Communication of findings.*

Students expressed the belief that presenting their results was something that motivated them to do well, and to fully understand what they were dealing with, as noted by one student who said, “you got to evaluate yourself on how much you really learned. How much your class really learned and everything, so I liked it. I liked the whole answering questions from grad students and other people that work there so I thought that was really good” (ST-I-9, p 9). The developers of the program noticed that having an immediate expectation of an oral presentation focussed the students so this was added to the program in 2008. A quote presented on page 72 included a teacher’s remark indicating that presenting their results had helped to create a feeling of ownership for students.

### *Collaboration.*

The program was designed for collaboration between scientists and students. Involving an expert to advise and support students as they made decisions throughout the scientific process was necessary to ensure that the results were potentially interesting to the scientific community, an essential piece of authentic scientific inquiry. Several students identified that working with ‘real’ scientists was part of their motivation to participate and that getting to know ‘real’ scientists on a personal level helped to change perceptions as was reflected in this comment from a feedback survey:

I thought scientists were uptight know it alls, but they are actually quite humorous. I think the scientific process. Well the real one anyway, is an amazing thing. You have to be really flexible as a scientist to be able to go with the flow. (ST-FS-4)

The comments of one scientist suggested that engagement was present and displayed in how students collaborated, explaining that:

Because of the questions they asked and the way they [interacted with the scientist] and with each other. Solving a problem when you leave them to it and they're actually engaging with one another and they're not talking about what they did last night but engaging on something to do with their research problem in front of them. It, you know, says to me that that's a genuine level of involvement. It captured their attention to the point where, if you leave them to it, they actually discuss it amongst themselves. (SC-I-5, p 136)

Data generated during this study seems to indicate that for students participating in the SotB program at the CLS synchrotron, there was a relationship between engagement and the authentic nature of their scientific inquiry experience. What follows are the findings that resulted from data analysis.

### *Findings*

#### *An additional indicator of engagement*

Data collected in this study provided strong evidence to suggest that these students were engaged with science learning while they participated in this program. Data suggested that perhaps there was an indicator missing from the framework. Long term involvement might have been another indicator of engagement. When several other indicators from the framework were present, student participation also exceeded the typical year-long participation required for the project. To date, every student that has had an opportunity to participate a second time, has chosen to do so. Several students found other ways to continue a connection with the CLS.

Some sought employment or work placement positions. Half of the team of university students that deliver outreach programs at the CLS are former SotB participants. Many of the student participants have remained in contact with their teacher or me or both in other ways such as email and/or social media, asking for employment references or advice.

As an example of the extent to which one group created a lasting connection to the CLS, thus demonstrating long-term involvement, is where scientific inquiry turned into a venture into the arts. Unbeknownst to the CLS, these students successfully acquired an ArtSmart grant to fund their new project. They learned to cut, weld, and acid treat metal and, under the tutelage of a local artist, they created two sculptures representing their science research. A six-foot version resides in the reception of the CLS facility (refer to Figure 5 for a photo of the completed version of the smaller sculpture) and a thirteen-foot version (the base of which is pictured here in Figure 8) towers over the main entry-way of their school. Part of the students' text on the sculpture presented to CLS explains the sculpture:

is a representation of the Centennial Collegiate student synchrotron experiment titled Spectroscopic Exploration of Acid-Treated Boreal Forest Soil. The stressed coniferous tree clinging to the earth within this sculpture represents the boreal forest and the earth is depicted as a soil profile. This soil profile represents the students' synchrotron scans which show aluminum selectively removed by acid rain. The metal represents aluminum and is acid etched to symbolize acid rain. This sculpture is intended to increase environmental awareness.



*Figure 8: Students pose with the sculpture created to represent the scientific results.*

This particular group of students chose to show their engagement by extending their science learning into art which took long term involvement to accomplish. Other students' demonstrations of long term involvement may not have been so visual, but showed in the other ways mentioned.

I return then to the framework proposed in this study, to use seven indicators of student engagement identified in the literature to identify behaviours consistent with engagement. This framework was useful for analyzing data generated in this study. It may be possible that other scholars interested in the study of student engagement would find such a framework useful as well. I suggest that the framework include the eighth indicator, involvement. Thus a more complete framework might be:

1. Persistence: the learner is persistent in seeking answers and overcoming challenges
2. Dedication: the learner provides a dedicated effort both physically and cognitively

3. Motivation: the learner establishes that the desire to participate is generated internally and not imposed upon from someone or somewhere else
4. Ownership: the learner demonstrates a sense of responsibility towards ensuring success
5. Participation: the learner displays enthusiasm during all or most aspects of the activity
6. Value: the learner indicates that the activity is worthwhile
7. Contribution: the learner asks high level questions or participates in discussions at a high cognitive level
8. Involvement: the learner continues or seeks to continue involvement in the activity or with the people or institutions connected to the activity after its closure.

Having utilized this framework to provide evidence that students were engaged, I turn to the second part of this research question, if the students were engaged, what engaged them? More specifically, I turn to the sub question, “Did experience in authentic scientific inquiry engage them?”

*An additional attribute of authentic scientific inquiry.*

In addition to the five attributes of authentic scientific inquiry identified through the literature, this study revealed additional pieces related to authentic scientific inquiry that might have contributed to student engagement. Those projects that included all of the attributes of scientific inquiry and where students showed the highest levels of engagement also included an additional attribute that was not identified in the literature, student-lead decision making. Decision making power, with respect to the details of what to investigate and how, resided with the students, with the caveat that responsibility for safety was always retained by adult supervisors. Teachers and scientists advised the students, but the students made the final



decisions. During the interview, one student commented that, “Letting the students free to do their project rather than holding their hands the whole way makes it harder, but makes the experience that much better because we are proud of what we have accomplished as a team” (ST-FS-7, p 13). Anecdotal notes of the program coordinator reflected similar sentiments:

Students felt that when decision making, figuring out where to go was more difficult than what to do. They learned to plan ahead but be flexible. They didn't expect to be making all the decisions. It gave them a sense of ownership, that they matter, and a sense of purpose. (TW-AN-6, p 2)

In light of this finding, there should be six attributes of authentic scientific inquiry:

1. Student involvement in the formulation of the question
2. Open-ended inquiry, where the answers are not known
3. Gathering and analyzing data, including sample collection and/or preparation
4. Communication of the results
5. Collaboration between students and scientists as well as among students, and
6. Student lead, where the decision making power resides with students.

*What engaged the students?*

Reviewing, comparing, and categorizing data with this framework as a guide, revealed several themes that provided clues to what enticed students to engage during participation in the program. Previously, while providing evidence of persistence, I explained that we, the program developers, had anticipated the students would struggle with the open-ended nature of authentic scientific inquiry and so asked students to reflect on that. Data, provided earlier in this thesis, revealed that this was not a difficulty for the students, but a motivator because of the challenge it

provoked. It seemed that conducting experiments that are not demonstrations of well known concepts, where answers cannot be checked in a text book, challenged, motivated, and engaged these students.

Several students indicated that leading the research, rather than following instructions, was part of what engaged them. This student summarized the general sense of data:

I think that a few things are crucial for the program. One, please continue to have students decide upon an idea for the experiment as this is what made the difference between an experiment and an experience. (ST-FS-4, p. 2)

Data indicated that being able to conduct experiments where students were able to make decisions rather than following a prescribed direction was a new experience and was part of what made this experience engaging for them.

Another theme that emerged centered on having the choice to participate. Data seemed to indicate that this made a difference to the engagement. A student in a situation where the entire class participated explained that the presence of students who would have chosen not to participate had a negative effect on the engagement of those who would have chosen to participate. When asked how to identify the difference, this was the explanation, “the ones [students] that you could see really weren’t involved, they would have chosen not to go” (ST-I-9, p. 11). In contrast, another student, where all of the participants chose to participate remarked:

I liked the atmosphere and the group work and that sort of thing. And it's fun because it didn't matter to our grades or anything. It was just something we chose to do so we didn't have to kill ourselves on it. (St-I-2, p. 7)

One of the scientists commented that when students chose to participate, they were willing to put more into understanding the project:

Within a small, like minded group, I think it sort of frees them to sit there and talk about, "...this is great! Look at this data we're collecting. That was different from the last one? What does it mean?" then take it to the next sense." (SC-I-5, p. 3)

According to the evidence, when all of the students working on the project have chosen to do so, their engagement in that project seemed to be higher.

Students also indicated that the idea of working directly with a 'real' scientist was part of their initial interest in participating. Their comments reflected that as they got to know the scientist better, their engagement deepened, as this quote indicated:

I think they were the first scientists I'd met and I was, <pause> you think of them as scientists and you expect to see the white lab coat on and see them researching in some sort of lab in the middle of nowhere but that wasn't the case at all. They were friendly and they actually had social skills. <Laughs> (ST-I-1, p. 8)

I wrote this mixture of commentary and quotes in an anecdotal note following a conversation with a group of student participants. It revealed how students were excited about getting to know scientists and how it seemed to prompt them to learn more:

At the end of the first day (orientation - no beamtime yet) students were asked what surprised them. "How wrong our impressions of scientists were." They envisioned a serious lab environment. "They joke around!" Impressed with how much they [the scientists] know. They come and answer questions very easily but are fun. How on earth

did they conceive it? All the tubes and cables - it's a masterpiece of engineering. I'm really thankful I'm here. (TW-AN-3, p. 4)

It seemed from data that working directly with scientists created some initial interest and engagement with the project from the very beginning. As the relationship between scientists and students deepened, so did engagement in the project.

