SCIENCE OUTREACH PROGRAMS: EXPLORING EMOTIONS, SCIENCE IDENTITIES, ATTITUDES, MOTIVATIONS AND DECISION MAKING ABOUT PHYSICS IN PHYSICS COMPETITIONS

by

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A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS

FOR THE DEGREE OF

DOCTOR OF PHILOSOPHY

in

THE FACULTY OF GRADUATE STUDIES

(Curriculum Studies)

THE UNIVERSITY OF BRITISH COLUMBIA

(Vancouver)

July 2009

ABSTRACT

This dissertation is an interpretive, phenomenological study of students' affective learning experiences in two science outreach contexts: the Physics Olympics and BC's Brightest Minds physics competitions. The role of emotions in the manifestation of students' perceived science identities, and impact on attitudes, motivations and decision making about physics are explored using complexity thinking as a theoretical frame.

The Physics Olympics and BC's Brightest Minds physics competitions are particularly rich sites for investigating the role of emotions in learning since students participate in teams on challenging activities where they experience success and failure, expressing strong emotions in the process. Students were interviewed before and after participating and probed for their emotions, attitudes and motivations in physics. During the events students were observed and video recorded. Lapel microphones worn by students captured conversational data as they interacted during the competitions. Data analysis involved mining the data corpus for expressed emotions and emergent themes guided by each of the three research questions.

Common emotions expressed by students at the events included fun, frustration, excitement and disappointment. Expressions of emotion were characterized according to how they were evoked: context, task or novelty evoked emotions. Key findings include that experiencing strong emotions can enhance motivation and learning and characteristics of the contexts and tasks that promote meaningful learning were identified. Conditions of emergence (diversity, redundancy, neighbour interactions and decentralized organization) were employed to describe the manifestation of student perceived science identities. Three types of science identities emerged: student perceived stereotypical science identities, student perceived individual science identities, and team science identities. Shared emotions and memories allowed identities to emerge and strong team science identities emerged from decentralized systems. Most importantly, science identities were dynamic and continuously shifting throughout students' experiences. Dynamic science identities contributed to shifts in student attitudes about physics where their descriptions of physics broadened to include necessary skills such as the ability to work within a team and apply physics concepts to real world situations.

This work contributes to a growing literature base in affective learning in science, informal contexts and learning through competitions and design activities. It also contributes to the study of emotions in education by recognizing the generative learning space that is created when emotions are present and the importance of paying attention to affective constructs such as raw emotions and science identity. Moreover, the results of the study contribute to improving teaching and learning of physics and suggest implementing activities both within and outside classroom contexts that are challenging and provide feedback so that emotions are evoked and expressed as students engage in them. Specific recommendations for designing competitions such as the Physics Olympics and BC's Brightest Minds are also offered.

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ACKNOWLEDGEMENTS

First and foremost I would like to acknowledge the hard work and guidance contributed by my supervisors. Thank you Dr. Samson Nashon and Dr. David Anderson for inspiring me to investigate emotions in informal learning contexts, Dr. Gaalen Erickson for your mentorship in advising me to tackle a PhD and in negotiating these final stages, and Dr. Chris Waltham for venturing into this educational endeavour from the Department of Physics and Astronomy. I am also indebted to several faculty members in both the Department of Curriculum and Pedagogy, particularly Dr. Brent Davis and Dr. Don Krug, and the Department of Physics and Astronomy, particularly Dr. Andrzej Kotlicki, for engaging with me in the research, teaching and learning experiences that were some of the most valuable of my PhD.

I am very grateful to have had the support of my fellow graduate students with whom I have had many meaningful conversations over the years around shared space (Wendy, Adriana and Gillian), complexity (Moshe, Tammy, Juan, Sheliza, Fiona, Jeff) and physics (Sandy, Rob, Tom). I would also like to thank my colleagues in science education outreach who have helped me maintain connections to teaching practice.

Generous financial support from SSHRC, UBC, The Faculty of Education, and TAG through scholarships, teaching and research activities has allowed me to fully engage in my academic pursuits and participate in the local, national and international research community. I am extremely thankful for this. Sincere thanks is also extended to the all the participants of the study for investing their time in educational research.

Finally, thanks to my friends and family, both near and far, for providing an endless supply of encouragement, patience and advice. To those who support me on a daily basis (Peter, Gwen), to my parents who are incredible role models, and to those whose support I sometimes take for granted (too many to name!), I love you and acknowledge and thank you for the significant impact you've had on my life and successes so far.

CHAPTER ONE

Introduction

This dissertation reports on a study that explored the complex relationships between emotions evoked during science outreach events and student attitudes, motivations, science identities and decision making about physics courses and careers. These relationships were studied in two informal learning contexts of physics competitions: the Physics Olympics and British Columbia's (BC) Brightest Minds[1]. Research into affective factors confounding students' engagement with science in such outreach programs is important given that there has been virtually no research on the impact of these programs on affective learning. The consequent understanding from this study will provide information to assist the creation of more effective outreach programs that can provide opportunities for students to 1) engage in meaningful learning in science, 2) develop higher order thinking skills, and 3) develop positive perceptions of and attitudes towards physics. In addition to providing empirical support for the value of studying these factors, a further goal of this work is to contribute to the development of theoretical underpinnings for understanding the role of the affective learning, especially emotions as an affective construct, in learning.

Affective Learning: Variables of Interest

The bulk of research in science education occurs in classrooms where cognitive outcomes are emphasized (Alsop, 2005a; Anderson & Nashon, 2007). There is now growing interest in researching and understanding the role of the affect in student science learning (Alsop, 2005b). Problems of low enrolment in physics have been linked to affective learning issues such as emotional connections to physics (Fischer & Horstendahl, 1997; Nashon & Nielsen, 2007; Rowsey, 1997). However, most studies are classroom-based and tend to focus on attitudes about science (Nieswandt, 2005).

[1] Detailed descriptions of the events can be found in Chapter 3, Appendices I and II.

Attitudes have been shown to depend on gender (Harding, 1991) and age where a tendency towards more negative attitudes from age 11 (e.g., Yager & Penick, 1986) has been shown in most countries. Student attitudes are closely linked to motivation and course choice (Crawley & Coe, 1990; Koballa, 1988a) which is a critical issue since enrolment in secondary science courses is the most significant indicator of choosing science as a career (Griffin, 1990).

Low female participation in science has been attributed to incongruence between scientific activities and gendered identities (Carlone, 2003). Brickhouse, Lowery and Schultz (1999) also argue that in order to understand learning in science "we need to know how students are engaging in science and how this is related to who they think they are… and who they want to be" (p. 443). Although the study of science identity emerged from the study of gendered issues in learning science, it is currently recognized as a more general problem as reported by Roth and Tobin (2007). They employed identity perspectives to examine learning in a wide variety of contexts including: urban schools, engineering faculties and young children's reading groups.

It is apparent that the current scope of emotions being investigated is limited to values, motivations, self-beliefs and attitudes. The types of emotions being investigated should be expanded to include 'raw' emotions such as fear and happiness, which appear to be neglected (dos Santos & Mortimer, 2003). Thus, in this dissertation, the study of affective learning in general, and specific constructs such as raw emotions and science identities are considered powerful means through which a better understanding of student attitudes, motivations and decision making about physics can be attained. These affective constructs are the variables of interest in the current study and are considered to be indicators of meaningful learning.

The term meaningful learning is usually associated with Ausubel's (1963) learning theory. He contrast meaningful learning and rote learning, and defined meaningful learning as the learning which occurs when knowledge is related to existing knowledge , when a deliberate effort is made to link new concepts to higher order understandings. Novak (1990) developed concept mapping as a technique for promoting meaningful learning. However, Ausubel (1968) also recognized the role of affect in meaningful learning, particularly long-term learning, and thus this study adopted a broader perspective on meaningful learning. Meaningful learning occurs when students are engaged and motivated and when affective constructs such as attitudes towards science are impacted alongside cognitive outcomes.

Choosing a Learning Context

Informal learning research has largely focused on studying learning in museum contexts (Rennie, 2007). Research into museum contexts is generalizable to a wide variety of environments including interactive science centres, zoos, and aquariums where science learning has been widely researched (e.g., Adelman, Falk, & James, 2000; Pedretti, 2002; Rennie, 2007; Rennie & McClafferty, 1996). Most studies have tended to employ or largely draw upon constructivist theories of learning (e.g., Anderson, Lucas, & Ginns, 2003; Anderson & Nashon, 2007; Dierking, Falk, Rennie, Anderson, & Ellenbogen, 2003). There have also been important implications for the design of informal learning settings, structure of museum visits (both by families and during school field trips) and methods that connect informal learning and classroom activities. Research into how people learn science in informal settings has provided support for a more holistic perspective on learning that incorporates a key role for the affective domain of learning. As a result, the role of the affective domain in science learning both in informal and formal (classroom) environments has been receiving increased attention from researchers (e.g., Alsop, 2005b; Koballa & Glynn, 2007). The current study extends this type of work into science outreach contexts, which are included in Lewenstein's (2001) expanded list of producers of science information for the public.

Science outreach programs are particularly rich emotional learning experiences and are primarily geared towards high school students in the process of examining their options for post secondary education. They are a diverse group of programs, initiatives and activities whose effects on student interest in science are now becoming the subject of intense study in both the United States and Canada. Recent U.S. studies (AAUWEF, 2004; USGAO, 2006) have recommended bringing more inclusive projects into the schools (as opposed to them being extracurricular) to foster systemic change with a focus on science content and skills over affective goals. These recommendations ignore a large body of research that points to the role of attitudes about science in student motivation, decision making, and learning about science in informal learning contexts (Rennie & Johnston, 2004). Besides large scale assessments and accountability reports, outreach programs are rarely subject to academic study. Some positive impacts on students' understanding of the nature of science and scientific inquiry have been reported (Bell, Blair, Crawford, & Lederman, 2003; Gibson & Chase, 2002).

In Canada, science outreach is being well supported, both by universities and funding agencies. Science outreach is often a component of a science faculty member's job description and the National Science and Engineering Research Council (NSERC) continues to implement its PromoScience program which awarded $2.75 million in 2008 to support science and engineering outreach projects. In 2004 the agency initiated a pilot project entitled CRYSTAL (Centres for Research in Youth, Science Teaching and Learning) to establish centres to study and implement ways to improve K-12 science education. In particular CRYSTAL Atlantique is investigating science outreach programs (Marshall, 2007; Sullenger & Cashion, 2007). The current study sought to examine meaningful learning in two popular physics outreach contexts, the Physics Olympics (Riban, 2000) and BC's Brightest Minds competitions. These two activities are popular among high school physics students in British Columbia and are considered to impact their attitudes, motivations and decision making about physics. Both competitions are very challenging and require students to work in pairs or teams and are emotional learning contexts. Thus, the learning that takes place in these contexts is described as meaningful.

Applying Complexity Thinking to Understanding Affective Learning

Complexity thinking (Davis & Sumara, 2006), which aids in understanding complex systems, has preoccupied and provoked the imaginations of physicists, biologists, computer scientists and sociologists for decades. They have been mystified and awed by the possibilities exhibited by systems such as ant hills and crowds, which self-organize, exhibit higher order behaviours, and act without the existence of a centralized controller (Johnson, 2001; Waldrop, 1992). Drawing on results from the study of complex systems, complexity thinking has also interested researchers in education. It complements constructivist and socio-constructivist discourses, which are dominant in science education and informal learning literature, by bringing about an awareness that knowledge or truth does not pass from the outside to within but exists in interactions. Current theorizing in complexity describes it as transdisciplinary since it is well aligned and informed by several theories (Davis & Sumara, 2006). It has the ability to elaborate on constructivism and situated cognition, is most usefully seen as an umbrella notion, not an explanatory one, and is being used to colour and shift perspectives in educational research and practice.

Learning is central to discussions of complexity. Complex systems have been described as learning systems (Capra, 2002) because they are adaptive and self-organizing. Rasmussen (2005) defines learning as "handling complexity" (p. 214). Learning in this sense is understood as "ongoing, recursively elaborative adaptations through which systems maintain their coherences within dynamic circumstances" (Davis, 2004, p. 151). Especially when compared to formal classroom structures, informal learning often displays many of the properties of complex systems such as the ability to *self-organize* into a whole that is greater than the sum of its parts (*emergence*), to communicate via short range relationships (*neighbour interactions*), and operate *far-from-equilibrium*. Competing at the Physics Olympics and BC's Brightest Minds competitions and in particular, learning associated with attitudes, motivations and decision making about physics through the emergence of emotions and science identities, will be discussed and characterized as a complex system by illustrating some of these qualities.

Over the years a number of different terms have been used to describe the interdisciplinary field of complexity: complexity science, complexity thinking or complexity theory. I will use the term complexity thinking because it is being used as a perspective on learning and teaching. To date the field has focused on limited areas including identifying nested systems of learning (Davis & Simmt, 2006), shifting awareness from individual learning to the learning collective (Senge, Cambron-McCabe, Lucas, Smith, Dutton, & Kleiner, 2000) and characterizing complex learning systems such as math classes (Davis & Simmt, 2003) and teacher education (Davis, Sumara, & Luce-Kapler, 2008). Existing literature situated within complexity research characterizes complex systems and their conditions and examines how these conditions can be manipulated or tinkered with. The current study recognizes the complexity of learning that occurs at the Physics Olympics and BC's Brightest Minds competitions and has the potential to provide deep insights into the meaningful learning that takes place in these settings. Current complexivist discourses on learning such as enactivism (where identities and knowledge are embodied in the interactiveness of dynamic forms) (Varela, 1999) and neuropsychology (Damasio, 1999; LeDoux, 2002) ascribe an important role to emotions and identity in learning.