So too, did the idea of conducting 'real' research and making a 'real' contribution to science also seemed to engage students as was shown in this quote:

Students became embroiled in a rather heated and emotional debate when they discovered there was [a particular element] in their sample. They were concerned there was potential for mining companies to decide to enter the area as a result (direct or not) of their research. This excited some students (economic development) and disturbed other (environmental impact). The debate lasted for some time before their scientist reminded them that the presence of [the element] had very little bearing on their research question and so they needn't address it at all. (TW-AN-3, p. 1)

This comment, from an application for beamtime written by a student, clearly demonstrated engagement from anticipated contribution:

We will also be allowed to conduct research, not simply have a trial run, but contribute to the scientific community itself, a prospect that is endlessly exciting. It is an experience we are all quite excited to be taking part in. (ST-Report-3)

Another theme emerged as several students remarked upon the insight into research they gained through this experience and related the experience to career decisions, as this student commented in the feedback survey:

I feel that this experience was very valuable. It is a once in a lifetime experience. I will probably never use the synchrotron again, but I wish I could. This experience taught me the real scientific method, not like the one we learn in school where you know the answer before you start. I am going into science next year so it is very valuable to learn what real scientists do before I am learning from them. (ST-FS-4, p. 4)

Data indicated that when students connected their SotB experience with future education or career decisions, they were curious and engaged in the project.

Comments from various sources indicated that both teachers and students recognized how different an experience like SotB was from school science, which seemed to engage students, even though they also found it more difficult:

“Plus, missing 2 days of school was quite appealing, though this was more work & more fun than being in school.” quote from lab book planning for presentation (Lab Book, p. 109)

There was just something different. Not just an average thing. We're all just big science geeks. It got us thinking about more different things. Beyond regular high school stuff, challenging us a little bit more, that sort of thing. (ST-I-2, p. 6)

As a teacher it makes my heart sing to have the kids experience the same joy of science and learning that I have. It is very neat to see students want to learn because it helps them understand what they want to know, rather than trying to learn for the exam. It is very cool to see the fire and passion for science and learning ignite. (T-PC-11)

YES! I learned more through this experience than I ever have through science class. (ST-FS-7, p. 13)

While the specifics of how the SotB experience was different were not always articulated, the theme of being different emerged as a common theme that engaged these students.

It seemed that once students overcame a challenge, that success motivated them to meet the next challenge. The more effort put into their project, the more engaged they were and willing to invest further effort. Evidence to support this was provided in a quote from a student interview on p 70 (ST-I-2, p 1). This seemed to extend to a desire to complete the project once it had started. Discussion with a student revealed that while they were 'interested' in the project from the beginning, once they arrived at CLS and began conducting the experiment, they became 'committed' to it, "I guess like after doing the experiment you kind of realize the merit of it and 'Wow! Look at what we actually did!'" (ST-I-8, p. 12). When asked why continue with writing articles and posters after the excitement of the experiment was completed, a student replied:

I started it so I was going to do a good job all the way through and and finish. Um, maybe the same reason I'm in engineering. I'm a little bit bull headed sometimes.[Laughs] I thought it was interesting so I just stuck with it. It was what I did. (ST-I-1, p. 5)

Having reviewed, compared, and categorized data with the indicators of engagement framework as a guide, the following emerged from several sources and participants as themes that engaged students during their participation in SotB.

1. Open-ended: conducting experiments that were not demonstration and for which there was no known answer

2. Student-lead: when students were empowered to make decisions regarding the direction their research would take rather than following pre-set instructions
3. Choice: students who chose to participate were more engaged, and where some participants had not chosen to participate a negative effect on the entire group was noticeable
4. Working with a “real” scientist: as familiarity increased with scientists, so did student engagement
5. Contribute to scientific knowledge: sometimes phrased as “real” research, when the anticipated answers were expected to be of interest to the scientific community, students were engaged
6. Career related experience: connecting the experience to anticipated careers or further education
7. Experiencing science that is different than “school science”
8. Overcoming challenges: successfully overcoming one challenge motivated students to increase engagement to meet the following one(s)

It is interesting to note at this point how many of the point on this list of what engaged these students are similar to the list of attributes of authentic inquiry. Both lists specifically mention open-ended inquiry, student-lead projects, and creating novel scientific information. If one considers working with scientists to be similar to collaboration then half of the items that engaged students in this context are directly related to the authentic scientific nature of the program.

## *Conclusions*

In this study we were interested in developing a richer understanding of student engagement in relation to the unique and successful science research outreach program, SotB, at the CLS synchrotron. To accomplish this we reviewed literature and, with the addition of an indicator revealed through the data, developed a framework through which student engagement could be studied that consisted of the following indicators: persistence; dedication; motivation; ownership; participation; value; involvement; and contribution. One could conclude from data resulting through this framework that students participating in SotB were highly engaged. Analysis revealed several factors that contributed to student engagement such as projects that were open ended, student-lead, and where students chose to participate. Students were engaged by the idea of working directly with scientists, conducting research that contributed to society's collective scientific knowledge, an experience that was different than school science, and that helped them with further education or career choices. Finally, as each challenge was overcome, students were more engaged and were willing to work harder to overcome the next challenge. This experience inspired one student to pursue a higher level of education than what had been contemplated prior:

I guess that would be one of the biggest decisions I've made is to go to university and that was kind of a motivator. Let's see, what I got out of it was just kind of a bit more of work ethic. The whole experience of it just caused me to think of things a little broader and ... set my sights higher. (Interview 1, p. 8)

The findings of this study might provide useful in two ways. First, researchers interested in investigating engagement, might find the framework developed for this study useful. The framework provided a method of identifying when participants in a given activity are engaged,



as well as lens to analyze the resultant data. While it was developed with the intention of use within a science education context, with an interest in student engagement, the concepts are not restricted to science and might be of use in other disciplines. Additionally, slight modifications might provide a helpful perspective to investigate engagement of participants other than students.

From a practical implementation perspective, the results of this study imply for teachers, curriculum writers and informal science education program developers that programs incorporating all six elements of authentic scientific inquiry may increase the levels of engagement for students/participants and may be an important part of a well-rounded, meaningful science education experience. It seemed that the elements of authentic scientific inquiry worked together to engage the participants of this program. No single element stood out and the highest levels of engagement were present only when all elements of authentic scientific inquiry were present. Comments from all participants also revealed that choosing to participate in the program rather than being required to participate, as part of a course, for example was also an important factor in engagement. I advise also that active student involvement in collecting and/or preparing the sample be considered as part of data collection and analysis from the list of elements identified in the literature. Scientists working with more than one school group, observers of the program, and the coordinator of the program all noticed that student actively involved in their samples, tended to display higher levels of engagement (CLS SotB Review Meeting 2009). In closing, I leave a summary of the experience as presented by one of the teachers:

[A] disconnect is the way in which textbooks portray the real life experience of scientists. You cannot duplicate the random happenstance of human beings working with technology and other human beings in the process of science and discovery. How you

deal with data, how you deal with anomalies, how decisions are made as to what the next steps are, the realities of funding and marketing, time constraints, real time costs, etc., cannot be accurately portrayed in a textbook and can only be approached in a classroom. These things must be experienced for people to really understand the social context of "real science". This, to me, is the pre-eminent value to our students' through their participation with the beamline project and this value extends to the paper writing and presentation process. (T-FS-4, p 5).

While it appeared to be true that the authentic nature of the scientific inquiry in this instance did contribute to the engagement of the students who participated in the program, extending this rationale to other programs should only be made cautiously. Chapter four included a list of eight things that seemed to contribute to the engagement of the students: open-ended inquiry, student-lead project, choice to participate, working with a 'real' scientist, contributing to scientific knowledge, experience related to possible career choices, and experience that was different than school science learning, and overcoming challenges. Some of this list and the list of attributes of authentic scientific inquiry are similar thus making it difficult at best to attribute the complex concept of engagement to either. Both of these lists provide consideration for those interested in either studying student engagement or attempting to entice students to engage.

## Chapter Five: Can Authentic Scientific Inquiry Result In Transformational Learning?

There were two guiding research questions for this study. The first focussed on engagement. Earlier thesis chapters addressed this question and concluded that there was evidence to show that students were engaged while participating in SotB and that the nature of the experience, authentic scientific inquiry, might have contributed to that engagement. The second question and sub question focused on the interplay between the overlapping elements of this landscape (see figure one), transformational learning. Is there evidence that transformational learning took place for any of the student, teacher, or scientist participants? If yes, what contributed to the transformational learning considering the landscape of authentic scientific inquiry and student engagement? The previous chapters have described the SotB program, establishing it as an experience in authentic scientific inquiry and that students were engaged during their participation in the program. The findings presented were based on analysis of data guided by frameworks developed through literature review. The purpose of this chapter is to show if analysis of data determined a potential for transformative learning in this particular landscape. As a paper under development and intended for publication, there is a necessity for duplication of content from earlier chapters, but I will endeavour to summarize or refer to other parts of this thesis wherever possible.