Theoretical perspectives in the field of emotion have been dominated by several traditions whose trends have moved from behaviourism to cognitive theories (Arnold, 1960; Leeper, 1970), social constructivism (Averill, 1980; Smith & Lazarus, 1993) and finally to phenomenological (Denzin, 1984) and complexity (Damasio,1999; LeDoux, 2002) perspectives. These trends mirror the progression of educational research in learning. Each of these perspectives presents a different way to interpret the role of emotions in the construction of identity and in learning, often through an understanding of self or consciousness. Some of the most recent theories of emotion speak to the interconnectedness of emotion, identity and learning and are implicitly complexivist (applying ideas from complexity thinking) (Weisel-Barth, 2006). Using a complexity theory framework, these connections can be made explicit and can provide both pragmatic and theoretical ideas about learning (Davis & Sumara, 2006). In this study the emergence of science identities from the emotions expressed by students while participating in the Physics Olympics and BC's Brightest Minds competitions, and the influence of science identities on attitudes, motivations and decision making about physics is interpreted and understood through a complexity thinking perspective. This perspective draws on theories of emotion and identity, but views them as integral parts of a complex learning system.

Conceptualizing and theorizing the emergence of science identities in emotional learning contexts has roots in neurological as well as psychological research involving emotions, consciousness and identity. Attention is an important aspect of learning where emotions (as meaningful disturbances) are understood to trigger and maintain attention and hence structural changes (Capra, 2002). Emotions help to mark, store and retrieve memories (Johnson, 2004). Donald (2001) and LeDoux (2002) also describe the role emotions play in activating memories, calling memories active feelings. Thus, emotion also plays an important role in perception. Through the use of emotions, we can store memories and maintain continuity of consciousness or self.

Links between consciousness and identity can be made through emergence. Identity can be considered a unity which emerges for learners and can provide a "narrative layer [that] gives ideas a certain autonomy from personal experience and creates the possibility of abstract beliefs and public discourse" (Donald, 2001, p. 322). Damasio (1999) describes identities as convergence zones that can be consistently and iteratively activated depending on the context, but that together form a greater whole, the autobiographical self which runs in the background at all times and allows for extended consciousness. According to several neurological perspectives (Damasio, 1999; Donald, 2001; LeDoux, 2002) emotions play a key role in the complex interactions from which unities (identities, selves) emerge that enable learning. This study used a complexity thinking perspective to define science identities as emergent from and manifest through student emotions, which were evoked during science outreach learning experiences. These identities adapted and influenced student attitudes, motivations and decision making about physics because they are all part of an interconnected dynamic learning system.

Thus, by drawing on a complexity thinking perspective used by neurologists to understand emotions, consciousness, identity and learning, this framework is used in the current study to interpret and understand the emotions expressed by students before, during and after participating in the Physics Olympics and BC's Brightest Minds competition. In addition, I explore in the following research questions how these emotions give rise to the emergence of science identities and the resulting influence on student attitudes, motivations, and decision making about physics.

Research Questions

As argued above, there exists a gap in literature on affective learning of science in science outreach contexts. Employing a complexity thinking perspective to elucidate the connections between emotions, attitudes, motivations and decision making about science can facilitate and enhance a deeper analysis and understanding of raw emotions and science identities in science outreach contexts. This way, it is possible to illuminate as well as establish their role in student science learning and decision making.

Thus, the current study attempted to address the following questions:

1) How can the emotions experienced during science outreach programs be characterized and understood?

2) How does participation in science outreach programs and the emotions evoked by these experiences contribute to the manifestation of students' perceived science identities?

3) How do students' perceived science identities influence their attitudes, motivations and decision making about physics?

Research Context and Methodology

This was a phenomenological study (Denzin, 1984; Outhwaite, 1975; van Manen, 1990), employing interpretive, case-study methods (Creswell, 2003; Gallagher & Tobin, 1991; Schwandt, 1998; Stake, 1995) to provide rich descriptions of students' affective experiences. Student experiences in two physics outreach contexts were studied: the Physics Olympics (PO) competition and BC's Brightest Minds (BCBM) amusement park physics competition (described below). The participants were comprised of five teams of Grade 11 and 12 students participating in Physics Olympics events in 2006 (1 team), 2007 (3 teams) and 2008 (1 team) and three BC's Brightest Minds teams in 2007. Methods were influenced by a hermeneutic perspective (Schwandt, 2003) where data collection and analysis of previous years' events informed the design and interpretation of subsequent rounds of data collection. Units of analysis included both individuals and groups or teams of students. The participants (35 in total) were interviewed twice, using a semi-structured interview format: before the event to determine their pre-event emotions and attitudes, and immediately after the event to clarify their expressed emotions during the event and to describe and interpret their post-event emotions and attitudes. Physics Olympics students were interviewed individually, however BC's Brightest Minds students were interviewed together with their partner. The interviews were audio recorded and transcribed verbatim for coding, theme searching, and interpretation. During the event individuals and groups of students were observed and video recorded. These data were complemented by recording their conversations during the events using lapel microphones and digital audio recorders. Triangulation (Erickson, 1986) was achieved by comparing data from the experiences described by students in interviews to their participation experiences during the event. Qualitative data analysis and reporting procedures (Erickson, 1986) and a complexity thinking perspective were used to identify and present emergent themes.

The Physics Olympics at the University of British Columbia (UBC) consists of six tasks, two of which are pre-built tasks that students must prepare before the day of the competition. During the competition teams of five Grade 11 and 12 students from high schools across the province of British Columbia compete in a variety of activities including quiz shows based on physics questions and trivia, laboratory or hands-on challenges, conceptual challenges and tests of their pre-built designs. The event is attended by about 60 teams and occurs each year on the first Saturday in March. The teams are divided into groups of 10 that cycle through the six activities throughout the day. (See Appendix I for detailed descriptions of activities and student experiences.) Results are tallied and at the end of the day the entire crowd (teams, coaches, parents, organizers and spectators) converge in a large lecture hall for a short physics show, door prizes and the announcement of the results. The top six teams in each activity are recognized with medals for the top three and finally the overall top three teams are announced and awarded trophies. Usually the head of the Physics and Astronomy Department at UBC is there to congratulate students. No monetary awards are given but the University of British Columbia values participation and achievement in the Physics Olympics when considering students for admittance and entrance scholarships.

The second event that was part of the study, called BC's Brightest Minds, is organized by the Faculty of Education at UBC and staff from Playland at the Pacific National Exhibition in Vancouver, BC. It is an annual one day event in May that has been running since 2006. High schools are invited to nominate a team consisting of two Grade 12 students to participate in the competition; typically about 25 teams enter each year. The competition asks students to use simple tools to take measurements and observations of rides and perform calculations. (See Appendix II for examples of BCBM questions.) Students are given three hours to complete the questions and during the first hour they have the opportunity to take measurements and experience the rides when no one else is using them. The competition takes place at the amusement park and is an extension of the popular amusement park physics program that many students participate in as part of their physics courses in high school. This event, however, is voluntary and does not count for course credit. Participating students receive free T-shirts and the top three teams are recognized where the top team shares a $3000 prize. The event receives quite a bit of media attention in the local community and the winning students are often interviewed by local papers.

Dissertation Overview

This dissertation is comprised of seven chapters. Following the introductory chapter, Chapter Two describes the theoretical framework and background literature that informs this work. Theories of emotion (cognitive, socio-cultural, phenomenological and neurological) and learning (constructivist, situated, and embodied), which this study considers are appropriate, are presented and interpreted through a lens of complexity thinking to establish the frame through which emotions, science identities and attitudes, motivations and decision making about physics were studied. A literature review involving critical synthesis of relevant studies in affective learning in science education in general, and specifically about science identity, attitudes, motivations and decision making about science are provided. Literature in the fields of informal learning, specifically in relevant contexts such as science outreach activities and competitions are presented. Chapter Three describes the methodology, methods, procedures and analysis that were carried out in the course of this study. Detailed descriptions of the Physics Olympics and BC's Brightest Minds situate the learner in the learning contexts. Three analysis chapters follow. Chapter Four explores the first research question, characterizing the emotions experienced by students. Chapter Five describes the manifestations of science identities. Chapter Six describes the influence of science identities on attitudes, motivations and decision making about physics. Finally Chapter Seven discusses the implications of the results and suggests avenues for future research.

CHAPTER TWO

Theoretical Grounding and Literature

Chapter One provided an overview of the variables of interest and theoretical perspective employed by this study. This chapter elaborates on complexity thinking, which was introduced in Chapter One as a theoretical framework for interpreting and understanding affective learning in general, and specific affective constructs such as emotions, attitudes about science and science identities. This perspective was used in consonance with a range of perspectives on the affect and its manifestations. In addition, how complexity thinking and perspectives on affect were used in framing the current study of the role of the affect in learning science in outreach contexts is discussed. This is followed by a more detailed thematic literature review of studies that have explored the affective constructs of interest within the following areas: a) science education and affective learning; b) attitudes, motivations and decision making; and c) science identity. Finally, the current study is situated within the broader field of learning in informal contexts by examining literature in: a) informal learning contexts, b) science outreach contexts, and c) learning through competitions and design activities. The chapter concludes with a reiteration of the lack of studies on the role of emotions in learning within science outreach contexts and a repeat of the research questions that were investigated in the current study.

Theoretical Perspective

Complexity Thinking

Complexity thinking is defined not by its methods of investigation, but by its objects of study. From the emergence of cities, weather patterns, flock behaviour, immune systems, and economics, early studies of complex systems strove to explain how complex intelligent behaviour emerged in the absence of a master controller (e.g., Johnson, 2001; Waldrop, 1992). Complex systems share several key qualities including adaptation, self-organization and emergence. Complex systems are learning systems (Capra, 2002) where learning is "understood in terms of ongoing, recursively elaborative adaptations through which systems maintain their coherences within dynamic circumstances" (Davis, 2004, p. 151). It is interesting to note that education has been slow to recognize and embrace its own complexity (Laidlaw, 2004). However, a comprehensive summary of thinking in the field is provided by Davis and Sumara (2006) in their book, *Complexity and Education: Inquiries into Learning, Teaching and Research.* A peer reviewed online journal (*Complicity*) and an annual conference also support the work of this research community. Theorizing in curriculum (Doll, Fleener, Trueit, & St. Julien, 2005) has employed complexity thinking and the field of math education has published empirical and theoretical work (e.g., Davis & Simmt, 2006). Recently, *Educational Philosophy and Theory* published a special issue (Vol. 40(1), 2008) on complexity theory.

Currently the bulk of research studies in science learning, especially those investigating affective constructs such as attitudes about science, are conducted from a constructivist or social constructivist perspective (Falk & Dierking, 2000; Hennessey, 1993). Constructivism is a coherence theory, that is, a theory that emphasizes the extent to which new knowledge and existing knowledge cohere (Davis & Sumara, 2006). Constructivists value the role a learner's history and past experience plays in their construction of knowledge. Constructionist and critical discourses have focused discussions of learning and teaching around epistemologies and politics, respectively. Complexity thinking complements all of these discourses by recognizing them as nested systems of individual knowing, collective knowledge and cultural identity (Davis, 2004) and allows for analysis to occur at different levels such as an individual, a collective (a team of students), or a group of collectives (a school) instead of focusing on either individual (constructivist) or group (social cultural theory) learning.

Several qualities of complex (learning) systems have been recognized as important in attempts to characterize instances of complexity. Davis and Sumara (2006) emphasize that complexity can not "be reduced to these aspects, but that these aspects are useful for helping observers identify and make sense of complex structures and dynamics" (p. 80).

Self-organization, also known as *emergence*, is the most commonly cited, and least well understood quality of complex systems. This is likely due to the mechanisms of emergence varying widely depending on the phenomena being studied. Emergence occurs when individual agents self-organize into a collective which has capabilities that exceed the possibilities of each individual agent working independently. Disorganized and organized complex systems can be discerned from one another (Hebb, 1949). Disorganized complex systems do not exhibit higher-level behaviour beyond broad statistical trends; the behaviour of molecules in a gas is an example. However, organized complex systems "act locally, but their collective action produces global behaviour" (Johnson, 2001, p. 74).

Davis and Sumara (2006) provide some examples from education literature that illustrate self-organization. *Schools that Learn,* (Senge et al., 2000) employs systems theory to elegantly allow its grander theme, that the educational whole is greater than the sum of its parts, emerge from dozens of case studies. In fact, although some educational research is turning to complexity thinking, few tackle emergence (Davis & Sumara, 2006). Davis and Simmt (2003) describe two cases of emergence in the context of math education. In one case, a collective of teachers emerged while completing some challenging academic tasks, and in the second, a classroom collective arose while developing a mathematical concept. They also argue that 'teachable moments' are often cases of emergence at the classroom level. Conditions of emergence (e.g., diversity, redundancy, neighbour interactions, and decentralized organization) will be employed in elucidating the emergence of science identities in Chapter Five.

Emergence occurs at critical points of instability, in *far-from-equilibrium* states. Complex systems tend toward disequilibrium with the help of *positive feedback*, a mechanism whereby small changes are amplified. This is in contrast to negative feedback mechanisms, such as those within a thermostat, which sense changes in the system such as a decrease in heat, and dampen them by activating a heat source. Positive feedback is a particularly useful idea in the current study when interpreting neurological perspectives in emotion. For example, psychologist Merlin Donald (2001) hypothesized that positive feedback was necessary in order for the brain to trigger moments of conscious awareness, an intermediary step to learning. Neurologists Damasio (1999) and

LeDoux (2002) view emotions as triggers of consciousness, identity, and thus learning. These perspectives will be elaborated on below. An example from educational research on the topic of questioning wait times can also be interpreted in terms of positive feedback. Research (Tobin, 1987) has shown that longer wait times stimulate a wider variety and more thoughtful responses from students. These discussions usually elicit more questions from students and often the discussion is amplified and encroaches on areas of knowledge that are beyond the scope of the lesson and the teacher's area of expertise. Not surprisingly then, some results have shown that teachers tend to revert back to short wait times in order to have more control over classroom discussions (Tobin, 1987).