### *Introduction and Methods*

What is transformational learning? The foundational work of Mezirow (1997) defines transformative learning as a change in a person's frame of reference or view of the world. Using an analogy of problem solving to aid in explanation of this definition, consider the process where

a learner approaches a problem (Kreber, 2006). The learner must consider this problem from their personal frame of reference. Should the resolution of the problem not fit that frame of reference, the learner must come to terms with that discrepancy. Upon reflection that learner might shift their perspectives or assumptions associated with that frame of reference to accommodate or include the new or expanded understanding. According to Imel (1998), these could be considered routine and expected parts of the learning process. For the purposes of this study, these would be referred to as perspective transformation. On occasion the cumulative effect of several perspective transformations or a significant event could cause a transformational learning experience. To continue the analogy, a transformational learning experience would require a change in the premise upon which the problem was predicated. The learner might reflect upon and realize a need to adjust, not just their understanding of the problem, but the very way the problem was approached. Mezirow (1997) refers to this as an epochal transformation. A transformational learning experience is one where a participant's point of view, perspective, or habit of mind is challenged through their experience. If, upon reflection, that point of view, perspective or habit of mind shifts or changes, one can assume that the participant underwent a transformative learning experience. For the purposes of this study, two categories of transformative learning were considered. A perspective transformation was considered to have been present when assumptions were challenged and changed. Epochal transformation was considered to be present if a significant change was noted, similar to Mezirow's epochal transformations. Within the context of this study, however, one must be able to identify when perspective transformation or transformational learning had occurred. The next section will address this, using indicators presented through the literature.

Data for this study were collected using a qualitative research approach involving analysis of several text-based documents: program reports, non-peer reviewed articles, and media reports, and others; field notes in the form of: field notes I collected during the progress of each groups' experience; my personal correspondence with students and teachers during the course of their participation; feedback evaluation surveys that were routinely sent to all participants; and ten semi-structured interviews of students, teachers, and scientists. Carson and Fisher (2006) established that a change in behaviours, as an indicator of transformative learning can be determined through an analysis of a person's writing. Reflection upon one's frame of reference is an essential component of transformational learning (Carson & Fisher, 2006; Cranton, 2002; Imel, 1998; Mezirow, 1997). When analyzing a person's writing or behaviour in search for evidence of a transformational experience, there are four main features to consider (p. 707):

- Identification of values, beliefs or assumptions
- Changing and/or reassessing values, beliefs and assumptions
- Making connections with cultural, social, and political realities; and
- Acting differently from habituated responses and/or taking on new behaviours

Additionally, Kreber's (2006) study that focussed on university teachers identified several behaviours that could be used in this study to identify transformational learning in high school teacher participants including: experimenting with alternative teaching approaches; writing critiques on "how-to teaching books"; writing an article on how to facilitate learning in the discipline and submit it to a scholarly journal; presenting findings from classroom teaching experiments at teaching-related sessions at conferences; and showing how goals of one's teaching relate to what students need to live successful lives.

For this study, indicators based on the literature were identified and outlined in Table 2 (p. 21) in the first chapter. To summarize, this study considered that a perspective transformation occurred if data revealed evidence that a participant became critically aware of assumptions; reflected upon challenges to those assumptions, and changed those assumptions or associated points of view as a result. Epochal transformation as identified by Imel and Mezirow, was considered for this study as involving a more significant change in a frame of reference or world view. In the context of this study, evidence of epochal transformation was considered present when reported directly by a participant, in that they described a significant change, or it was reported as an observation of a change in behaviour by another participant. Specifically, data generated in this study were reviewed and when a comment was made that indicated a participant had reflected upon his or her own frame of reference and changed that frame of reference as a result, it was recorded in field notes. Also, if a participant made an observation about a change in perspective or behaviour, as an indication of transformational learning, that was also recorded. These field notes were then analyzed to determine if themes or trends emerged where I might be able to determine if transformational learning had occurred and if insight into what might have contributed to that transformational learning could be gained. The next section shares some of the quotes and insights considered within this framework of transformational learning analysis.

### *Evidence of Perspective Transformation*

To be considered evidence that the participant experienced perspective transformation, literature reviewed previously established that the person must have first recognized that their understanding was based upon a frame of reference, reflected upon a challenge to that frame of

reference and changed accordingly. If, based on the quote, I felt that the experience of participation in SotB had challenged the perspective(s), indicated that he or she had reflected upon that, and had changed their perspective(s), I considered this evidence of perspective transformation. This section is devoted to sharing evidence that pointed to possible perspective transformation of participants in SotB. There were several perspective transformations that were evident from data.

Students reported that as a result of their SotB experience, their perspective of scientists changed. This change was an unmistakable theme in the data. Several of the student comments indicated that their perspective of scientists prior to participating in SotB seemed to closely match the stereotype described by Türkmen (2008, p. 56), as people who “wear a white coat and work alone in a laboratory. Scientist was elderly or middle aged and wears glasses.” Several quotes from surveys revealed that aspects of this stereotypical perspective were altered. “I learned that scientists are just normal people not the crazy guy in a lab coat most people imagine” (ST-S-15, p. 2) and “I learned that researchers and scientists are more normal than I imagined them to be” (ST-S-14, p. 10) showed that these students perceived scientists as “crazy” or somehow not “normal” until they got to know them. The attire of a white lab coat, or lack thereof, was a common observation. The following quotes provided examples of student comments, “No lab coats! The shock of the century! And they're nice people too!” (ST-FS-10, p. 13) “Its [sic] no longer people in lab coats but people in normal clothes” (ST-S-10, p. 13). To serve as an example, I offer this description of a change in perspective by a student during their interview:

I think they were the first scientists that I'd met and I was, you think of them as scientists and you expect to see the white lab coat on and see them researching in some sort of lab

in the middle of nowhere but that wasn't the case at all. They were friendly and they actually had social skills. ... I think that was kind of what we noticed the most was scientists are, the ones we were working with weren't the stereotypical scientists. (ST-I-1, p. 8)

The quote above also demonstrated students' view of a personality type that presents scientists as lacking social skills but possessing, and requiring, extreme intelligence, the epitome of which has been trademarked by the character of Sheldon in the popular television show Big Bang Theory™. Several students' comments revealed a change to this perspective of scientist personalities. A few examples are provided here:

I realized that researchers are not all geniuses and that they have achieved their status through curiosity and hard work. This is something that I wish to work towards. (ST-FS-1, p. 5)

I got to know them closely and figured that Scientists [sic] are not extraordinary beings they are just normal human beings with a good work ethic and they work very hard. ... They are not the most intelligent people on the Earth, but they are diligent, hard working and have a burning desire to do something. (ST-FS-6, p. 30)

I thought scientists were uptight know it alls [sic], but they are actually quite humorous. (ST-FS-1, p. 4)

This concept of scientists as lacking in humour was also the topic of several comments. One group of students was asked at the end of their orientation, what, if anything, had surprised them. They replied, "How wrong our impressions of scientists were!" They had envisioned a serious



lab environment but found, “They joke around!!” (emphasis in original, ST/TW/ST-AN-3, p. 4). During a casual discussion, a different group of students was asked if their experience had changed their view of scientists to which their collective response was that, “scientists were human, normal and casual. They have a sense of humour, but nerdy. They expected them to be much more serious” (TW-AN-6, p. 4). Data also suggested that teachers’ perspectives of scientists might have undergone a perspective transformation as well. This comment from a teacher, “Charisma is more important than I thought in research leaders” (T-FS-15, p. 1) showed some reflection on the personality traits of successful scientists though it was the only comment of its nature. However, several teachers made comments about how open scientists were to sharing their expertise and time, as was shown in these examples:

I was pleasantly surprised to see how interested the professionals were in teaching kids. I was surprised to see how important they thought the kids were. I found the researchers to be friendly and approachable. I was initially hesitant to participate because I thought I would be wasting the scientists' very valuable time due to my lack of knowledge/expertise. I found the researchers to be very excited about what they were doing and very willing to share. They were very patient and helped guide us through everything. (T-FS-6, p, 10)

My perception of science and how it is done was fairly accurate, but I did not expect the researchers to be so welcoming and so willing to devote time to high school students. (T-PC-1, p. 2)

surprised? The researcher's patience and openness. (T-FS-10, p. 5)

Evidently, according to these students and teachers, scientists were: curious, hard working, cool, busy, regular people, dedicated, patient, resourceful, sleep deprived, casual, relaxed, easy to talk to, knowledgeable, charismatic, down to earth, open, flexible, flawed, have a good work ethic, diligent, brilliant, real, surprisingly with tattoos, humorous, welcoming, and normal, but this list was not what these participants expected before their experience.

A second theme that emerged from data revealed a perspective transformation centered on a change in students' views toward the nature of science. While no comments articulated specifically what the perspective was prior to participating in SotB, comments clearly showed changes after reflection upon what they thought science was. It seemed that several students came to realize that science was more complex than they understood prior to their experience as these quotes from a newspaper article and field notes demonstrated, "I guess I just got an appreciation for the depth of things that are around us. And I realized how complex science can get" (French, 2006) and "before this, I didn't relate biology to other areas of science, before the experience. Now I see how all are needed to address questions" (ST-AN-9, p. 2).

Similarly, data revealed a perspective transformation in relation to the nature of scientific research. Several student comments demonstrated an understanding that authentic scientific inquiry was quite different than their school-based inquiry experiences as this student explained, "It was really great to experience the scientific research process, since the way things actually get done is quite different from the way high school labs are conducted" (ST-FS-1, p. 2). A similar sentiment was expressed by this student, "It's eye opening to see the scientific process. I didn't know what I was getting into until we were doing it. It's creative and flexible - not as structured" (ST-AN-6, p. 1). A better understanding of what students perceived as different from their school-based experiences could be obtained from this quote:

I thought that research was so easy before. I thought scientist just had a question and did their experiment and found the answer; but there are so many more variables to it than that. You go in looking for one thing and don't find that, but find many more great things. (ST-FS-2, p. 5)

After experiencing research through SotB students realized that their expectations of time and effort for scientific research wasn't realistic as evidenced in these example quotes, "Labs don't take one day let alone 75 minutes. A few months or a year would be good!" (ST-AN-14, p. 4) and "Although expected, the trials and tribulations of doing 'real' research was probably still the most surprising. The amount of time and dedication required for successful research was very eye-opening for me" (ST-FS-12, p. 5). Several students also came to the realization "that research is an ongoing challenge that gives more questions than answers" and "that it is never ending. Each answer leads to another question" (ST-FS-13, p. 7 and 9 respectively). Finally, the perspective of having to build scientific knowledge was revealed as a new addition to student understanding of the nature of scientific research. The next two quotes provide examples of evidence in data:

This experience definitely changed my view of research. It made me realize just how many experiments with uninteresting results are done before one is done that teaches us something new and unexpected, and how preliminary studies often need to be followed up with more in depth studies in order to discover something meaningful. (ST-FS-1, p. 2)

I didn't know that science was so hit and miss with the results of experiments, but I liked the 'unknown' factor of the process. ... I also discovered how the scientific process proves

something over the course of many experiments which build upon one another, checking for mistakes and using previous knowledge. (ST-FS-2, p. 2)

I, personally, experienced a 'eureka moment' regarding the nature of scientific research. The following reflection recorded in my anecdotal notes explained:

Generally the feeling on this experience is confusion. [The beamline scientist] is very excited about the possibilities of this experiment but the students are struggling with making the connection between the detail & volume of information. Teacher expressed that the students feel that they are looking for some big question they will answer. [Teacher] has advised them to consider it information gathering. This feeling continued through the big discovery ... until I pointed out that it was a paradigm shift the students/teachers/I hadn't undergone yet. We were still thinking to answer a question, the scientist was exploring, using all the tools at his disposal ... to see what he could see with each one. (TW-AN-8, p. 3)

According to data in this study, students found they had to transform their perspective of the nature of scientific research to include a creative and flexible process, with multiple variables that made research more difficult and complex so that it required considerably more time and dedication. In addition, instead of immediate answers they realized that scientific knowledge is built slowly, over time, with many experiments, several of which produce uninteresting or negative results.

In summary, data supported the possibility of several perspective transformations, primarily in student perspectives. Their view of what a scientist was and what some of the related personality traits were seemed to shift away from the crazy, serious, intelligent extremes

of the stereotype to a “normal” person who applies their intellect and works very hard. Student views of the nature of science appeared to expand to include a much more complex understanding of what constitutes science in their world. Likewise the nature of scientific research also expanded to accommodate a much more complex process that was quite different than what they had been familiar with through school. Among the evidence of these relatively small perspective transformations, there seemed to be a few moments where an epochal transformation had potential to occur. The next section will provide evidence to support that possibility.

### *Evidence Of Epochal Transformations*

An epochal transformation involves a significant change in a frame of reference such that it changes the world view and/or the habitual behaviour of the individual who has undergone the transformation (Imel, 1998). According to Mezirow (1997) it is possible for several perspective transformations to have a cumulative epochal transformation effect. In this study, there were data supporting both epochal transformation for some participants of SotB as well as evidence of smaller scale transformational learning that were evidenced in changes to behaviour. First, I will outline data that demonstrated some participants experienced enough of a change in their frame of reference to cause a lasting change in their behaviour thus suggesting transformational learning, although on a small scale. I consider these examples to be of epochal transformation because they seem to be more significant than perspective transformation as they appear to have altered the behaviour of the individual and persisted after the end of participation in SotB. The second part of this section will provide three examples that might be considered significant or epochal transformation in this situation.

*The potential.*

One of the themes that emerged through data analysis centered on student self-perception. As a result of participating in SotB some of the participants seemed to come to see themselves as scientists and involved in research. One student stated specifically that the most significant thing they learned from their experience was that, “the job of a research scientist is not out of reach” (ST-FS-15, p. 7). In response to a similar question another student replied, “It kind of made me realize that for the most part hard work always pays off” (ST-I-1, p. 9). A teacher made the following observation that a student participant, “was much more willing to tackle problems in physics that would scare [the student] before” (T-I-7, p. 36). Interestingly, this theme of shifting self-perception, to see themselves in science, was not restricted to the students. Some teacher participants also showed changes in how they perceived themselves involved in science. This quote provided an example, “I always thought of research as being completely out of my range of understanding, but it can actually be done by "real" people!” (emphasis in original, St-FS-11, p. 1). At the least, both students and teachers could see themselves as part of the research community after participation in SotB, as evidenced by these quotes:

I've learned that science in school is really not what we are doing. I have learned that REAL science involves more connection with the REAL science community and I would love to see more connections made with the schools and scientists. (T-FS-14, p. 10)

(Interviewer) Do you see yourself differently? (Student) Yep, more scientific, more involved in the community for sure, than someone who was just say studying. I actually did the research. I put everything together. (St-I-9, p. 19)

Data provided thus far should likely be considered perspective transformations. They represent a shift in participants' perspective of themselves and whether or not they could be scientists or involved in science. To consider these data part of an epochal transformation, there must be evidence of significant change and/or habitual behavioural change. If one assumes that these shifts in perspective had a significant effect on self perception, this would reveal itself in other ways. The next four quotations are from teachers as they described the impact they felt the SotB experience had on their students:

My kids came to see me at the end of last year. It was the most beautiful experience in their life. It was a life changing experience. It had a profound impact. It gave them self confidence that they can succeed and can try. (T-PC-10, p. 1)

They were an outstanding group of kids. It's very satisfying to watch them continue on with their lives because they've done some, already in three years, some remarkable things. I don't know whether they would have done exactly the same things if they'd not been involved in this project, but my feeling is not. I think this project gave them confidence. I think it gave them the feeling that science is not intimidating. (T-I-3, p. 2)

The change didn't seem to be very big. It was subtle but very important in that their respect for what the scientific community does and how they operate has increased. So they respect the scientific process more so than they would have before they went. ... They were doing a lot more planning, and taking a leadership role within their lab group, and going through the the scientific process of doing a lab, reporting results and concluding the results. (T-I-6, p. 6)

Of 4 students when we started, 2 were pretty sure going into science and 2 not - now all four are - it was a life changing experience. (T-PC-14, p. 3)

These descriptions of four different groups of students showed that student behaviour did change and that their teachers attributed those changes to their participation in SotB. It could be argued that the perspective shift in self-perception of these students was significant enough to raise their confidence when involved in science and that this persisted for the students, and is thus evidence to support an epochal transformation experience.

To build on the previous point that the self-perception perspective transformations were significant enough to be considered epochal transformations, data suggested that the SotB experience had an effect on some of the students' education and career decisions. Most of the students were participating in SotB as an extra-curricular activity, meaning that they chose to participate and that they were not receiving academic evaluation and credit for their work. One could assume from this that the student participants in SotB were likely to have already had an interest in science and might have been planning to further their science education and consider a career in the sciences. When asked if their SotB experience had an effect on decisions related to their education and career choices, the overwhelming response was that it confirmed their desire to enter the sciences. Here is an example of these types of responses, "I knew that I would take sciences in university but I guess this experience has even made me want to pursue that career even more" (St-S-11, p. 2). There were a few responses that provide insight into how the experience affected the decisions of some of the other students. It seemed that for some students, the SotB experience helped them understand that while they had a keen interest in science, that didn't necessarily extend into science research:



This SOTB experience increased my interest in pursuing a science career in the stress [note: writing was illegible and 'stress' is my best guess] of scientific research, but I'm taking courses oriented around how science affects society in university. (St-FS-13, p. 11)

During a discussion of the student's post-sec training they were enrolled in at the time of this study, the student explained that the course was not research oriented but certainly lab-based:

(Student) It is, but I thankfully have this potential to get into research if I want. That's what kind of intrigued me about this program. (Interviewer) Is it possible that your experience had an effect on that career choice? (Student) Possibly, because I kind of got a taste of what research was like but I don't really know for sure if that's what I want to do so I chose something that gave me options. (St-I-2, p. 11)

There were also a few students who intimated that their SotB experience helped them to understand that they did not want to go into scientific research. It seemed that for most of the students who participated, their SotB experience had an effect on the decisions they made regarding further science education and/or whether or not to pursue a career in science. Since these are observable behaviours and major life decisions, I considered the data as evidence to support the potential for epochal transformation in this situation. As previously pointed out, however, students were not the only participants in SotB who were affected in this way.

Behaviour of some teacher participants also changed as a result of their participation in SotB. Several of the teachers reported that they had changed some of their classroom practises because of their experience, thus providing support for the potential for an epochal transformation for teachers in this situation. A teacher reported in their survey (T-FS-14, p. 1)

that as a result of having worked in a situation where the research was not a demonstration, as is typical in classroom experiments, she was forced to face a fear of uncertainty and the unknown, “I did not enjoy the unknown. I like to have all of my answers before I step into the ring. BUT that is part of my learning and I love that part too” (emphasis in original). In another part of the survey a comment from this teacher showed how facing the unknown changed their behaviour, “As a high school teacher, I'm so used to having to do it all alone that now I feel much better about at least asking people at the University for help.”

A different teacher talked about how science in school had a culture of punishing mistakes:

One of the things that's stuck with me and I'm actually doing some experimental work with my kids this year, is this culture of punishing mistakes. My very first talk that I heard in this building [at CLS], somebody asked [the scientist] “Do you guys ever make mistakes with this big equipment?” and he was so quick to say that, “Man, we make more mistakes than we get things right around here.” He said, “But that's where we do our learning.” And so now, I'm starting to look at ideas and well how can I promote making mistakes. (T-I-7, p. 30-31)

This teacher provided several examples of how novel methods of assessment were being applied in the classroom. The quote above showed that the SotB experience played a role in the reflection upon and changes to current assessment practises and thus could serve as an example of an epochal transformation.