The study of complex systems is made challenging by their characterization as *ambiguously bounded*, open systems. They are continuously exchanging matter and/or information with their surroundings. Although they are constantly influencing and being influenced by their context, they also maintain their essential qualities and patterns and are thus organizationally closed. Interesting questions arise such as where does an agent stop and a collective begin? In a complex social system (e.g., a team working together to design a pre-built challenge in the Physics Olympics), it becomes difficult to attribute particular acts or ideas to individuals. Since complex systems are nested within other systems, it also hard to distinguish one from another, or one level of analysis from another. For example, attitudes about science influence student learning in science and vice versa. In fact, attitudes are a part of the hidden curriculum of every science course. Complexity thinking allows researchers to ask, when or should attitudes about science become part of the explicit curriculum, or can they be separated from the disciplinary knowledge system?

Complexity thinking was an appropriate choice of theoretical framework for the current study for three main reasons. Firstly theoretical perspectives in emotion (elaborated on below) are implicitly complexivist (Weisel-Barth, 2006) and the use of complexity thinking to develop a perspective which sees identity as manifest in emotions recognizes the dynamism of the nature of identity. Secondly the learning system at the Physics Olympics and BC's Brightest Minds competitions exhibited qualities of complex systems. Depending on the level of analysis emergence of unities was observed. Physics

Olympics teams cohered around pre-built projects and self-organized into teams to construct their projects. The projects that emerged were more advanced and sophisticated than what individual students could have produced on their own. Finally complexity thinking is transdisciplinary and can be used in concert with well established theories of learning such as constructivism and situated cognition which have contributed greatly to the field of learning, identity and science education. In the current study, complexity thinking proved to be a useful theoretical and analytical framework for thinking about the interrelated nature of the affective constructs of interest in this study, particularly emotions and science identity.

Emotion and Identity

Theoretical perspectives in the research field investigating emotion have been dominated by several traditions whose trends closely mirror those of educational research in learning. Each presents a different way to interpret the role of emotions in the construction of identity and in learning, often through an understanding of self or consciousness. For example, cognitive theories (Arnold, 1960; Leeper, 1970) of emotion were an important step in the research when they acknowledged that emotions were not purely physiological and were also important in decision making and coping responses, but ascribed little role for the self or consciousness. Social constructivist theories (Averill, 1980; Smith & Lazarus, 1993) expanded the domain of emotions from the individual to include society, institutions and cultural practices. To varying degrees social constructivists believed emotions were expressions of learned social and cultural norms, but perceived the self as powerless against social and cultural forces.

Neurological and phenomenological perspectives were heavily drawn upon in the current study, but represent just one way to approach the interconnectedness between emotions and identity. Phenomenological perspectives (Denzin, 1984) argued that emotions were crucial to one's sense of self, more importantly, that through emotion we learn about ourselves. Embodied emotions are key to this perspective and according to Merleau-Ponty (1962) humans perceive and make meaning from the social and physical world through the body's senses which result in emotional states. Neurological evidence and theorizing have shown that emotions guide rational thought (Damasio, 1994) and a sense of self or identity was needed in order to make links between emotions and consciousness (Damasio, 1999). Some of the most recent theories of emotion use frameworks that speak to the interconnectedness of emotion, identity and learning and are implicitly complexivist. Immordino-Yang and Damasio (2007) wrote "neurological evidence suggests that the aspects of cognition that we recruit most heavily in schools, namely learning, attention, memory, decision making, and social functioning, are both profoundly affected by and subsumed within the processes of emotion" (p. 3). The current study was framed and implemented using complexity theory. Thus, it served to explicate the interconnections embedded in the data on student learning in science outreach contexts.

The nature of emotions is complex and qualities of complex systems can be used to characterize the role emotions play in decision making, the emergence of identities and learning. Complex systems are *structure determined*, therefore it is the system, not its context, that determines how it will respond to its conditions (Davis & Sumara, 2006). Emotions are embodied (Merleau-Ponty, 1962) and built into our structure through our experiences as human beings. Neurological evidence has found emotional areas of the brain, which when damaged, impede real-life decision making, but context-free logical thinking skills remain intact (Damasio, 1994). This brain region is now understood as crucial to triggering neuronal and somatic events that together make up social emotions such as embarrassment and compassion (Immordino-Yang & Damasio, 2007). Immordino-Yang and Damasio (2007) offered biological and evolutionary reasons for the dependence of rational thought on emotion. They hypothesized that acts of decision making are made in relation to emotional goals. In complex systems, independent entities act selfishly and locally to produce higher-order behaviours. They wrote "the brain has evolved under numerous pressures and oppressions precisely to cope with the problem of reading the body's condition and responding accordingly and begins doing so via the machinery of emotion" (Immordino-Yang & Damasio, 2007, p. 6).

Psychologist Merlin Donald's (2001) three level theory of awareness used a similar evolutionary perspective to describe the *emergence* of consciousness in humans and also attributed a strong role for emotions in the process. He claimed that an increase in the complexity and number of circuits in the brain improves the capacity for conscious deliberate review and refinement of our actions. Through the use of emotions we can store memories and maintain continuity called consciousness. These levels of increasing complexity of awareness leading to consciousness are examples of a complex system that *self-organizes* through short-range interactions (neural connections created at the most basic level by emotions) and simple rules. The consciousness that emerges from the complexity of experience does not control or determine what is perceived or paid attention to but perception and awareness do depend on emotions. Thus decisions and responses made by individuals are dependent on consciousness (and hence emotions) but not determined by it in a predictable, mechanical way.

Experiences that evoke emotions, such as the Physics Olympics and BC's Brightest Minds competitions, trigger a chain of physiological events that lead to changes in the body and mind (Damasio, 1994), including focusing of attention, recall of memories and learning associations between events. These triggers may operate similarly to *positive feedback loops*, which have the potential to push the system to a *far-from-equilibrium* state, allowing for *emergence*. Donald (2001) suggested that positive feedback loops trigger conscious awareness such that "the mind attends, registers, and changes its bias and the next encounter with the same situation fixes the chain of attentional habits that directs future learning in that context for a lifetime" (p. 228). 'Mood congruity' has been observed by researchers when memories, recorded within an associated network with feelings attached to them, are recollected that are congruous with your current mood (Johnson, 2004). "Our emotional state skews our sense of perspective by seeking out memories that match our current mind-set instead of a balanced representative sample" (p. 147). Therefore the brain is creating ideal conditions for learning by avoiding equilibrium, amplifying emotions and novelty, and creating structural changes.

As described above, Donald (2001) used increased complexity of neuronal connections created by storing emotional memories to explain the emergence of consciousness. Damasio (1999) also sought to solve the problem of consciousness and found that a sense of self was necessary in order to know a feeling. Emotions, feeling and consciousness are all represented bodily in an organism. He suggested that consciousness developed because it was useful for organisms to know and be aware of their emotions for survival. Damasio described identity as the consistent and iterative activation of convergence zones. A large range of actions can be responsible for activation, including emotions. Thus emotions are part of the "fundamental data that define our personal and social identities" (1999, p. 223).

Identity is a good example of how the affective learning system is always adapting. Emotions amplify memories (LeDoux, 2002) and thus play a key role in the emergence, activation and adaptation of identities. Each act of learning is a structural change and identity is formed through endless activation of updated images and memories (Damasio, 1994). Each time a memory is recalled in a new context it is rewritten or changed, shaped by experiences that have occurred since the original or previously activated memory (Johnson, 2004). Damasio (1999) described how our identities adapt over the course of our lives and experiences. "The idea each of us constructs of our self, the image we gradually build of who we are physically and mentally, of where we fit socially, is based on autobiographical memory over years of experience and is constantly subject to remodeling" (p. 224). Thus identities arise from and are affected by each experience of emotion.

In this study, complexity thinking was used to interpret results and theorizing from neurology to highlight the complex system of learning where emotions play a key role in decision making and identity formation. Emotions are integral to rational thought, contribute to the evolution of our consciousness and activate memories and neuronal patterns that lead to our sense of identity. This study of emotions experienced while learning in science outreach contexts and their contribution to the manifestation of students' perceived science identities was approached with this perspective and is situated within the literature on affective learning in science and learning in informal contexts.

Science Education and Affective Learning

An important movement in science education was that of 'conceptual change' at the beginning of the 1980s (Posner, Strike, Hewson, & Gertzog, 1982) that described learning as the restructuring of everyday conceptions into coherent cognitive ideas (Duit & Treagust, 2003). Soon criticisms of the rationality of conceptual change theories were voiced and the inclusion of constructs such as an individual's goals, intentions, purposes, expectations and needs were called for (Pintrich, Marx, & Boyle, 1993). Actually much earlier, Schwedes (1973) criticized physics teaching for not taking into account the whole child, ignoring their interests, desires, experiences and feelings. Wagenschien (1999) emphasized that there is no significant scientific discovery that is unaccompanied by emotions. So although the affective domain of learning is being recognized in both educational (Boler, 1999; Hargreaves, 1998) and psychological fields (Jonassen & Gabrowski, 1993), little research has been conducted on the influence of affect in learning subject matter (Laukenmann, Bleicher, Fuß, Gläser-Zikuda, Mayring, & von Rhöneck, 2003). This is especially true in science education due to its long standing cognitive tradition (Alsop & Watts, 2003) evidenced by contemporary theorizing in the field which draws heavily on the cognitive elements of Piaget and Vygotsky's ideas, largely ignoring that they too emphasized the importance of affect. Recently Alsop has (2005a) argued for the need to "bridge the Cartesian divide" and "render visible the dilemma of considering affect as an obstacle or barrier to reason and enlightenment" (p. 9).

There has been increased interest in investigating the role of affect in science learning. A mini issue of the *International Journal of Science Education* (Vol. 25(3), 2003) reported on work being completed in the area and in particular the editors called for "the need to explore the relationships that learners have with science and science education and how these develop from (and might contribute to) their sense of self and identity" (Alsop & Watts, 2003, p. 1046). Research in the area of affective learning includes investigation of affective constructs such as attitudes, motivations, self-concept, and emotions.

Studies have typically focused on classroom contexts and some examples include the study of interest-based curricula (Häussler, 2003), students' emotional reactions to particular physics topics (Alsop & Watts, 2000), and the impact of teachers' emotions on how they enact their science pedagogy and relationships in their classrooms (Zembylas, 2005). The most recent studies of emotions in science classrooms have found that perceived teacher competencies impact students' emotions (Gläser-Zikuda & Fuß, 2008) and have explored classroom demonstrations as sites of interactions that help to generate emotional energy (Milne & Otieno, 2007).

To build on findings from classroom contexts more work needs to be conducted in informal settings. Dierking (2005) suggests that "museums, science centres, zoos, aquariums, the Internet, and the family are actually better settings in which to investigate the relationships between affect and cognition in learning" (p. 112). While many studies may report results about affective learning, few studies in informal environments actually target these outcomes (Dierking, 2005). A recent long range study of visitors' memories of informal learning experiences such as world exhibitions has shown that strong positive or negative affect leads to increased memory vividness (Anderson & Shimizu, 2007). The types of affective constructs being investigated also need to be expanded to include raw emotions (dos Santos & Mortimer, 2003) and science identity (Brickhouse et al., 1999) since most studies examine values, motivations and attitudes (Nieswandt, 2005). Finally, methodologies to probe the richness and detail of students' emotions and ways of representing these emotions continue to evolve in this emerging body of research. Alsop and Watts (2003) aimed to provide examples of a range of methodologies when they edited a special issue on science education and affect and the use of multiple methods including a combination of qualitative and quantitative methods has been called for (Zembylas, 2005; 2007). The current study attempts to address some gaps in the literature base of affective learning in science by looking at affective constructs such as raw emotions and science identities along with commonly studied attitudes, motivations and decision making about physics within an interpretive study of informal contexts. Below, literature and theoretical perspectives in the study of attitudes, motivations and decision making about science and science identity will be described and used to provide a context for why complexity thinking perspectives were used in this study.

Attitudes, Motivations and Decision Making

Attitudes, motivations and decision making about science are interrelated in the study of affective learning. Research and perspectives in attitudes and motivations will be presented, focusing on studies that connect the two and include decision making (rarely a field of investigation of its own right). This synthesis does not endeavour to offer a thorough review of all the research studies that have been conducted in this field, in particular within each sub construct that exists, but to provide a synthesis of results that informed perspectives on attitudes, motivations and decision making for the current study.

Research in the affective domain of learning in science education is dominated by studies into attitudes about science. Within formal and informal contexts much research has been conducted to investigate the influences on and of attitudes, motivations and decision making about science. It is an important area of study because it can contribute to 1) achievement in science, 2) a better understanding of the relation between affective and cognitive learning, and 3) interpretations of science related decisions and actions (Koballa & Glynn, 2007). The latter is of particular interest in this study because while the interplay and interdependence of affective and cognitive learning is recognized, affective learning is the primary focus of the current study.

Attitudes about science have both cognitive and affective dimensions (Oppenheim, 1992), where beliefs and images are associated with the cognitive dimension and values and personality are associated with the affective dimension. Affective attitudes are believed to be deeper and more stable than cognitive attitudes. Nieswandt (2005) proposed that "cognitive and affective components influence each other in a kind of equilibrium...which in the end leads to behaviour" (p. 42). Both affective and cognitive components of attitudes have been researched extensively and are usually collapsed into one construct. Thus the studies reviewed here employed a broad definition for attitudes about science which encompasses both cognitive and affective aspects. In the current study, attitudes about science, specifically physics, also included both the affective and cognitive components, and was used to elucidate how students feel about physics rather than their tendency to display expert scientific attitudes or attributes (Koballa & Crawley, 1985). In this study, attitudes about physics included general positive or negative feelings about the subject or issue (Petty & Cacioppo, 1981) as well as what is often called a belief or opinion about physics (Ajzen & Fishbein, 1980) such as *Physics is fun*. Therefore, in this study they were consistently called attitudes *about* physics, rather than the more narrow (often confined to the affective component) attitudes *towards* physics.

In their review of research on attitudes about science, Osborne, Simon and Collins (2003) identified several trends and implications. Four major attitude attributes are generally agreed upon: attitudes are tenacious over time (Koballa, 1988b), learned (Koballa, 1988b), correlated to behaviour (Koballa, 1988b; Shrigley, 1990) and a function of personal beliefs (Ajzen & Fishbein, 1980). Factors such as classroom environment, teachers, parental involvement and curriculum have all been shown to have effects on student attitudes about science (Nieswandt, 2005; Osborne et al., 2003). Attitudes depend on gender (e.g., AAUWEF, 1999; Harding, 1991) and age, where a tendency for attitudes to decline from age 11 (e.g., Yager & Penick, 1986) has been shown in most countries. Finally, many studies have attempted to show a link between positive attitudes and achievement in science (e.g., Webster & Fisher, 2000; Willson, Ackerman, & Malave, 2000), but in their survey of the literature on attitudes, Osborne et al. (2003) concluded that they are only moderately correlated. Exceptions include Oliver and Simpson's (1988) longitudinal study which claimed that attitudes were a strong predictor of achievement in science but also found that motivation and science self-concept were more strongly correlated to achievement.

Student decision making about course enrollment or career paths is influenced by science interests, self-confidence in science and the attractiveness and relevance of science courses and/or careers (Robertson, 2000; Woolnough & Guo, 1997). Shrigley (1990) found that student decisions about science could be predicted on the basis of their attitudes provided that: (a) attitudes and behaviours are measured and specified to the same degree (for example, a specific attitude can predict a single act but not a multi-stage act); (b) social context and individual differences are taken into account; and (c) intentions regarding the decisions are known. In order to fulfill these conditions student behaviour must be observed and intentions explored using qualitative methodologies such as interviews and ethnographic observations.

Despite the affective nature of attitudes their study has largely been conducted with quantitative scales such as the Attitudes Towards Science and Science Teaching Scale (Moore & Sutman, 1970), Attitudes toward Science Inventory (Gogolin & Swartz, 1992), Views on Science-Technology-Society (Aikenhead, Ryan, & Fleming, 1989), Attitudes Towards Learning Science Scale (Francis & Greer, 1999), and the Colorado Learning Attitudes towards Science Survey (Adams, Perkins, Podolefsky, Dubson, Finkelstein, & Wieman, 2006). Few qualitative methodologies, like the current study, have been employed to probe deeply into attitudes about science in specific contexts (Osborne et al., 2003) despite recommendations from Potter and Wetherall (1987) who wrote that a good understanding of an attitude can only be made in the context of its use which is best elucidated by qualitative methodologies. Nieswandt (2005) echoes this sentiment by proposing that causal effects should not be pursued, rather studies should be exploratory and inductive in nature, employing quantitative and qualitative approaches because attitudes may manifest in different ways to different people.

Motivations in science are studied less frequently than attitudes about science (Koballa & Glynn, 2007). The current study used a cognitive perspective where students' motivations were described by students who volunteered reasons and explanations for their behaviours (Glynn & Duit, 1995). Social perspectives on learning also informed the current study where students' identities motivated them to learn skills necessary to maintain their membership within a community (Lave & Wenger, 1991). Several motivational constructs including arousal, interest and curiosity were examined. Arousal, often in the form of anxiety, has been shown to motivate science learning, but only if the level of emotion is not too much or too little (Cassady & Johnson, 2002). Similarly, interest stimulated in students by activities that are moderately discrepant from their current knowledge must not surprise them too much, or be too unfamiliar (Pintrich & Schunk, 1996). Students who are intrinsically motivated often experience a phenomenon called "flow" (Csikszentmihalyi & Hermanson, 1995) defined as an engrossing feeling, surpassing enjoyment, that occurs when people are concentrating intensely on a task. Finally, self-efficacy, a motivational construct that describes students' perceptions of their abilities, is a good predictor of student achievement and decision making (Joo, Bong, & Choi, 2000). Given the results of previous work in motivations in science, this study interpreted motivations by observing students' emotions evoked by activities, their emerging perceived science identities and the reasons students attribute to their behaviour. These often included revelations about student self-efficacy and their attitudes about physics.

Student decision making about physics is of interest because much research in the area of physics education is motivated by problems of low enrollment. The issue has been approached from many angles including the study of gender issues to explain the under-representation of women in physics (AAUWEF, 1999), and attitudes towards physics (Nashon & Nielsen, 2007). As early as 1974, Gardner observed that the trends in attitudes towards physics in general mirror enrollment rates and that attitudes are far more important than cognitive factors in accounting for subject choice curricular interventions. Recently, Robinson and Ochs (2008) concluded that to improve enrollment in high school science courses, no new courses need to be offered, rather existing courses need to be taught differently. In particular they recommend including more activities and topics that are interesting and relevant to students, illustrating the important role motivation and attitudes play in decision making. Crawley and Coe (1990) studied middle school students' intentions to enroll in optional high school science courses and found that attitude toward enrolling was a major predictor. Therefore attitudes, motivations and decision making about science are intertwined and are hence complex.

Results from research in motivation hint at the role of another construct, science identity, that is emerging as important to science education researchers. Self-concept is a global construct that describes ideas one has about one's identity and one's relations to others. Self-efficacy, a motivational construct, is a component of self-concept and has been shown to be the best predictor of students' grades in introductory college courses (Zusho & Pintrich, 2003). However, Nieswandt (2005) argued that self-concept and self-efficacy have been neglected in attitudinal work in the sciences and advocated for the incorporation of more complex and dynamic perspectives that attempt to explore the interdependence of affect, motivation and cognition. A recent study of the Programme for International School Assessment (PISA) results found that students who were highly engaged in curricular and extracurricular activities were also more likely to have high self-concept, self-efficacy and had the highest aspirations for future study (Linnakylä & Malin, 2008). Researchers attempting to create a model of affective learning in physics added self-concept and self-efficacy into the model along with common attitudinal and motivational constructs (Gungor, Eryılmaz, & Fakıoglu, 2007). In science education the study of science identity has emerged to describe notions of self-concept and self-efficacy in a science context. Perceived science identities were used as a construct in the current study to facilitate connections between emotions expressed by students, and the impact of participating in science outreach contexts on student attitudes, motivations and decision making about physics.

Science Identity

Science identity is an important construct to consider in any attempt to examine affective learning in science. When considering attitudes, motivations and decision making about science, self-concept emerges as important. Neurological perspectives in the study of emotion (described above) employed identity to account for the link between emotions and consciousness, and possibly cognitive processes (Damasio, 1999). Therefore, science identity has been a construct of interest for some researchers. Calabrese Barton (1998) is usually cited for her critical and feminist perspective on identity in science as "who we think we must be to engage in science" (p. 379). She found that teaching science from a lived experience (van Manen, 1990) perspective allowed homeless children to connect to complexified representations of science and identities in science. Brickhouse (2001) employed a situated cognition perspective (Lave & Wenger, 1991) to describe the practices that create gendered identities for women in science. The identity-in-practice perspective attributes the construction of identity to participation in activities associated with a particular practice, in this case science activities. Carlone and Johnson (2007) published a model of science identity that has three dimensions: performance, competence and recognition. This allows for a multitude of configurations of science identities, for example Tonso (2006) found that in some cases engineering students with the highest status (recognition) were the least skilled. Moje, Tucker-Raymond, Varelas, and Pappas (2007) recently discussed science identity research, disagreeing on different theoretical approaches but agreeing that the work is important.

Links between science identity and student attitudes, motivations and decision making about science have been explored by several studies, usually from feminist or critical standpoints. Low female participation in science has been attributed to incongruence between scientific activities and gendered identities (Carlone, 2003; Nespor, 1994). Carlone (2003) also found that classroom practices such as messages of teacher as physicist/authority promote good student science identities but do not make them accessible to female students. Lee (1998) used identity and scientific self-concept to account for gendered patterns in student interests where discrepancies between self-concepts and perceptions of those in science related disciplines were associated with lower interest in those disciplines. Hannover and Kessels (2004) had similar results when they compared student self-prototypes (identities) to school-subject prototypes. Their results found that science identity had an effect on course choice and career related decision making. In the United Kingdom, Hughes (2001) found that students' decisions whether or not to pursue science were dependent on how their scientist identities were informed by the variety of discourses available to them. School science does not provide learners with a wide range of identities or discourses within which to situate their science learning (Brickhouse et al., 2000) and for some, learning science involves risk and the unknown, requiring "border-crossing" into the subculture of science (Aikenhead, 1996). Recently Calabrese Barton, Tan, and Rivet (2008) created hybrid spaces where different identities and practices were combined (e.g., singing rap songs in science class) to interrupt traditional practices in science classrooms.

Critical and feminist work in science identity has been largely carried out on a case study basis and to extend these results and reveal larger patterns in students' understandings of science identity, Shanahan (2007) used role identity theory (e.g., Collier & Callero, 2005) to explore the attitudinal and behavioural expectations students have about particular roles in the science classroom and the extent to which they identify themselves within these roles. Students had clear ideas about the role of a science student and intelligence and objectivity were important measures students used to identify with this role. Recent research in the area of science identity has explored its role in science learning. Findings have shown that the development of scientific literacy, the ability to use science specific discourse in particular contexts, is facilitated by the development of a positive science identity (Reveles & Brown, 2008) and that classroom interactions impact science identities (Rahm, 2007). Science identity is often studied using written surveys (e.g., Bleeker & Jacobs, 2004). However, the Draw a Scientist Test (DAST) was developed as an alternative method of accessing perceptions of scientists, including those of children who are too young to write. The DAST has been widely used to elucidate stereotypes students have about scientists and gender differences (see Flinson, 2002, for a review), but has also been criticized for not asking students to draw several types of professions for comparison (Losh, Wilke, & Pop, 2008).

Thus it appears that science identity is an important construct that provides a powerful lens through which a better understanding of student attitudes, motivations and decision making can be attained. However, using solely situated learning perspectives (Lave & Wenger, 1991) to define identity leaves little space for emotions to contribute to the construction of science identities. Emotional responses to participation are limited to choosing whether to participate or not and are based on the assumption of relatively stable senses of science identity. In reality science identities shift (Roth & Tobin, 2007) and the emotional spectrum and array of responses individuals can have during learning experiences are broad and complex in nature. Roth and Tobin (2007) argue for new methods of theorizing and researching identity that recognize the dynamics of identity construction where we are "both actively involved and passively subjected to the individual|collective [dialectical relation] production of our identities" (p. 342). Few studies have aimed to study the dynamics of identity formation, or how particular learning experiences enable student science identities to adapt. However, Nieswandt (2007) conducted a study of Grade 9 students' affective and cognitive variables over the course of a year and found that positive self-concept was critical to developing conceptual understanding of chemistry concepts. Employing complexity thinking to interpret the role of emotion in identity construction, and studying student emotions before, during and after a learning activity is a step in this direction.

Theories of emotion show that emotions play a key role in the construction of identity and sense of self (Damasio, 1999; LeDoux, 2002). Complexity thinking was used to describe a frame that interprets identity as emergent from evoked emotions and emotional experiences. Thus, the current study takes the perspective that various perceived science identities are manifest through the evocation of emotions during meaningful learning experiences. However, drawing on situated learning perspectives, perceived science identities remain student impressions of who scientists are and what they do and their perception of how their own characteristics fit within that framework.

Informal Learning Contexts

Research into science outreach programs such as competitions fits within the body of work encompassed by informal learning. Since the 1970s informal education has been building a substantial research base with much of the work being conducted in museums, particularly within the field of science education. Learning in informal environments is characterized as 1) involving self motivation, 2) involving voluntarism, 3) guided by the learner's needs and interests, and 4) cumulative throughout the learner's entire life (Dierking et al., 2003; Rennie & Johnston, 2007). This perspective draws heavily on constructivist and socio-cultural perspectives and values methodological perspectives for studying informal learning such as preserving the authenticity of contexts which necessitates the use of a wide variety of methods. In addition to a substantial baseline of research that has been developed in the field of informal learning (Falk, Dierking, & Foutz, 2007), studies from a wider variety of informal learning contexts such as community-based organizations, summer camps, Internet, media and outreach programs, have contributions to make to understanding the nature of science learning (Dierking et al., 2003).

Research into affective learning in science centres responded to criticisms that entertainment is valued over education (Fara, 1994; Parkyn, 1993; Ravest, 1993) by highlighting affective outcomes as an important part of learning in informal contexts. Wellington (1989) argued that science centres can contribute to all domains of learning but that the fundamental educational aim lies in the affective. Recent theoretical frameworks such as the contextual model of learning (Falk & Dierking, 2000) and policy statements on learning (Dierking et al., 2003) have laid to rest the debate about whether visitors are learning or having fun during informal science learning experiences, "all of these things combine to make each person's visit a unique experience and its outcomes complex" (Rennie & McClafferty, 1996, p. 65). Thus, research into how people learn science in informal settings has provided support for a more holistic approach to studying learning in general that incorporates a key role for the affective domain of learning.