Changes in classroom practise were observed for two other teachers as well. One teacher connected a change in how material was presented to the SotB experience in this way:

My teaching is now kind of a little bit more focussed on a driving question. So rather than just teaching a specific concept because that's how it follows the curriculum, I might put forth a question to the students and build the concept around that question, implement all the preciseness and precisions of that concept as we go throughout the unit. (T-I-6, p. 5)

Since this teacher recognised a change in practise and reported it during an interview regarding participation in SotB that demonstrated there was reflection and a subsequent change in behaviour connected to the SotB experience, an example of Carson and Fisher's (2006) description of transformational learning. The second example of a change in the practises of a teacher was an observation from a student while reflecting on differences in school labs after the SotB experience, "he made it open-ended for us, he wouldn't tell us what answer we should get when we do this lab." (ST-I-9, p. 10) While it is impossible to really know what motivated this change for the teacher, it did demonstrate a change in accordance with a key feature of SotB and so might be considered evidence of an epochal transformation for that teacher. While it seemed that the examples provided could be epochal transformation, there were examples of spaces where epochal transformation were more obvious. These are presented in the next section.

#### *Stories of epochal transformation.*

The previously provided examples were of potentially significant changes in a frame of reference, self-perception in relation to a career in science or 'doing' science, that lead to significant life decisions for students. As well, I have provided examples of situations where teachers have changed their practises as a result of reflection upon their SotB experience. These could be considered evidence of transformational learning, but not necessarily the epochal

transformations referred to in Mezirow's work. There were, however three stories shared during interviews that could be considered as epochal transformation in this context. The first story was revealed as a recurring topic throughout an interview with a student. As we discussed the student's experience participating in SotB and what he learned through that experience, the student referred to a difference in the way he thought about things. Although difficult to articulate, the student referred to a lasting effect that now set him apart from his university colleagues. It seemed the student felt that because the other university students had not had an authentic scientific inquiry experience with research similar to SotB while in high school, their thought processes were different. Those students were not able to understand research as well:

But I know my thinking has changed because of it. ... I could say that when I was learning about research in class and everything, it changed the way I think about, like, how they went through the process of designing and the process of getting, like preparing and doing up everything like that. Yeah, like I can understand it a lot better, I think, than most students. (ST-I-9, p. 17)

The student mentioned several times that because he already had experience with research, this set him apart. It seemed the student more closely identified with the research community compared to his student colleagues. This student felt "more scientific, more involved in the community for sure than someone who was just say, studying, I actually did the research" (ST-I-9, p. 19) When offered the opportunity to summarize what the most significant effect from the SotB experience was, the student said, "the entire experience just changed how I think" (ST-I-9, p. 19). Changing how someone thinks, to the profound extent this student implied, would indicate that they had experienced an epochal transformation.

The second story also centers on a profound change in a participant's world view that affected the life decisions of this student. In this case, as a direct result of participating in SotB, this student realized that the career path they had planned was not what they really wanted. In the few months after participating in SotB and leading to graduation from grade twelve, the student decided to enter engineering instead of the construction industry. These snippets of the interview provided the story in the student's words:

(Interviewer) Do you think programs like that are important? (Student) Yep I do cuz [sic] it was a little bit of a motivator for me when I came too. Just that there's a lot beyond a high school education. That was fairly big for me, just realizing that there's a lot more out there ... that is there to experience. (St-I-1, p.5)

I think it just kind of motivated me to look for a higher education in, I chose engineering.  
(p. 8)

(Interviewer) Would it be fair to say that you're experience has had an effect on the decisions you made in terms of your career path and what courses to take and things like that? (Student) Um, yeah, um I think it did. It was kind of a for sure thing after that.

Like this, "I'm going to look for a university" cuz [sic] before that I had kind of considered just going straight into construction. Umhmm and that was kind of the, "all right, I don't want to do construction any more. I want to look for a higher education."

And I guess that would be one of the biggest decisions I've made is to go to university and that was kind of a motivator. Let's see, what I got out of it was just kind of a bit more of a work ethic as I was saying before, and just the whole experience of it was, just

caused me to to think of things a little broader and like you were saying, set my sights higher I guess. (p. 9)

It kind of opened things up. It helps you see things through a bit different perspective. (p. 10)

As the excerpts from the interview showed, the SotB experience profoundly changed how this student viewed the world and what their role within that should be. This indicated that a epochal transformation had occurred for this student.

The final story that illustrated a epochal transformation for a student has been introduced already in chapter three. The section entitled Story one: A Turnaround, related a tale about a student, referred to in this thesis as ‘Jane’, that had been struggling to succeed in Physics 20, participated in SotB and subsequently become motivated and enthusiastic about science. She has since been successful in taking two more high school science courses as well as university Physics. This story is undeniably one of an epochal transformation. I offer this tale again, but rather than my words, the observations of her teacher. The interview started with a description of Jane’s story, but we returned to it several times throughout the interview:

The girl that struggled with Physics in grade 11, when I got back from this trip and had, the following fall, the Open House at our school in October, her parents came to that Open House with the distinct reason of finding me and telling me, “What did you do to this girl?” and I kinda [sic] wondered what they were asking and I said, “What do you mean?” and they said, “She won’t stop talking about this trip to the synchrotron.” Well this very same girl went on to not only take the forensics course, she took grade 12 Physics. Now she’s just completed first year Physics in university. This girl has gone

from being afraid and getting 51 in Physics 20, to taking on and seeing the sky is the limit in science and it was totally due to the fact that she went to the synchrotron and got to do real science in real time. ... So she's coming out of her shell. She's pursuing science as her passion just cuz [sic]... She was a very, very shy girl. Grade 12 was a great year for her she found her direction and she chased it and chased it. (T-I-7. p 2)

(Teacher) All of them, after this visit, had a very clear and visible bent to pursue science after high school. (Interviewer) And how did you know that? (Teacher) Jane was obvious. Her parents came to me and told me there was an actual transformation in this kid. (p. 35)

I think it's the exposure to authentic science that allows them to see that, "Wow, I can do that." (p. 36)

(Interviewer) Could you see anything in the classroom, in terms of how they approached their science courses afterwards? (Teacher) Jane, yes, she was much more willing to tackle problems in physics that would scare her before. Kay, and that's one big change I saw in her. She suddenly realized, "Oh, I can do this." (p. 37)

Well just to watch Jane go. That was my microcosm of the whole experience is seeing that girl do a 180 on science and now she's pursuing it at post secondary level and nobody would have guessed that in her grade 10 year. (p. 51)

It was clear from this interview that from the perspective of Jane's teacher and her parents, the SotB experience had been a transformational one for her.

## *Implications*

In this landscape where an informal science education program, SotB, enabled high school students to collaborate with scientists to conduct an authentic scientific inquiry project, and where it has been shown that students were engaged in their learning while they participated in the program, this study investigated whether or not this intersection might nurture a space for a transformational learning experience. There were two categories of transformational experiences identified through the literature, perspective transformation and epochal transformation. The first was identified as common and expected in the learning process. The second involved a much more significant and foundational change in a person's world view and usually included a lasting change in behaviour.

Data revealed that there were several indications that students, and teachers became aware of, reflected on, and altered assumptions related to three frames of reference: the nature of science, the nature of research, and the image of a scientist. The perspective of the nature of science transformed for students and teachers in that it became much more inclusive and complex. Possibly as an extension, or at least in relation to this, perspectives of the nature of research were also transformed. Data from students and teachers revealed that their original perspective of research required expansion to include time and dedication to navigate a complex and difficult, but creative and flexible process with multiple variables providing few immediate answers, and requiring many experiments. It became apparent that while not all students held a stereotypically eccentric 'Einstein' image of a scientist, several did. Some students and teachers viewed scientists as alone, formal, and lacking in both a sense of humour and social skills. After the SotB experience, students and teachers demonstrated a perspective transformation where they described scientists as curious, dedicated, patient, resourceful, and knowledgeable people who



were easy to talk to, down to earth, humorous, 'normal' and even cool. Surprisingly, some even had tattoos.

There were also indications of transformative experiences that, while more than a slight shift in perspective, did not seem to meet the descriptions of Mezirow or Imel's epochal transformation. This could potentially be considered spaces of transformational learning but within a third category to be added to the framework outlined through the literature. There were changes to some of the students' perceptions of themselves in that they appeared to have gained confidence and were able to see themselves as scientists or as doing science related activities. Several students also reported that their experience with SotB influenced their decisions regarding further education and career paths. If one connects these two things, the relatively minor changes in self-perception might be considered a cumulative effect leading to a more significant change in how the student views themselves and their role in the world, which could be an indication of a transformational learning experience. If changes in habitual behaviour are considered as an indication that transformational learning might have occurred, then there is evidence that some of the teachers participating in SotB have also had such an experience. Several of the teachers have changed some of their teaching practises after reflecting upon their SotB experience. These changes included changing the culture of the science classroom to allow learning from mistakes, building knowledge from a focussing question, and that accessing experts to provide knowledge is ok. Finally, there were stories shared as examples of significant, epochal transformational learning experiences for three students where there were obvious and substantial changes in how these students viewed their world.