Attitudes and motivation in science have received attention from researchers in informal learning. Studies in informal learning have clearly demonstrated that learning in these contexts involves both the cognitive and affective domains (Dierking & Falk, 1994) and have demonstrated positive changes in attitudes about science after museum visits (e.g., Anderson, 1991; Ostlund, Gennaro, & Dobbert, 1985). Participants in informal learning environments are intrinsically motivated (Paris, 1998) and have experiences that are "rich and emotion-laden" (Falk & Dierking, 2000, p. 21). Exhibits that are emotionally evocative, such as critical issues-based installations, increase engagement and motivation during science center visits (Pedretti, 2007). Current trends towards naturalistic, interpretive research methods are helping to contribute to a better understanding of non-cognitive outcomes of informal learning experiences. Jarvis and Pell (2005) conducted a longitudinal study of student attitudes after visiting a space museum and found that students' positive attitudes persisted two months later. Research has highlighted ways in which visits to museums can be improved in order to get maximum attitudinal and cognitive gains such as adequate preparation and follow up and an awareness of students' agendas (Anderson, Lucas, Ginns, & Dierking, 2000).

Work that is particularly relevant to the proposed study is in the area of attitudes and extra curricular activities. Hofstein, Maoz, and Rishpon (1990) found that students enrolled in extracurricular science activities were significantly more interested in science activities and found learning to be more enjoyable and attractive. A series of studies conducted in Israel (Milner, Ben Zvi, & Hofstein, 1986; Scherz, Ben Zvi, & Hofstein, 1986) demonstrated clear links between enrollment in secondary science courses and affective variables and recommended extracurricular activities as an effective method of enhancing student motivation in science. Their findings were further validated by Resnick (1987) who reported a positive correlation between out-of-school science activities and attitudes and Woolnough (1994) who found extracurricular activities to be a significant factor in course choice for post-16 students. George and Kaplan's (1998) study of various influences on science attitudes found that participation in extracurricular science activities such as science clubs and fairs had a strong effect on science attitudes and posited that it is important to develop indicators of students' participation in these types of activities. In Baker and Leary's (1995) in-depth study of girls' decision making about science, they found that girls with positive attitudes attributed them, in part, to participation in science related extracurricular activities. Therefore, the character of informal learning contexts, namely that they are less structured, voluntary and experiential, create particularly rich sites to evoke emotions and study affective learning. There is convincing evidence that they can have a positive impact on attitudes about science and student decision making and thus speak to the need to further investigate the contribution of science outreach contexts to student science learning. The current study endeavoured to characterize key effects in specific science outreach contexts, namely the Physics Olympics and BC's Brightest Minds physics competitions.

Science Outreach Contexts

Science outreach contexts are a diverse group of programs, initiatives and activities whose effect on student interest in science is now becoming subject to intense study. Studies conducted mainly in the United States have sought to characterize the nature of these programs and evaluate their effectiveness in addressing the alarming downward trend in the enrollment and completion of science, technology, engineering and mathematics (STEM) degrees. One such study by the U.S. Government Accountability Office (USGAO) (2006) examined 200 programs that had received a total of two billion dollars in investment from 13 U.S. federal agencies to increase participation of underrepresented groups (gender, ethnic) in STEM degree programs and careers. The report recommended more evaluations of program effectiveness (through standardized, quantitative measures) before investing additional money and infrastructure into these programs. The American Association of University Women Educational Foundation (AAUWEF) (2004) presented a report examining 196 gender equity projects for trends and patterns over the last decade. It was found that the key goals of outreach projects could be classified as awareness, affect and academic. The affective objectives were the most common. Recommendations included bringing gender equity projects into the schools (as opposed to them being extracurricular) to foster systemic change and to focus on science content and skills over affective goals. These recommendations ignore a large body of research, particularly from the field of informal learning that points to the important role attitudes about science and other affective constructs play in student motivations and decision making about science. For example, the National Science Foundation (NSF, 1998) reported that many adults attribute their initial interest in science to informal outreach programs.

Research and literature about science outreach has not been extensive but some work has been conducted. Barab and Luehmann (2003) found that while university researchers have developed a wide array of research-based, successful and innovative curricula for outreach programs, the majority of them either do not get implemented or are used in ways that are inconsistent with the original philosophy or principle under which they were developed. Therefore, dissemination of materials and strategies developed by faculty has been identified as a key issue for the success of science outreach (Krasny, 2005). Besides large-scale assessments of outreach programs, information about individual programs usually comes from accountability reports (e.g., Owens, 2001; Thompson, 2003). Other sources of information on outreach programs include scientists, often deeply involved in these initiatives, who share their experiences in prestigious scientific journals such as *Science* (e.g., Alper, 1994), at conferences (e.g., Beck-Winchatz, 2005) and in teacher practitioner journals that report on professional development opportunities offered by outreach programs (e.g., Acerra, 2004). Some specific models for outreach are being explored and studied by universities. These include service learning models (e.g., Gutstein, Smith, & Manahan, 2006) where undergraduate and graduate students conduct outreach in school science classrooms. However, most of the research in this area examines the impact and benefits for the participating university students, but not on the classroom or student science learning. It seems outreach programs are rarely subject to academic study, but some positive impacts on students' understanding of the nature of science and scientific inquiry have been reported (Bell et al., 2003; Gibson & Chase, 2002). Van't Hooft (2005) found that when middle school students participated in an alternative energy project by engaging with solar panel technology in collaboration with groups such as the U.S. Department of Energy and the Foundation for Environmental Education, positive impacts on their perceptions of learning science, particularly around inquiry and construction of knowledge were observed. Heinze, Allen, and Jacobsen (1995) found that science outreach initiatives improved student attitudes about science and professional development outreach for teachers promoted positive attitudes towards inquiry for participants (Lott, 2003) but more research into the impact of these kinds of contexts on affective constructs is necessary.

In Canada, research into science outreach is being well supported, both by universities and funding agencies. One branch of NSERC's CRYSTAL project, CRYSTAL Atlantique, is investigating outreach programs at the University of New Brunswick (UNB) (Sullenger & Cashion, 2007) and Saint Francis Xavier University (St. FX) (Sherman & MacDonald, 2007; Marshall, 2007). Ultimately the endeavour will result in a research-based model for effective informal learning and science outreach and will provide insights into factors that affect science interest, attitudes, and achievement (Sullenger & Cashion, 2007). The St. FX component of the CRYSTAL grant is studying nine outreach programs in Nova Scotia from three different perspectives: those of the students, teachers and outreach program organizers. Some preliminary results from a study of a chemistry summer camp have been presented and the researchers found that students' recall of information and use of scientific terminology in interviews indicated that the camps stimulated interest and that students learned science concepts during camp activities (Sherman & MacDonald, 2007). Interviews also illustrated that the summer camp experience was a positive one. Moreover, positive attitudes about science and scientists were expressed by participants. A second component of the project reported that participation in a summer academy experience led to improvements in school performance as well as increased interest in everyday and classroom science (Marshall, 2007).

Physics Olympics and BC's Brightest Minds competitions provided outreach contexts for the current study. Thus what follows is a discussion of literature that is specific to the nature of competition activities.

Learning through Competitions and Design

Most literature on science competitions and design activities fall within the quantitative realm of research and have found the events to be good learning activities

(Abernathy & Vineyard, 2001; Jones, 1991; Ozturk & Debelak, 2008a). However, there appears to be a lack of qualitative or rigorous theoretical and methodological frameworks (e.g., Koser, 1985; Millar, 1984, Riban, 2000). The students in Abernathy and Vineyard's (2001) study expressed, after participating in science fair and Science Olympiad events, that they enjoyed participating, would choose these types of competitions over other types and that they valued learning goals despite the fact that the goals were embedded in the competitions. Although some evidence from classroom contexts indicates that competition can lead to negative attitudes (Covington, 2000), none of these effects were observed by Abernathy and Vineyard (2001). In fact, Olson (1985) found that competitions such as science fairs may help to build self confidence and increase motivations to work in science. Motivations, healthy self-concept, coping with subjectivity, and interacting with supportive role models have been described as affective benefits of academic competitions (Ozturk & Debelak, 2008b). Jones (1991) found that gender trends in participation in science fairs and Olympiads closely resemble the numbers of women choosing science courses and careers.

Most criticisms of competitions lie in issues of intrinsic and extrinsic motivations (Deci & Ryan, 1985). However, in a comprehensive review of literature on motivating learners, Hidi and Harackiewicz (2000) raised concerns about the tradition of motivational research to focus on intrinsic motivation and individuals when there is both evidence and theory to support the potential positive influence of factors such as situational interest, extrinsic interventions and performance goals on achievement and motivations. In fact, there is evidence that academic competitions can help students develop a healthy goal orientation (Dweck, 1986). Ozturk and Debelak (2008b) argued that competitions that engage students over a sustained period of time are intrinsically motivating since extrinsic motivation alone is insufficient to push students through the challenges and frustration that accompany many academic competitions. In the same vein, Wigfield and Eccles (1992) recommended that more research should be conducted to investigate 'task value' as a key component of student attitudes about science so that characteristics of tasks that are perceived positively by students be identified and incorporated into learning experiences. In particular, tasks such as design activities can promote intrinsic motivation in students who are participating in competitions (Sadler, Coyle, & Schwartz, 2000).

Design challenges have trickled down from elite engineering schools to high school and middle school competitions. French (1999) described the design process as iterative and comprised of some of the following steps: problem solving, conceptual design, selected schemes, and working drawings. The focus and benefits of design curricula have been emphasized, not in terms of craft or technological skills acquired, but in process, creative thinking and problem solving skills; from a meta-cognitive perspective (Johnson, 1992). However, Warner (2003) warned that "the very nature of the thinking processes involved in design may run contrary to the traditional structures encouraged in most school curricula" (p. 7). Open-ended design has become common in technology education courses in the U.S. (International Technology Education Association, 2000) and technology is featured prominently in science standards (American Association for the Advancement of Science, 1993). Lewis (2006) compared science-based inquiry curricula and design-based technology curricula to illustrate convergences and divergences, and concluded that complementarities between the two call for more integration between these subjects in schools. One of the reasons cited for making connections between science and technology more explicit through design is the need to make science more appealing by illustrating its relevance to the real, designed world. Some curricula have been created to incorporate design into pre-college courses, for example Learning by Design (Kolodner, Crismond, Gray, Holbrook, & Puntambekar, 1998) and Kids Interactive Design Studio (Kafai, 1996).

Successful cognitive outcomes have been the focus of most recommendations for implementing design-based curricula (e.g., Crismond, 2001; Kolodner, 2002) but the value of design challenges for promoting affective learning, particularly sustained student engagement and interest have also been recognized. Reiva (2001) described the benefits of a project-based science curriculum, which encouraged "students to become immersed in real problems, think creatively, and reach for high standards" (p. 47). Research into design activities has reckoned several important advantages of using challenges including: initiating students into the discourse of communities of practice of scientists and engineers (Roth, 1995) and providing a wider range of experiences with science where low female participation in science and engineering is in part attributed to lack of experience with science outside of traditional classroom contexts (Kahle & Lakes, 1983). A recent study by Silk, Schunn, and Cary (2007) showed that a science curriculum that included design could have powerful positive effects on the most at-risk students in the most challenging schools.

Emotions evoked during design activities have also been studied. Starling (1992) recognized that problems and decisions emerge when built-in expectations, anticipations or models of the project are disappointing; presumably accompanied by emotions of frustration, sadness and anxiety. Gläser-Zikuda, Fuß, Laukenmann, Metz, and Randler (2005) found that social interactions and student-centered projects elicited emotional responses from students. You (2007) examined the role of emotions in conflict resolution among teams of students participating in a design competition. In this case conflicts did not necessarily have negative effects on student motivation. Emotional intelligence, initial levels of intrinsic and extrinsic motivation and the group atmosphere were factors that helped to counterbalance negative emotions.

Characteristics of design activities that lead to the cognitive and affective outcomes described above include multiple iterations (Linn, 1995), feedback (Hmelo, Holton, & Kolodner, 2000) and reflection (Schön, 1983). Sadler et al. (2000) studied design challenges at the middle school level and provided several recommendations for designing effective challenges. They intimated that tests against nature rather than elimination style contests were more motivating because students could measure their design's improvement over several iterations, which can promote intrinsic motivation. Some researchers have warned that implemented in certain ways design projects may lead to an absence of science if the process of construction becomes the focus (Roth, Tobin, & Ritchie, 2001) and that reflection must be incorporated into the process if abstract ideas are going to be extracted from the process (Blumenfeld, Soloway, Marx, Krajcik, Guzdial, & Palincsar, 1991). Therefore, there exists a literature base around design activities but not necessarily in the context of science outreach and competitions. The current study contributes to the body of literature in the area of informal learning by studying science outreach competitions and the emotions evoked while participating in tasks such as design activities.

Research Focus

This chapter has described the theoretical perspective and a synthesis of the previous work that informed the design of the current study. Complexity thinking was used as a transdisciplinary framework complemented by neurological theories of emotion to conceptualize the role emotions play in the emergence and manifestation of identity. Literature reviews in the area of affective learning and science education revealed that science identity is an important construct in understanding connections between attitudes, motivations and decision making about science. Finally the field of informal learning has emphasized the impact of these contexts on affective constructs, but more qualitative, interpretive research needs to be conducted in science outreach contexts such as physics competitions. Building on previous research and the possibilities of employing a new theoretical framework of complexity thinking, the following research questions were explored:

1) How can the emotions experienced during science outreach programs be characterized and understood?

2) How does participation in science outreach programs and the emotions evoked by these experiences contribute to the manifestation of students' perceived science identities?

3) How do students' perceived science identities influence their attitudes, motivations and decision making about physics?

These questions outlined a program of study that began by characterizing emotions and lead to the manifestation of perceived science identities and finally to examining possible influences on students' attitudes, motivations and decision making about science. The next chapter describes the methodological approaches and methods employed in the current study as well as the details of the procedures, contexts and participants.