It would seem that this context does potentially provide a space where the transformation of some perspectives can be expected as those changes were revealed in almost every student

group that participated in SotB and these changes were noted in several sources of data. As students become familiar with scientists as individual people rather than images, and as they experience authentic scientific inquiry, their frames of reference shift to include aspects to which they had not previously been exposed. There is potential for epochal transformation experiences as well. The most remarkable examples of epochal transformation were revealed in student data rather than teachers', but there were only a few. Data relating to teachers revealed potential for transformational learning that seemed to cause reflection and change to teaching practises, although not on the same profound scale as the students' stories. Data in this study, while having provided some insight into the experiences of the students and teachers, did not reveal what specifically within this complex landscape contributed to these transformative experiences. As a result, these findings should be generalized only with extreme caution. It would be interesting to pursue further research with teachers who have the opportunity to experience a similar program involving authentic scientific inquiry to more closely investigate perspectives before and after the experience or investigate differences in the perspectives of teachers who do not have a similar opportunities to see how their views of effective pedagogy in the science classroom differ.

## Chapter Six: Summary And Conclusions

### *Context and Landscape*

This study and this thesis have been a five year adventure in authentic scientific inquiry, student engagement, and transformational learning as it relates to the Students on the Beamlines program at the CLS. It has been a wonderful adventure that enabled insight to build at each step. The chapters of this thesis represent the lenses through which I explored the landscape using the research questions as my guide and the methods to navigate. Chapter six, the final chapter will summarize what I have come to understand through this journey and where future adventures might take me, or others interested in further exploration or similar landscapes.

A purpose of this study was to investigate the engagement of students in science learning. SotB presented an opportunity as a site for investigation as a unique program where student participants seemed to be engaged and where there appeared to be the possibility for transformational learning. There were two over-arching questions guiding this study. The first centered on gaining insight into engagement. Are the participants engaged? And two sub questions: What engaged them? Does participation in authentic scientific inquiry affect the engagement of the students? The second question was, is there evidence that transformational learning was taking place for participants? A related sub question was, if yes, what contributed to the transformational learning considering the landscape of authentic scientific inquiry and student engagement?

To address these questions, one must first understand the context of the program. A key feature of SotB was the authentic scientific inquiry nature of its design. To define and describe what is meant by authentic scientific inquiry, I turned to the literature to develop a framework to

assist in identification and understanding of authentic scientific inquiry. According to the literature review presented in the first chapter, a framework to focus understanding authentic scientific inquiry would require open-ended inquiry through collaboration; student involvement in the design of the project, in gathering and analyzing data, and in communication of the results. Chapter one contains an explanation of how SotB fits this framework. Table 3 (p. 27) provides a quick reference. This was the first lens through which this landscape was viewed and a rubric was developed to assist with understanding and comparing the authentic scientific inquiry aspects of each student project (see table 4, p. 38).

Having established in chapter three that SotB as an example of authentic scientific inquiry, I turn to the engagement part of the landscape. A review of the literature, presented in the first chapter, helped to describe engagement and resulted in a framework with the following attributes or indicators of engagement: persistence, dedication, motivation, ownership, participation, value, and contribution. A rubric was developed based on this framework to aid in identification and comparison of engagement between SotB groups (see table 5, p. 40). This framework provided a second lens through which I could survey the landscape to determine if, how, and to what extent students were engaged while participating in the authentic scientific inquiry-based SotB program. Both of these lenses allowed me to delve into the experiences of the participants of SotB to gain insight into their experience.

I turn finally to the place where the fields of the landscape overlap, transformational learning (see figure 1, p.2). As the lenses of authentic scientific inquiry and student engagement were overlaid with SotB, I tried to bring into focus whether or not the landscape nurtured transformational learning. Again a brief review of the literature, presented in the first chapter, provided an explanation of what was meant by transformational learning. The literature defined

two categories of transformational learning, identified for the purposes of this study as perspective transformation and epochal transformation. In both categories the participant must have faced a challenge to a perspective, in the case of the first category, or a world view, in the case of the second, and then, upon reflection, consciously changed that perspective or world view. In the epochal transformation category this change is likely to include altering behaviour related to that world view. So armed with what to look for to find the potential for transformational learning, namely identification of a significant change in perspective and/or changes in behaviour, I set off on my adventure.

Using these frameworks to analyze data generated within this landscape provided insight into engagement and transformational learning. These findings are summarized in the next section.

## *Findings*

### *Insight into engagement.*

An initial finding was that students were engaged while participating in SotB thus addressing part of the first guiding research question. Every group demonstrated several of the attributes derived from the literature review suggesting that the framework might be a useful tool for future investigation into engagement, but data generated did not provide detailed insight to determine if any attribute was significant. Having established that students were engaged, there was also insight into the first sub question, what engaged them? Data analysis revealed several emergent themes connected to student engagement. Students seemed to be more engaged when their project included:

1. Open-ended inquiry: conducting experiments that were not demonstration and for which there was no known answer
2. Student –lead: students were empowered to make decisions regarding the direction their research would take
3. Choice: choosing to participate resulted in higher engagement and the inclusion of students who did not have that choice had a negative impact
4. Working with a “real” scientist
5. Contribution to scientific knowledge: or “real” research where results had potential to produce novel information
6. Career related experience
7. Experiencing science that is different than “school science”
8. Overcoming challenges

Data also suggested that an additional attribute to the framework of engagement might be considered, long term involvement. When using this framework to develop a richer understanding of and insight into student engagement, data revealed that when students demonstrated all or most of the attributes listed in the framework, students seemed to extend their connection to the program and with the CLS beyond what was required for participation in the program, even extending their science experience into art. Several students have maintained contact for years after their participation in the program and some have sought employment at the CLS. Data suggested that a more complete framework for the study of engagement would include the attributes listed in table 6.

*Table 6: Framework for Attributes of Student Engagement*

<b>Attribute</b>	<b>Description</b>
<b>Persistence</b>	the learner is persistent in seeking answers and overcoming challenges
<b>Dedication</b>	the learner provides a dedicated effort both physically and cognitively
<b>Motivation</b>	the learner establishes that the desire to participate is generated internally and not imposed from someone or somewhere else
<b>Ownership</b>	the learner demonstrates a sense of responsibility towards ensuring success
<b>Participation</b>	the learner displays enthusiasm during all or most aspects of the activity
<b>Value</b>	the learner indicates that the activity is worthwhile
<b>Contribution</b>	the learner asks high level questions or participates in discussions at a high cognitive level
<b>Involvement</b>	the learner continues or seeks to continue involvement in the activity or with the people or institutions connected to the activity after its closure

It seems that, as the literature review had established, engagement has again been shown to be a very complex construct with multiple facets and thus requires an equally complex framework to explore it.

The second sub question that guided this investigation into engagement asked if authentic scientific inquiry had an effect on the engagement of the students. There seemed to be a relationship between student engagement and the authentic nature of their scientific inquiry. During projects that included all of the attributes of authentic scientific inquiry and where students demonstrated the most indicators of engagement, data suggested an expansion to one attribute of authentic scientific inquiry and the addition of a new one. Data showed that during

these SotB experiences, students had also participated in the collection and/or preparation of their own samples. In addition, data revealed that participants' description of these experiences included references to how handling their own samples made the SotB experience more 'real' than typical school-based experiences, thus suggesting that the authentic scientific inquiry attribute of gathering and analysing data could be expanded to include collection and/or preparation of their sample. Also, a theme emerged from data analysis that suggested 'student-lead decision making' as a sixth attribute for consideration as part of an authentic scientific inquiry framework. This emerged as a contributor to student engagement and as something that students and teachers considered unique about the experience that made it seem more 'real' to them. These insights into the experiences of these students suggested that a more complete framework to describe authentic scientific inquiry might include these attributes:

1. Open-ended inquiry: where the answers are not known and there is potential for novel information of interest to the scientific community to be produced
2. Student driven: where the decision making power for the direction of the inquiry resides with students
3. Collaboration between students and scientists, as well as among students
4. Student involvement in:
  - a. Project design including formulation of question
  - b. Sample collection/preparation and data gathering/analysis
  - c. Communication of the results in multiple forms such as posters, oral presentations, and articles to varied audiences including peers, public and scientific audiences



The work of this study provided a richer understanding of what seemed to have enticed the students who participated in the SotB program at the CLS as well as insight into students' view as authentic scientific inquiry in contrast to the scientific and education communities as had been presented through a review of the literature.

*Insight into transformational learning.*

The search for perspective transformation and/or epochal transformation as evidenced by references to changes in perspective or behaviour resulted in some interesting insights. Data revealed that there was a perspective transformation in three frames of reference. Evidence showed that students and teachers adjusted their perspectives on the nature of science, the nature of research and their image of a scientist as a result of their experiences in SotB. Three specific stories, presented in detail in the previous sections, pointed to changes in a frame of reference that could be considered epochal transformation since they resulted in significant such as alteration of career plans, changing “the way I think about things” generally, and changing the approach to learning and engagement with science.

Analysis of data in this study pointed to ambiguity in the framework developed to study transformational learning. There was evidence that students and teachers were altering their frame of reference and that it involved more than a shift in perspective because it resulted in a change in behaviour, but would not fit the description of Meisrow or Imel's epochal transformation. Several teachers changed their classroom practises after participation in SotB and attributed those changes to their experiences with the program. While some students found that their experience with SotB confirmed their frame of reference regarding their future with science education and/or a scientific career, other students found that their experience changed

that frame of reference and altered their plans accordingly. Since changing plans and future aspirations could be considered a change in behaviour and life plans are a significant view of the world, I felt that this indicated an additional category in this framework might be necessary (see table 7).