CHAPTER THREE

Methodology and Research Design

This study explored the relationship between emotions, science identities and attitudes, motivations and decision making about physics. The study of affective constructs such as these calls for mixed methods, including interpretive and phenomenological methodologies (Zembylas, 2007). This chapter begins by describing methodological considerations that were taken into account in order to develop an interpretive, case study design which could explore the research questions and provide thick descriptions of students' emotional experiences while participating in the Physics Olympics and BC's Brightest Minds competitions. These contexts and the participants are described in detail. The methods that were used to probe students' emotions and attitudes are outlined and finally the analytic framework which employed a complexity thinking perspective to analyze the study is presented.

Research Design

The design of this study of emotions, science identities and attitudes, motivations and decision making about physics drew upon methodological issues in the study of emotion in education and principles of complexity thinking. A complexivist approach to research design and analysis is transdisciplinary, and calls for attention to be paid at multiple levels of analysis. It also acknowledges the role of several theoretical and methodological perspectives. The study of emotion must be conducted in the face of several challenges, particularly in the area of science education. Emotions are more dynamic, complex and difficult to describe than cognition (Boler, 1999; Zembylas, 2007). The dominance of cognitive psychology in educational research has lead to the neglect of emotion and researching a phenomenon such as emotion has proved to be problematic.

Alsop and Watts (2003) emphasized the importance of achieving congruence between philosophical and theoretical frameworks and methodological frameworks in affective education. The study of learning in informal environments such as physics outreach contexts is often undertaken from a constructivist standpoint but complexivist sensibilities may have a lot to offer the field in terms of understanding affective learning in these contexts.

Constructivist theories of learning and their focus on the individual learner along with psychological methods have led to the widespread use of surveys and self-reports in the study of affective constructs such as attitudes about science (Koballa & Glynn, 2007). Zembylas (2007) presented interactionist perspectives on emotion as the next step in the study of emotion and advocated for methodological approaches, which examine how emotions are embodied, enacted and performed. These include mixed methods, which are interpretive rather than causal. When emotions are theorized from a complexivist standpoint (Chapter Two) the interconnectedness of the learner, their social context, objects, and curriculum, are recognized, and the need to study emotions in context using phenomenological methods arises. Thus, this was a phenomenological study (Denzin, 1984; van Manen, 1990) employing interpretive (Gallagher & Tobin, 1991; Schwandt, 2003), case-study methods (Creswell, 2003; Merriam, 1998) to provide rich descriptions of students' experiences and emotions.

The current study employed van Manen's (1990) phenomenological methods that aim to capture and explicate phenomena as they present themselves to consciousness and attempt to get at the essence (structure) of the phenomena in question. Denzin's (1984) perspectives on the phenomenological study of emotions also informed the design of the current study. Denzin (1984) acknowledged that, "the meanings of emotions are often covered up, hidden, distorted, or buried within the everyday world or clouded by prior 'scientific' understandings" (p. 7). Thus, the structure of emotion can be laid bare by being studied phenomenologically. Since emotions must be studied as lived experiences from within, their essence or emotions-as-processes must be captured through "rigorous intuition, abductive interrogation, and understanding" (p. 11), in other words described and interpreted. Therefore, the descriptive, interpretive discipline of social phenomenology (Denzin, 1984) is appropriate in the study of emotion. Similarly, for identity the use of phenomenology makes sense. According to Denzin (1984), emotional feeling and expression is part of the everyday practices of the person, and these practices reveal the self or one's identity. Importantly, "emotional practices make people problematic objects to themselves" (p. 89). Therefore, through emotional experiences we learn about ourselves.

The social phenomenological study of emotion involves several assumptions and characteristics including that "no emotional experience is ever experienced exactly the same way a second time" (Denzin, 1984, p. 5). Complexity thinking also recognizes the shifting nature of emotions and identities, which begs that they be studied in the context of the situation in which they are experienced. Therefore, for the current study, students' experiences were captured at multiple points during their participation in the events including pre-event interviews, observations while they prepared and participated in the Physics Olympics and BC's Brightest Minds events, and post-event interviews. "The prose of lived emotion must be captured" (Denzin, 1984, p. 7), thus multiple instances of emotionality were generated for triangulation. The current study attempted to capture emotion in both interviews and in the moments of participating, both on video recordings and on lapel microphones.

A phenomenological study must begin with a phenomenological question. Phenomenology does not problem solve; phenomenological questions are meaning questions. It is believed that when meaning questions are addressed in this way a better or deeper understanding of phenomena is achieved and as a result one can act more thoughtfully or appropriately to particular situations. The aim of the current study was to use a phenomenological perspective to probe "What is the nature of emotional learning experiences such as science outreach competitions for senior high school students?" In exploring this question, issues such as attitudes about science, science identity and decision making in science are likely to emerge, along with other (unexpected) themes.

Phenomenology is an interpretivist philosophy, a branch of qualitative inquiry into the understanding of human action that is distinct (theoretically and methodologically) from hermeneutics and social constructionism (Schwandt, 2003). Interpretivist approaches seek to find meaning in action. Potter (1996) described two tools that are useful in the reconstruction of the everyday, intersubjective world:

indexicality and reflexivity. Indexicality calls attention to the dependence of utterances on the context of use, whereas reflexivity describes how utterances are not only about something, but do something. However, in this study hermeneutic philosophy (Gadamer, 1981) also influenced study design and data collection. Understanding is 'lived' (Schwandt, 2003), and since data collection took place over a three year period, experiences from past events shaped subsequent observations and interview protocols.

The current study employed interpretive case study research (Merriam, 1998) to obtain rich, thick descriptions of students' emotional experiences. Case study research is defined in several different ways (e.g., Merriam, 1998; Stake, 1995; Yin, 1994). However, Merriam's claim (1998) that the end product is what defines a case study where the product is a holistic and detailed account of a phenomenon was quite an elucidation to the current study. Merriam (1998) defined three types of case studies: descriptive, interpretive and evaluative. The current research adopted the interpretive case study methodological framework to develop conceptual categories and to support theoretical assumptions.

Consistent with the view that a case must be bounded (Merriam, 1998), two case contexts are presented in this dissertation in terms of students' experiences in the preparation and participation in the Physics Olympics and BC's Brightest Minds competitions. Both of these events are bounded in time (from the formation of the team until the results are announced), in space (they exist in a specific location) and in terms of people (specific teams of students are chosen to participate). Multiple cases are often used to improve the precision, validity and stability of the findings (Miles & Huberman, 1994). If more cases are included there is greater variation across the cases and interpretations are likely to be more compelling. However, in multiple case studies Miles and Huberman (1994) warn that, "cross case analysis is tricky. Simply summarizing superficially across some themes or main variables by itself tells us little. We have to look carefully at the complex configuration of processes within each case, understand the local dynamics, before we can begin to see patterning of variables that transcends particular cases" (p. 205-206).

In case study research several techniques are available to enhance the validity and reliability of a qualitative study. Internal validity is defined as how closely research findings match reality. Since the reality being studied is that of the lived experience of human beings and interpretations are based on data accessed directly through observations and interviews, we are 'closer' to reality than if data were collected by an instrument such as a survey. The internal validity of the current study was strong where interview data was triangulated with video and lapel microphone data and researchers' observations.

External validity, or generalizability, must also be addressed in qualitative case studies. Although generalizations are, in one form or another, a limitation of case study, qualitative research, reader or user generalizability can be achieved when enough detail is provided so that the reader can identify whether the findings can apply to their or other similar situations. Rich descriptions and multi-site design are strategies employed in the current study to improve external validity. "If you know in detail what happened and you know how or why it happened, it seems to me that you are usually informed enough to take action" (Eisenhart, 2006, p. 701). A complexity thinking perspective recognizes the value of case study research because it endeavours to study the uniqueness of the particular in order to understand the universal. Thus, in the current study's design, a phenomenological attitude in research paired with case study methods conducted through a theoretical lens of complexity was used to explore students' emotional learning at the Physics Olympics and BC's Brightest Minds competitions.

The Learning Contexts

Multiple contexts and cases within each context were examined in this study, which can improve the precision, validity and stability of the findings (Miles & Huberman, 1994). Often similar and contrasting cases are chosen. In the current study, the cases share commonalities and differences, which have hopefully helped to highlight what the key structures are, if any exist, in creating meaningful emotional learning experiences. The two case contexts that have been chosen are both competitions, offered as part of science outreach programs and participation was voluntary: the Physics Olympics and BC's Brightest Minds amusement park competition. These two contexts are each meaningful to myself, the primary researcher, and were chosen because of strong emotional events both experienced and observed by me in those contexts. As a teacher I participated in the Physics Olympics with my students for two years and I am an organizer of the BC's Brightest Minds competition. Thus, for each context I have a particular perspective, either as a teacher, or organizer, which influenced my analysis. In general, these past experiences situated me closer to the participants and allowed for freer dialogue during interviews and a more in-depth analysis informed by past and present experiences.

Physics Olympics

The Physics Olympics (PO) (Riban, 2000) at the University of British Columbia (UBC) is in its 31st year (2009) and consists of six tasks, two of which are pre-built tasks that students must prepare before the day of the competition. During the competition teams of five to ten Grade 11 and 12 students from high schools across the province of British Columbia compete in a variety of tasks including quiz shows based on physics questions and trivia, laboratory or hands-on challenges, conceptual challenges and the opportunity to test their pre-built designs. The event is attended by about 60 teams and occurs on the first Saturday in March. The teams are divided into groups of 10 that cycle through the six tasks throughout the day. Results are tallied and at the end of the day the entire crowd (teams, coaches, parents, organizers and spectators) converge in a large lecture hall for a short physics show, door prizes and the announcement of the results. The top six teams in each task are recognized with medals for the top three and finally the overall top three teams are announced and awarded trophies. Usually the head of the Physics and Astronomy Department is there to congratulate students. No monetary awards are given but the University of British Columbia does value participation and achievement in the Physics Olympics when considering students for admittance and entrance scholarships.

Examples of pre-built tasks include challenges such as designing 1) an instrument made entirely out of food that can play *Twinkle, Twinkle Little Star* in the key of G (PO 2006), 2) a submarine that will sink, collect nails and rise without polluting the water it is in (PO 2007), and 3) an elastic powered car that will turn 90° half way through its three metre course (PO 2008). Common on-site tasks include the Electric Maze activity where students use a multi-meter to identify components in a circuit (PO 2006 and 2007) and the Intuitive Physics task where students use a computer simulation program to determine the nature of variables by exploring the relationships between them (PO 2006 and 2007). More information about past Physics Olympics events and specific tasks can be found at http://noether.physics.ubc.ca/Olympics/olympics.html. Detailed descriptions of Physics Olympics tasks and the experiences of the teams studied in 2006, 2007 and 2008 are contained in Appendix I.

Amusement Park Physics Competition

This event, called BC's Brightest Minds (BCBM), is organized by the Faculty of Education at UBC and staff from Playland at the PNE in Vancouver, BC. It is an annual one-day event in May which has been running since 2006. High schools are invited to nominate a team consisting of two Grade 12 students to participate in the competition; typically about 25 teams enter each year. The competition asks students to use simple tools such as a measuring tape and altimeter to take measurements and observations of several rides and perform calculations. Students are given three hours to complete the questions and during the first hour they have the opportunity to take measurements and experience the rides while no outside visitors are using them. The competition takes place at the amusement park and is an extension of the popular amusement park physics program that many students participate in as part of their physics classes in high school. This event however is voluntary and does not count for course credit. Participating students receive a free T-shirt and the top three teams are recognized where the top team shares a $3000 prize. The event receives quite a bit of media attention in the local community and the winning students are often interviewed in the local paper.

The BC's Brightest Minds tasks are designed to be challenging, where the top paper usually receives a mark of about 75%. Students are asked to take detailed measurements such as the height of the highest hill of the rollercoaster. Full marks are only awarded if students fully describe their experimental method and they are also expected make estimates, justify assumptions and recognize the sources of error in their approaches. Some questions ask students to use their measurements to perform calculations such as the speed of the ride or the magnitude of particular forces. Other types of questions ask students to make observations and answer theoretical questions such as the effect of mass on the wave swinger ride or the factors at play while a roller coaster rounds a banked curve. Examples of some questions from previous BC's Brightest Minds events are included in Appendix II.

Participants

The participants of this study ($N_{total} = 35$, $N_{female} = 9$) were recruited according to ethics protocols at UBC. An advertisement for research subjects was posted on a local physics teachers' listserve and schools were chosen at random from those who expressed interest. Individual team members were chosen by their teacher and from this group of students those who consented to the study were interviewed and video recorded. Students who were on a team but did not consent to the study could still participate in the event and were not effected by the study. One PO team from St. Elizabeth Secondary (SES) was studied in 2006 as a pilot study to test and refine research study design. The research design was implemented again in 2007 for three BCBM teams (the maximum number the researcher could observe with the aid of one assistant) and three PO teams, of which SES was one in order to study the same school twice. SES was studied again in 2008 to take advantage of opportunity to study some particular students and the development of their science identities and attitudes, motivations and decision making about physics over the course of two years. It also provided an opportunity to gain richer insights into how students remember their emotional experiences and how participation impacts their decision making at several instances during their school careers. Tables 1 and 2 summarize the details of the study's participants. The names of students and schools have been disguised to protect the identity of participants.

Table 1: Participants (N=29) in Physics Olympics (PO) event. (*) denotes students who were participating in the PO for the second time. (+) denotes students who participated in the study for two years in a row. Bold students were in Grade 11.