*Table 7: Revised Framework for Transformational Learning*

<b>Perspective Transformation</b>	<b>Transformational Learning</b>	<b>Epochal Transformation</b>
<ul style="list-style-type: none"> <li>• Participant becomes critically aware of assumptions</li> <li>• Participant reflects upon challenges to those assumptions</li> <li>• Participant changes assumptions and associated points of view</li> </ul>	<ul style="list-style-type: none"> <li>• Participant changes a frame of reference, or world view</li> <li>• Participant makes small changes in behaviour accordingly</li> <li>• Changes are evident only to the participant or those directly involved in the activity</li> </ul>	<ul style="list-style-type: none"> <li>• Participant changes a frame of reference or a world view</li> <li>• Participant changes habitual behaviour accordingly</li> <li>• Changes affect other frames of reference and may or may not effect additional behaviour changes</li> <li>• Changes are evident to others regardless of direct involvement in related activity</li> </ul>

During the writing of this thesis other works came to my attention that extended the construct of transformational learning beyond those initially considered in this study. Lange (2004, p. 123) pointed out that “transformative learning is not just personal transformation but societal transformation.” None of the evidence presented in this thesis would point to social transformation, but that may be a function of time. Mezirow’s 1997 Letter to the Editor clarified my obvious misunderstanding. My definitions required a change in behaviour for epochal transformation to be considered present. Lange purports that the change is not truly transformational unless it moves beyond the personal and evokes attempts at societal change or social activism. In his letter Mezirow (1997) stated, “the action depends upon the nature of the dilemma, but when the disorienting dilemma is the result of oppressive action ... the transformation process *requires* that the learner take action against her oppressor, and, where appropriate, collective social action” (p. 60, emphasis in original). It is apparent that my proposed categories of definitions lack complexity and therefore the complexity of my conclusions might also be less sophisticated.

If one considers a further shift in categories, however, where the third category is renamed to ‘Personal Transformation’ and a fourth is added, ‘Social Transformation, the work presented here showed that this landscape did produce evidence of transformational learning, within the first three categories of the framework, as well as offered insight into transformations for students and teachers within this context. It was unclear whether the transformations could be connected to the landscape of this study, namely to authentic scientific inquiry, the framework of student engagement or specifically to the SotB program. Perspective transformation was evident in data related to every group of students. Transformational learning was evident regardless of the number of indicators of engagement or attributes of authentic scientific inquiry

present. And, interestingly, the three stories of, previously identified as epochal transformations, but more accurately named personal transformation, were from student groups with fewer attributes of authentic scientific inquiry. I am not sure of the implications of this except that more research is needed before any conclusions could be offered. Other areas of this study did offer some conclusions that could be drawn, however, and these I present those in the next section.

### *Conclusions and Implications*

Within this context of an informal science outreach program, there are a few conclusions that could be drawn from this work. Three frameworks were developed to provide insight into the experiences of these participants. The revised frameworks for authentic scientific inquiry, engagement and transformational learning presented earlier in this chapter might be helpful to guide the work of science education researchers as they seek to compare programs using similar tools. Curriculum developers might use the revised framework for authentic scientific inquiry when advising classroom practitioners or informal educators who wish to incorporate authentic scientific inquiry in their classrooms and programs as it provides a useful list of attributes to attend to during development. The original framework developed for this study was based on a review of the literature. The authors of those papers represented educators, education researchers, and scientists, in the context of natural research scientists as opposed to social scientists as would be the case for the educational researchers. Since this framework required revision to include insights derived from the perspective of students, further research into the differences in perspective of authentic scientific research among students, teachers, and scientists might prove to be interesting for science education development. Generalization of conclusions

based on these frameworks should only be considered with caution as this study was conducted within a unique context and the findings identified in the previous section may not be applicable in other contexts. This caution is particularly true for conclusions based on the use of the rubrics within the authentic scientific inquiry and engagement frameworks. These rubrics were developed in an attempt to clarify analysis of data gathered in this study and are particular to this context. I am the only person to assess these data using these rubrics and this context is the only one where these rubrics have been employed. A logical next step to developing these tools for more widespread use would be to first determine if my assessment of the context holds when others use the tools, and second, to see if the tools are useful when applied to other contexts.

A cautious conclusion that could be drawn based on this study is the insight into what engaged students participating in this specific context. Curriculum developers, classroom teachers, outreach program developers, and the scientific community could benefit from attending to this list as they attempt to engage students in science learning. This list is very practical and could easily be incorporated into many different inquiry-based science learning classrooms or programs:

- Open-ended inquiry
- Student – lead
- Choice
- Overcoming challenges
- Working with a “real” scientist
- Contribution to scientific knowledge
- Career related experience
- Experiencing science that is different than “school science”

Since data did not indicate if any of these were more important or more effective in engaging students, an opportunity for further research presents itself. Somewhat related, it would seem that those developing inquiry-based curriculum or programs wishing to engage students in

science learning, might consider incorporating as many of the attributes of authentic scientific inquiry as is reasonable within a specific context as there are many similarities between the attributes of authentic scientific inquiry and this lists of things that engaged these students.

In conclusion, I feel that I can confidently say that the research that I have undertaken for this study did provide, for me, a richer understanding of what engaged the students involved in this particular experience and of how that experience might have created a space where transformational learning occurred for students and teachers. Some of these understandings might be transferable to other, similar programs. In addition, I have developed some frameworks and tools that may be useful for program evaluation efforts in terms of inquiry-based programming or engagement, but these tools need a great deal more investigation.

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Appendix 1: Program Feedback Survey Before Participation

**Students on the Beamlines survey – before the experiment at CLS**

Thank you for filling out this survey. We are for this information to improve our program. There will be two – one before and after your trip to CLS. We will not give your specific information to anyone.

**Basic information for statistical purposes:**

Circle your gender:    male                      female

Province where you attend school: \_\_\_\_\_

Circle the appropriate description for your school:    urban                      rural

How old are you (at the time of visiting CLS)? \_\_\_\_\_

What year of school are you in? (eg. Grade 11 or Sec V) \_\_\_\_\_

**Optional questions:**

Are you of First Nations, Métis, or Inuit ancestry?    Yes                      No

Have you immigrated to Canada?    Yes    No    If so, from which country? \_\_\_\_\_

**Program Evaluation Information:**

1. Is your participation in Students on the Beamlines (SoB)
  - a) Extracurricular (no evaluation, for interests sake)
  - b) Part of a class/course (involves evaluation)
  - c) Other, please explain \_\_\_\_\_
2. If your answer to question 1 was a) extracurricular, how did you become involved? Example answers could be advertising poster, class announcements, teacher invited, through a friend, etc.  
\_\_\_\_\_  
\_\_\_\_\_
3. If your answer to question 1 was b) part of a course, did all of the students in the course participate or only a few? How was participation decided?  
\_\_\_\_\_  
\_\_\_\_\_
4. What are you most interested in learning about during your experience at CLS?  
\_\_\_\_\_  
\_\_\_\_\_
5. If I have the chance, I would really like to ask the following question of someone at CLS ...  
\_\_\_\_\_  
\_\_\_\_\_

**Answer the following questions using a scale of 1 – 5 with 1 representing least and 5 the most.**

6. How would you describe your interest in learning science generally?    1    2    3    4    5

7. How likely are you to continue taking science classes in school (secondary or post-sec)?

1 2 3 4 5

8. How likely are you to pursue a career in science after school? 1 2 3 4 5

9. How would you describe your preparation for your synchrotron experiment? 1 2 3 4 5

If you are willing to answer further questions about your experience, please provide us with your contact information:

Name: \_\_\_\_\_ Email: \_\_\_\_\_ Phone: \_\_\_\_\_

Appendix 2: Program Feedback Survey After Participation

**Students on the Beamlines survey – after the experiment at CLS**

Thank you for filling out this survey. We are asking for this information to improve our program. There will be two – one before and after your trip to CLS. We will not give your specific information to anyone that isn't directly related to this program.

**Basic information for statistical purposes:**

Circle your gender:    male                      female

Province where you attend school: \_\_\_\_\_

Circle the appropriate description for your school:    urban                      rural

How old are you (at the time of visiting CLS)? \_\_\_\_\_

What year of school are you in? (eg. Grade 11 or Sec V) \_\_\_\_\_

**Optional questions:**

Are you of First Nations, Métis, or Inuit ancestry?    Yes                      No

Have you immigrated to Canada?    Yes    No    If so, from which country? \_\_\_\_\_

**Program Evaluation Information:**

10. Do you feel that the experience was of any value to you? If so, how?

\_\_\_\_\_  
\_\_\_\_\_

11. What did you particularly enjoy during the experience?

\_\_\_\_\_  
\_\_\_\_\_

12. What did you not enjoy and feel needs to be changed before another student group is brought in? \_\_\_\_\_

\_\_\_\_\_  
\_\_\_\_\_

13. Did anything surprise you? What was it?

\_\_\_\_\_  
\_\_\_\_\_

14. Did this experience affect your perception of the following? If so, how?

Of science? \_\_\_\_\_

Of research? \_\_\_\_\_

Of researchers? \_\_\_\_\_

\_\_\_\_\_  
\_\_\_\_\_

15. Is there something that you've learned that really stands out?

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16. Do you have any advice for me as I develop this program for other students? Is there something I should do more or less of? What did you find to be helpful or not helpful? What should absolutely stay the same? What really needs to be changed (and how)?