Event	PO 2006	PO 2007	PO 2007	PO 2007	PO 2008
School	St. Elizabeth Secondary (SES)	St. Elizabeth Secondary (SES)	Water Hill Academy (WHA)	Summergrove High School (SHS)	St. Elizabeth Secondary (SES)
N	4	7	6	7	5
Team Members	Phil (*) Rob Brad Tom	**Allen** **Barry** Colin Dean **Elyse** Frank **Glen**	Alex Beth Cora **Derek** Eddy Felix	Adam Bob (*) Cam (*) Diane Ellen Fred Greg	Barry (*,+) Elyse (*,+) Glen (*,+) Henry (*) Ian (*)

Table 2: Participants (N=6) in BC's Brightest Minds (BCBM) event. All students were in Grade 12.

Event	BCBM 2007	BCBM 2007	BCBM 2007
School	Queen High School (QHS)	Kent High School (KHS)	Center Ville Secondary (CVS)
Team Members	Stacy Jane	Paul James	Laura Jared

Most Physics Olympics participants (see Table 1) (N=29) were in Grade 12, however some were in Grade 11. Only six of the 29 students studied were female and on any given team there were never more than two female students. Some Grade 12 students had participated in the event before as Grade 11 students. Since a team from St. Elizabeth Secondary (SES) was studied for three years in a row, three students participated in the study twice. Each school that participated in the Physics Olympics had a very different experience. The team's experience was dependent on how the teacher created the team, preparation for the pre-built design, the school's past history at the PO, and their experiences at the event. Below a short description of each team's experience will be provided. Appendix I contains descriptions of each team's PO experience including tables detailing the tasks for each PO and which students participated in individual tasks.

The 2006 team from St. Elizabeth Secondary (SES) (a small, private catholic school) was comprised of four male Grade 12 students, one of whom had participated in the event the year before. They were all in the same physics class (that of Mr. John, the PO coach). To create the team, Mr. John toured all Physics 11 and 12 classes at SES and delivered a short presentation about the event. He invited all students who were interested to participate in the preparation of the pre-built designs. From the students who participated in the designing and building of the pre-built tasks he chose up to 10 students to attend the PO event. In 2006, only 5 students (4 of whom consented to the study) could attend the event because of numerous extracurricular conflicts. Brad and Tom worked primarily on the catapult car pre-built design, and Phil and Rob (with the help of other students) created a musical instrument out of food. At the PO, Phil had to perform *Twinkle, Twinkle, Little Star* for the judges and an audience of fellow competitors and spectators.

In 2007, 10 students represented SES at the PO and seven students participated in the study. This group was very different than the year before, none of its members had participated before (since the team in 2006 were all Grade 12 students), four students were in Grade 11 and one student was female. Mr. John used the same recruitment method to allow this team to emerge. The pre-builts (a submarine and a lifter) were prepared by all the students working collaboratively.

Finally, in 2008 the SES team (N =5) was comprised entirely of Grade 12 students who had participated in the event the year before. Mr. John did not use the same open invitation technique to choose his team members. He invited students who had participated before and/or who had also represented the school in another science competition that had occurred in the fall. Three students, Barry, Elyse and Glen, participated in this study for the second time. The entire team worked on one of the pre-built designs, a car that could turn 90° part way through a 3 m course, with the exception of Henry who took upon himself the responsibility to design and build the second pre-built, a multi-meter to measure current, voltage and resistance. Harry had a lot of experience with electrical work and his father was an electrician, so he seemed well suited for the task.

In 2007, two other schools were included in the PO study. The first, Summergrove High School (SHS), had a history of successful experiences at the Physics Olympics. Most of these students were enrolled in the International Baccalaureate (IB) physics program. All the students who participated in the event (N = 7) were in Grade 12 and two students, Bob and Cam, had been members of the 2006 SHS PO team which had won second place overall at the event. In this large, academic, public school, many students often wanted to join the PO team. To create the team, Mr. Patrick, their physics teacher, chose a leader for each of the six PO tasks (pre-built and on-site tasks included). Students who were interested in particular tasks such as the pre-built, or the Electric Maze, attended preparation activities for three weeks before the event. Task leaders coordinated efforts to prepare. In the case of the Electric Maze task for example, the leaders would conduct activities to review and practice concepts of electricity and familiarize students with the equipment. The pre-built teams worked on and built their designs. If more than five students (the maximum number allowed to participate on any particular task at the PO) were interested in participating, it was up to the leaders to cut people from the team.

The final PO team that was studied in 2007 was from Water Hill Academy (WHA), an elite private school. Unlike all the other students who participated in this study, these students did not volunteer to participate in the PO. The members of this team were assigned by their physics teacher, to participate in the event. However, they still invested much time and effort, outside of school hours, including staying up the entire night before the event to design their pre-built challenges. Most of these students were extremely high achieving, academic students. Some had already completed Physics 12, others were in the Advanced Placement (AP) physics program, and one was in a Grade 11 pre-AP physics program. This team worked collaboratively on the pre-builts and each member of the team (N = 6) participated in the study.

The BC's Brightest Minds participants (see Table 2) were all Grade 12 students (N=6) who were chosen by their teachers to represent their school in the competition. Teams from three different schools were studied. Stacey and Jane attended Queen High School (QHS). They both had good marks in physics but neither chose physics as their favourite subject. They both planned to attend university the following year to study computer science and life sciences respectively. Paul and James attended Kent High School (KHS) and they were enrolled in AP Physics. They were chosen to participate because they had the highest marks in their class. Paul planned to study integrated science and James wanted study business at university. Laura and Jared attended Center Ville Secondary (CVS) and were chosen to represent their school because they were generally good students. Both planned to pursue post secondary education, but by starting at the college level studying geological engineering (Jared) and arts leading to architecture (Laura).

Data Collection and Analysis Methods

Several authors have written considerably on phenomenological methods in education (Moustakas, 1994; van Manen, 1990). Distinctions must be made between methodology, methods and techniques or procedures (van Manen, 1990). A methodology is the philosophic framework, which includes fundamental assumptions, orientation to life, and view of knowledge. The term method can be confused with procedure but implies that the specific procedure is backed by a particular theory or philosophy that makes it a mode of inquiry. For example interviewing methods will differ whether you are conducting an ethnography or a case study. Finally techniques are the procedures that were implemented to carry out a particular method (where the method was carefully chosen to reflect the methodological perspectives). The methodology of phenomenology aims to be suppositionless (van Manen, 1990) and thus resists the tendency towards predetermined procedures and steps. Therefore, for a phenomenological study there is no set of procedures to be mastered, rather they need to be created and tailored to the study at hand. Similarly, case study research calls for the employment of any method that can contribute to the rich description of the case.

Complex systems embody a nested structure which calls for analysis to take place at several different levels (Davis & Sumara, 2006). This study paid particular attention to both the individual and team units of analysis. Students were interviewed individually in the case of the Physics Olympics. However, observations of preparations before the event and participation during the event were made of students interacting as part of a team. Some individuals wore lapel microphones during the activities to capture their comments, and usually others' comments were also recorded since students worked together closely on activities. Occasionally, a general recorder was placed on a worktable to capture the discussions of the entire team during the task. For the BC's Brightest Minds, interviews were conducted in pairs and thus the primary unit of analysis for that event was that of the team. However, students were asked to respond individually to some questions during the interviews. Emergent indicators of emotions and identities are presented at both the individual and team level of analysis. Complexity thinking acknowledges that these develop and adapt simultaneously where each influences and impacts the other. With this view, understanding of complex phenomena such as identity must be presented as partial, incomplete and biased.

Interviews

The bulk of the data in the current study was pre- and post-event interviews, complemented by observations. In each context, the participants were interviewed before and after the event in order to probe their motivations for participating in the event, attitudes about science and conceptions of science identity. Interviews after the event focused on emotional occurrences during the event. Questions were formulated depending on what the researcher saw and heard at the event (either in person or on video data that was viewed before conducting the post-event interview). Participants were asked to clarify things that they said and did at the event and to explain some of the feelings and emotions that they expressed.

Interviews for the Physics Olympics were conducted individually but interviews for the BC's Brightest Minds were conducted in pairs because in this case there was not much chance to get to know these students before the event and they were more likely to be comfortable and conversational when they were interviewed together. Individual PO interviews allowed students to speak candidly about their own emotions, strengths and weaknesses and issues such as team dynamics. PO pre-event interviews occurred while the researcher visited the schools to observe students' preparation efforts, usually after school the week before the event. PO post-event interviews occurred the week after the event and occurred during school hours when students had permission to leave a class for half an hour or during lunch time depending on the students' and teachers' preferences. BCBM's pre- and post-event interviews took place the week before and the week after the event. The researcher visited the school at a convenient time negotiated between the students and teachers, usually right after the school day, to conduct the interview. Interviews took place in quiet, private locations throughout the school (e.g., an empty classroom). It was important that interviews were conducted away from the student's teacher or fellow team mates. The interviews were semi-structured (see Appendix III for interview protocols and connections to research questions), recorded, and transcribed verbatim for data analysis and lasted between 15-30 minutes. Participating teachers were interviewed after the event to determine how teams of students were formed, their motivations for participating and impressions of the event. Teacher interviews also provided a means to triangulate interpretations of students' emotions and provided background on students' personalities, relationships between participating students and their experiences during event preparation.

The hermeneutic phenomenological interview should resemble a conversation (van Manen, 1990). In conversation some of the meanings of the experience may be revealed. A second goal of the interview is to obtain narrative accounts of the experience. Since interviews are often unstructured (and ideally conversational) it is very important that the researcher remain focused on the essential question of interest. In the current study the interviews were unstructured and at times resembled a conversation because the researcher and the participants had shared experiences. For example, the researcher had participated in the Physics Olympics before, had observed the participants' preparations, and was present at the event. (See Appendix IV for a sample interview transcript.)

Observations

The second important source of data included observations which complemented interview data. Students were observed while both preparing for and participating in tasks (in the case context of the PO) or simply while participating (BCBM case context). To observe students' experiences at the Physics Olympics the researcher attended and contributed to some preparation sessions where students were designing the pre-built designs and took extensive field notes, paying particular attention to expressed emotions. Each team was video taped continuously during the event and some students wore lapel microphones while they competed to capture their expressed emotions during the event. If the task was a laboratory activity where students were gathered around one lab bench for the entire activity a general audio recorder was put on the bench to capture the utterances of all the students. In other tasks, some students were chosen to wear lapel microphones. No one student wore a lapel microphone for an entire PO event. In 2006 and 2008, when only one PO team was studied, the researcher observed several (but not all) preparation sessions and collected the video and audio data while the team competed at the PO. In 2007, when three teams were studied, the researcher was able to observe two teams at the same time because they were in the same group of 10 teams throughout the day. The other team was video taped by an assistant. The amusement park competition did not require much preparation, thus the team was video taped during the competition and again students wore microphones. The researcher could not observe all three teams all the time since they were spread throughout the amusement park. She did circulate and observe individual teams throughout the event. Most of the observations for this event were drawn from the video recordings of the event, which were collected by research assistants.

'Close observation' is a technique where the researcher both observes and participates in the subject's lifeworld. It "involves an attitude of assuming a relation that is as close as possible while retaining a hermeneutic alertness to situations that allows us to constantly step back and reflect on the meaning of those situations" (van Manen, 1990, p. 69). For example, in the Physics Olympics study I attended many of the pre-built preparation sessions and helped out where I could. At the same time I was not the teacher and my relationship with the students was not complicated by any other responsibilities. It was easy to maintain a certain distance because there was little to distract me from the task at hand, to observe their preparations and participation at the events. If these had been my own students I would have had many other interactions with them (grading, discipline) which would have interfered with my ability to reflect on their engagement in competitions. Observations and field notes were used to inform interpretations of students' expressed emotions and behaviours and were used to search for universality and particularity (Erickson, 1986). Methodological triangulation was also achieved by matching observations of occurrences during the event to students' recollections and reflections of the events (Stake, 1995).

Analytic Framework

The analytic framework for the current study was informed by both phenomenological and complexity thinking perspectives. A phenomenological perspective informed the design of the research and its ability to answer questions and make claims (Denzin, 1984; van Manen, 1990). Qualities of complex systems were used as a form of educational inquiry (Davis & Sumara, 2006) to characterize the learning system. The bulk of the data for this study were from the transcripts of pre- and post-event interviews and complemented with field notes, video and microphone recordings from the events. Preliminary analysis looked for key themes and critical emotional events (Gallagher & Tobin, 1991). Data analysis was primarily referred to as reflection, specifically hermeneutic phenomenological reflection, described by van Manen (1990) as the act of reflecting in order to interpret and explore the essence of a phenomenon. "Insights into the essence of a phenomenon involve a process of reflectively appropriating, of clarifying, and of making explicit the structure of the lived experience" (van Manen, 1990, p. 77). Many qualitative research methodologies involve searching for themes in the data by using grounded theory (Glaser & Strauss, 1967). In phenomenological studies the themes reveal the structure of experience. Themes act to focus phenomenological description and the future progress of the research. Themes were derived by 1) looking at a text as a whole and trying to capture a fundamental meaning in an excerpt, 2) selecting statements or phrases that recur throughout the data that reveal an essential structure of the experience, and 3) analyzing text line by line for themes.

The data in this study were mined for statements or expressions of emotions that recurred and appeared to represent some essential features of the learning experience. 'The Physics Olympics was fun.' was an example of a statement that recurred and was coded as an expression of the emotion of enjoyment. Themes were not meant to be universal truths, merely to hint at an aspect of the phenomenon. Fun was an expectation that students had of the event and was a commonly shared feeling among participants. Themes were next examined for universal or essential qualities. The researcher questioned whether these were aspects or qualities that make a phenomenon what it is and without which the phenomenon could not be what it is (van Manen, 1990). In this case, the Physics Olympics or the BC's Brightest Minds competitions, would not have had the same essence if students did not expect the experience to be fun (i.e., they wouldn't volunteer) and they would not engage in the activities as fully. Thus 'The Physics Olympics was fun' was a part of the essential structure of the experience.