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**Answer the following questions using a scale of 1 – 5 with 1 representing least and 5 the most.**

17. How well prepared did you feel for your experiment at CLS? 1 2 3 4 5

18. How would you describe your interest in learning science generally? 1 2 3 4 5

19. How likely are you to continue taking science classes in high school? 1 2 3 4 5

NA

20. How likely are you to take science classes in post-secondary school? 1 2 3 4 5

NA

21. How likely are you to pursue a career in science after school? 1 2 3 4 5

22. Was your decision to pursue a career in science affected by your SotB experience? If so, how?

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If you have any comments that you wish to make, please feel free to add them here.

If you are willing to answer further questions about your experience at a later date, please provide contact information:

Name: \_\_\_\_\_ Email: \_\_\_\_\_ Phone: \_\_\_\_\_

Appendix 3: Program Feedback Survey (without before)

**Students on the Beamlines survey**

Thank you for filling out this survey. We are asking for this information to improve our program. We will not give your specific information to anyone.

**Basic information for statistical purposes:**

Circle your gender:    male                      female

Province where you attend school: \_\_\_\_\_

Circle the appropriate description for your school:    urban                      rural

How old are you (at the time of visiting CLS)? \_\_\_\_\_

What year of school are you in? (eg. Grade 11 or Sec V) \_\_\_\_\_

**Optional questions:**

Are you of First Nations, Métis, or Inuit ancestry?    Yes                      No

Have you immigrated to Canada?    Yes    No    If so, from which country? \_\_\_\_\_

**Program Evaluation Information:**

23. Is your participation in Students on the Beamlines (SotB)

d) Extracurricular (no evaluation, for interests sake)

e) Part of a class/course (involves evaluation)

f) Other, please explain \_\_\_\_\_

24. If your answer to question 1 was a) extracurricular, how did you become involved? Example answers could be advertising poster, class announcements, teacher invited, through a friend, etc.

\_\_\_\_\_  
\_\_\_\_\_

25. If your answer to question 1 was b) part of a course, did all of the students in the course participate or only a few? How was participation decided?

\_\_\_\_\_  
\_\_\_\_\_

26. Do you feel that the experience was of any value to you? If so, how?

\_\_\_\_\_  
\_\_\_\_\_

27. What did you particularly enjoy during the experience?

\_\_\_\_\_  
\_\_\_\_\_

28. What did you not enjoy and feel needs to be changed before another student group is brought in? \_\_\_\_\_

\_\_\_\_\_



29. Did anything surprise you? What was it?

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30. Did this experience affect your perception of the following? If so, how?

Of science? \_\_\_\_\_

Of research? \_\_\_\_\_

Of researchers? \_\_\_\_\_

31. Is there something that you've learned that really stands out?

---

---

32. Do you have any advice for me as I develop this program for other students? Is there something I should do more or less of? What did you find to be helpful or not helpful? What should absolutely stay the same? What really needs to be changed (and how)?

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**Answer the following questions using a scale of 1 – 5 (1 means least; 5 most; NA is not applicable).**

33. How well prepared did you feel for your experiment at CLS? 1 2 3 4 5

34. How would you describe your interest in learning science generally? 1 2 3 4 5

35. How likely are you to continue taking science classes in high school? 1 2 3 4 5 NA

36. How likely are you to take science classes in post-secondary school? 1 2 3 4 5 NA

37. How likely are you to pursue a career in science after school? 1 2 3 4 5

38. Was your decision to pursue a career in science affected by your SotB experience? If so, how?

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If you are willing to answer further questions about your experience, please provide contact information:

Name: \_\_\_\_\_ Email: \_\_\_\_\_ Phone: \_\_\_\_\_

### **Appendix C: Interview Protocol**

To facilitate note-taking, I would like to audio tape our conversations today. Is this all right with you? I will stop recording this at any point at your request. Your participation is voluntary, and if you wish, you can answer only those questions that you are comfortable with. There is no guarantee that you will personally benefit from your involvement. The information that is shared will be held in strict confidence and discussed only with the research team. You may withdraw from the research project for any reason, at any time, without penalty of any sort and if you withdraw from the research project at any time, any data that you have contributed will be destroyed at your request. Is it all right with you if we proceed? Thank you for agreeing to participate, this should only take about half an hour.

You have been selected to be interviewed today because you have been identified as someone who has a great deal to share about your experience with Students on the Beamlines. The purpose of this study is to develop an understanding if the elements of authentic scientific inquiry contribute to authentic engagement and potentially to a transformative experience for people who participate in the Students on the Beamlines programme. Our intention is not to evaluate you or your experiences but to learn more about engagement and this experience to help improve science education.

*These questions will be asked of all participants, though they may be worded slightly differently for students than for teachers or for scientists. Significant differences will be noted.*

#### Questions for Background Information:

- i. How long ago did you participate in SotB?
- ii. Describe your experience in your own words (not the synchrotron experiment, but the experience. What was it?)
- iii. Was the experience what you thought it would be when you first became involved? Describe that.
- iv. Who developed/designed your SotB project (probe: by the students, teacher, or scientist)
- v. SotB was designed to be open-ended inquiry, when you do not know what you will find. Did you find this to be a challenge for you in this situation? (probing to see how they felt about having teachers and scientists that didn't know the answers)
- vi. Did you contribute to the presentation/poster/article? Did that affect your experience?

#### Questions to discover evidence of authentic engagement:

- i. Did you find that the project (or any part of it) challenged you? In what way? (note that this refers not only to the scientific inquiry but everything - working with other groups of people, the situation, etc.)
- ii. How did you overcome that challenge? What motivated you to overcome this?
- iii. Did you find anything about this experience to be difficult? Please explain. Is it difficult for you still? What changed? When? How?

- iv. Why did you decide to get involved in this project?
- v. Why did you stay involved in this project? Did your reason(s) for staying involved change at any point?
- vi. Would you participate in a similar project again if given the opportunity? Why?
- vii. Do you think this project was important? To you? To society? To science? For education? For others involved? Meaningful? Explain in what way/why not ...

Questions to uncover evidence of a transformational experience:

- i. Have you used things that you learned from your experience since then?
- ii. Think about the teachers (or 'your fellow teachers' when interviewing teachers) that were involved in this experience. Did you notice a change in them? Describe it?
- iii. Think about the scientist that was involved in this experience. Did you notice a change in them? Describe it? (This question would be omitted when interviewing a scientist unless it happens to be one of the rare occasions where there was more than one scientist involved then it would read, 'the other scientist involved').
- iv. Think about your fellow students (or 'the students' for teachers and scientists being interviewed) that were involved in this experience. Did you notice a change in them? Describe it?
- v. Has your experience affected the decisions that you've made since then? Describe how.
- vi. Has your experience had an effect on the classes (or professional development sessions for teachers being interviewed, or outreach activities for scientists) you chose to register for?
- vii. Has participation in SotB caused you to reflect your choices of career?
- viii. Has participation in SotB affected your choices of career?
- ix. Do you think you approach (teaching) your science classes or labs differently as a result of your experience? (in parenthesis for both teachers and scientist that are also professors)
- x. Do you think your experience has changed your perspective? Explain - probe for changes in views of science; research; scientists/teachers/students; outreach.
- xi. Did your experience change how you view yourself in any way? Explain
- xii. At what point did you notice your opinions and perspectives begin to change? When did you know that you had changed?
- xiii. What did you 'get' out of participating in this?

Appendix 5: Sample page from data analysis spreadsheet .....

A		B	C	D	E	F	G	H	I	J	K	L
		Cite	source	community	reporting	Authentic	Pers	Dedi	Intri	Own	Enth	Valu
1	Evidence											
2	I haven't been back at school for half an hour and already my Principal is bringing student tours through my room so that I can tell them about the synchrotron.	corresp3	corresp	teachers	teachers	2				x		x
3	I was surprised by how much of the science my students were able to pick up in such a short time. They did an excellent job of grasping the operation of the various experiments, even though they didn't have as much background knowledge as I would have liked. Their level of interest and understanding was impressive. ... I think my opinion of what students could take away from this experience has changed. I underestimated just how much students who are keen to learn stand to gain from this experience.	survey3	survey	students	teachers	2	x		x			x
4	I enjoyed seeing my students engaged in real science. Although experiments in class are valuable for their education, they're no substitute for real experience in a lab doing real experiments. They are more engaged and they take far more away from the experience.	survey3	survey	students	teachers	2			x			x
5	I learned to appreciate the findings scientists make in this type of field (geologists). I also learned many interesting facts and procedures.	survey5	survey	students	students	2						x
6	It allowed me to see more of what I could do in the future.	survey5	survey	students	students	2						x
7	I do feel that the experience was of value to me, I now have a good idea of how real research is done.	survey5	survey	students	students	2						x
8	It showed me how research is done and that not everything is always as fast and efficient as we would like.	survey5	survey	students	students	2						x
9	I'm not sure this was authentic. The students didn't feel to me like they were driving the research b/c they didn't really understand what was going on. They were merely following (beamline scientist's) lead. ... They were unable to go over data b/c it is on the server, not printed and able to be reviewed. Having to switch b/forth put blocks in for continuity and understanding.	anecd8p2	anecd	students	me	24			x	x		x
10	When I put the "story" together explaining the paradigm shift - students all nodded and several became excited They loved the idea of discovering something new & being part of it all. Understood the paradigm thing but became intimidated again when told they would have to explain it.	anecd8p2	anecd	students	me	24			x	x		x
11	One of the students from his group was the valedictorian at graduation. He mentioned the synchrotron experiment in his speech (including an explanation of light waves with hand gestures - inside joke). The teacher felt that this was an experience that the students would never forget. From a teachers perspective the experience to be able to open the doors and show the scientific community at work and living breathing scientists to students who rarely get a chance to see them.	interview6	interview	students	teachers	24			x	x		x