For some research questions, particularly the second question about the manifestation of science identities, complexity thinking was more heavily relied upon to identify and select organizing themes. In this case, conditions of emergence of complex systems (Davis & Sumara, 2006) were used to elucidate how student expressions of emotions contributed to the manifestation of science identities. During data analysis, the themes emerged as a result of employing a complexity perspective. Not all the known conditions of emergence were imposed upon the data set, thus the themes can still be said to be emergent, but when they occurred and exhibited characteristics indicative of a condition of emergence, then it was characterized as such. Thus constraints existed, arising from employing a particular lens for data analysis and interpretation.

Data from student microphones and video recordings were not transcribed but were viewed repeatedly by the researcher. In most cases it was not possible to hear students' discussions on video, thus the students' lapel microphones were queued to match video data and both were listened to and watched simultaneously. Since at least two students were wearing lapel microphones for every task, all video data was viewed at least twice and lapel microphone data was listened to once. Thus, student experiences of each task during the PO and the entire BCBM event were viewed from at least two different (student) perspectives. This created a very thick data set that allowed for a better understanding of the case (Stake, 1995).

Qualitative analysis software capable of supporting video, audio and text data (NVivo 8) was used to view emotional events and to identify, transcribe and code emotional events. Interviews were audio taped and transcribed verbatim and were uploaded into NVivo 8 for coding. Fortunately, recent developments in qualitative analysis software allowed for the coding of all the data sources (including text, video and audio sources) to be stored, displayed and analyzed within the same software package. Frequency of particular codes, within individual sources, cases, or overall, were displayed and tools such as searches and matrices were used to find connections between sources, cases and codes (Lewins & Silver, 2007).

The first pass of coding viewed all the data (video, audio and interviews) and coded it for both verbal and non verbal expressions of emotion. Video and lapel microphone data were examined first, followed by interview data. This allowed for the researcher to have a good idea of what happened at the event in order to interpret student reflections in post-event interviews. Data within one case were analyzed completely before moving on to the next case. Initially over 40 different codes for emotions emerged, but after collapsing categories such as fun and enjoyment, frustration and time stress, four codes emerged as particularly frequently expressed (disappointment, excitement, frustration, and fun). A list of emotion codes and their frequency is included in Appendix V. Drawing upon reflections on the data, the researcher's own perspective and experience, and complexity thinking, the emotions were organized and presented within themes depending on how they were evoked. From a second pass of coding emotional experiences, three types of agents evocative of emotions emerged (context, task, and novelty). These helped to characterize emotions (research question one) and to reveal the structures of these learning experiences that contributed to their particularly emotional character. The theoretical framework of this study viewed science identities as emergent from emotions, thus emotion codes were examined again for evidence of science identity in order to answer the second research question: How does participation in science outreach programs and the emotions evoked by these experiences contribute to the manifestation of students' perceived science identities? Science identities were coded whenever students drew connections between themselves and the actions/characteristics of scientists or science concepts. Evidence of indications of science identities appeared to be defined by conditions of emergence in complex systems, hence their use in locating and describing the emergence of science identities from expressions of emotion. These conditions (diversity, redundancy, neighbour interactions and decentralized organization) also revealed the essence and structure of learning experiences at the Physics Olympics and BC's Brightest Minds events.

Finally the last research question called for a fourth pass through the data to examine the impact of science identities on student attitudes, motivations and decision making about physics. The results from the second research question, the emergence of several science identities, and a complexity thinking perspective which sees emergent entities (such as science identities) as dynamic, adaptive and learning systems, shaped the coding for the third research question: How do students' perceived science identities influence attitudes, motivations and decision making about physics? Thus shifts in student attitudes, motivations and decisions were identified, interpreted and described by looking at differences in student descriptions of physicists and what physicists do in pre- and post-event interviews, and by reflecting on what students said that they learned by participating in the events.

Emergent themes from transcripts and particularly indicative statements expressed by students were triangulated with video and lapel microphone data, and field notes and observations from the events. Member checks were conducted to verify the robustness and consistency of the coding framework.

Ethics Protocols

Data collection procedures for the proposed study took place both in schools and in outreach contexts. In all cases, proper ethical procedures were followed. University ethics applications for conducting high risk studies (because students were video recorded) were completed for all four rounds of data collection. Approval was also sought from participating school boards. (See Appendix VI for UBC ethics certificate and Appendices VII and VIII for approval from school boards.) Students were asked to sign assent forms and their guardians signed consent forms. (See Appendix IX for a sample consent form.) In all cases consent from students, parents, principals and the school boards was obtained.

Integral to proper ethics protocol is the maintenance of student safety and confidentiality. At all stages of the study, participation was voluntary and participants were advised and reminded of their rights to withdraw or refuse to participate without jeopardizing their participation in the outreach event or their academic standing in their courses. Participant data were kept secure and to maintain confidentiality, names were not stored with interview, audio or video data. Results that were reported used pseudonyms for students and schools and locations were not identifiable.

CHAPTER FOUR

Characterizing, Interpreting and Understanding Emotions in Outreach Contexts

Data analysis was guided by complexity thinking which provided a lens for organizing and interpreting the data corpus. As argued earlier, this framework was considered appropriate to study emotion and learning in contexts such as science outreach competitions because complex systems are dynamic and adaptive, in other words, learning systems. Secondly, complexity thinking proved useful in interpreting neurological and phenomenological perspectives on emotions and their role in learning. Evoked emotions lead to changes in bodily structure and are involved in 1) the storage and activation of memories, 2) rational decision making, and 3) manifestation of identity. Emotions were thus interpreted as expressed in students' reflections on their experiences (statements such as 'It was fun.') and their behaviour and expressions while participating. This framework, enriched by the literature reviewed in Chapter Two, informed the framing and implementation of the study as discussed in the preceding methodology chapter, including data organization and analysis techniques. Therefore, this chapter discusses the outcomes of the analysis by responding to the first research question: "How can the emotions experienced during science outreach programs be characterized and understood?"

Following careful examination of the data corpus through a series of coding schemes, theoretically determined, several themes relating to how emotions were evoked emerged. See Appendix V for emergent themes (codes) of emotion and their frequency. Therefore, in response to the first research question, the discussion in this chapter is framed around three main themes which attempt to capture the features of these science outreach contexts that contribute to the evocation of strong emotions. The three themes, Context, Task, and Novelty evoked emotions were each characterized by emotions of frustration, excitement, disappointment or fun. These themes emerged at several levels of analysis. Autonomous unities, collectives of unities, and collectives of collectives are levels of complexity nested within each other and exhibit similar dynamics in that they adapt and respond to stresses in similar ways but on different timescales or on different unities (Davis & Sumara, 2006). Analysis at a particular level of complexity is incomplete or partial without acknowledging the dynamics happening simultaneously at other levels. Therefore, necessary attention was paid to the multifaceted nature of the experience including the general context of the events (context evoked emotions), specific and particular tasks that students were called upon to complete (task evoked emotions), and students' expectations about, familiarity with and comfort level of participating in these kinds of events (novelty evoked emotions).

Data collected during the BC's Brightest Minds and the Physics Olympics competitions and pre- and post-event interview data were coded for expressed emotions. Several themes emerged that illustrate trends across teams and events. While over 40 different codes for emotions were generated, some emotions were consistently and frequently experienced in both case contexts. These emotions were those of **fun**, **frustration**, **excitement**, and **disappointment**. Student data are used to illustrate how each of these emotions were evoked. The story of the evocation of students' emotions will be told using examples from student interviews conducted before the event, from video and audio data collected while students participated in the competitions, and from student reflections in post-event interviews.

Context Evoked Emotions

Context evoked emotions is a broad notion which encompasses descriptions of emotions that arose because of the unique contexts created by the Physics Olympics and BC's Brightest Minds competitions. Context evoked emotions emerged as a theme because there was strong evidence that the nature of science outreach contexts such as Physics Olympics and BC's Brightest Minds competitions created a surprisingly small subset of common emotions among the cases (teams) and individual students who participated in these activities. Over the course of three years, the experiences of eight teams (35 students) from six different schools in two different types of events were documented. A small subset of emotion indicators (**excitement**, **disappointment**,

frustration and **fun**) emerged as those, which were predominantly experienced by most students and most teams during the events. When emotions were analyzed at the level of context, they were experienced by teams as wholes, or as individuals who were part of a team. Three sub-themes of context evoked emotions are discussed. They include the venue and competitive atmosphere, structure of the events, and the social nature of participation.

Venue and Competitive Atmosphere

Context evoked emotions were expressed as a result of participating in a competitive, science outreach event. In both contexts, the Physics Olympics and BC's Brightest Minds, students chose to participate in an event that was held in an informal learning context that was separate from any of their regular curricular expectations. The unique informal learning environment provided by these science outreach competitions generated a significant amount of **excitement** among the participants because of the specific venues and the competitive nature of the events.

The Physics Olympics competition was held at the University of British Columbia and was attended by 60 teams from across the province. The novelty and number of people participating created the expectation and experience of an exciting environment. In pre-event interviews students expressed anticipations exemplified by statements from the three students below:

> Elyse: It's going to be exciting, watching everyone have fun. It's going to be cool. Not everyone thinks so. [PO, SES 2007]

> Diane: I think it will be really busy, like lots of people there, and stressful and um, I worry that we won't really know what to expect. We'll have pretty conceived ideas of what it will be and all of a sudden it won't be at all what we're thinking. So we'll be thinking a certain way and we have to just be more open to, like, what is going to happen. [PO, SHS]

Alex: [I think it will be] a little bit stressful. I don't think, we're pretty prepared for a few aspects, I don't think we're prepared for all the activities. So I'm maybe a little stressed there. I think it'll be kind of exciting. I guess I've never entered an event like this before so it's hard to know. [PO, WHA]

For some students participating in BCBM the amusement park was an exciting context to watch and ride the rides:

Stacy: Ooh ooh time! It's going up. [Watching a ride go up.] [BCBM, QHS]

Stacy: When you're going down, don't you feel yourself going up? I do! [BCBM, QHS]

Since both events were staged within a novel, competitive and challenging atmosphere, students were excited to try new ideas and to achieve success. This state of anticipation was, in a way, evoked by the nature of expectation about the novel contexts that the participants perceived. This supports work in students' experiences of competitions, which have been shown to intrinsically motivate students (Olson, 1985) and increase situational interest (Hidi & Harackiewicz, 2000).

Brad: It [physics] can be a lot more fun when applied like that in a competition. I never thought it could be done like that. [PO, SES 2006]

Examining emotions provides evidence of intrinsic motivation. Expectations of success seemed to generate feelings of excitement before the event:

Eddy: [I expect it to be] pretty exciting. Get to see other people's stuff and I don't know how ours is going to compare to theirs. [PO, WHA]

Res: Were there times that you felt excited?

Brad: Well yeah I guess, the instrument, I just wanted to see how it was going to work out. [PO, SES 2006]

Bob: We're going to win! WIN! [While having a team photo taken.] [PO, SHS]

Each team that was studied exhibited high levels of energy and excitement (as exemplified below) during the events, however not all tasks evoked the same amount of excitement (see task evoked emotions below). During both competitions, moments of excitement occurred most often when the students had come up with a new idea that they were excited to try or when they had achieved a level of success during the event or task.

Stacy: Oh that's brilliant! Let's start doing that! [BCBM, QHS]

Stacy: We actually got something that makes sense! [Students do a high five.] [BCBM, QHS]

Allen: Test each connection and we'll link together the ones that work. [He is talking very fast and excitedly.] [PO, SES 2007]

Beth: It's pretty good, I don't know if I can do better. I think you can! We can do it! Go big, let's go big!! Man! What the heck! [PO, WHA]

Ellen: We finished it so fast! I never realized how fast it was! [She is laughing and happy, talking to other teammates after the Optics task]. I think it was like. When we were doing it, it seemed so long. We were one of two teams who the target. We did OK. [PO, SHS]

In these cases, emotions provide evidence that students are experiencing Csikszentmihalyi and Hermanson's (1995) concept of 'flow of experience' where "when goals are clear, feedback is unambiguous, challenges and skills are well matched, then all of one's mind and body become completely involved in the activity" (p. 71). Thus the students appeared very motivated and deeply engaged in the learning activity.

Post-event interviews were conducted to probe the students' perceptions of their emotions expressed while participating in the events. Students' comments agreed with researchers' interpretations of in situ observations (described above). For example Ellen's statements immediately after the Optics task (see above) corroborated with her post-event interview response:

> Res: What was the most exciting moment?
>
> Ellen: When other people from the different tasks came back and said - like yeah we think we did pretty well. That was pretty good too. They were really excited. And Optics you know we got the first part done so that was pretty good. [PO, SHS]

Excitement was indeed a strong expression of emotion that many students experienced.

> Res: What was it like, preparing for the Physics Olympics?
>
> Diane: We figured that out, which was kind of exhilarating. Maybe that's the wrong word. Exhilarating, it's kind of too excited. [PO, SHS]

> Cam: Yeah that was pretty exciting! I remember jumping up and down when we won it [the competition the year before]. [PO, SHS]

> Dean: In the Mystery task, when we were doing the radar. And were looking at the dots and seeing how they aligned with the lines and we were trying to get closer and closer. It was really exciting, trying to get them closer, you're doing it over and over again, trying to perfect it. Get more and more dots closer to the line. [PO, SES 2007]

> Glen: And then also every time we made a discovery as to how to make our tower more efficient, everyone was really excited. [PO, SES 2007]

Thus feelings of excitement were closely tied to the informal, competitive and challenging context of the event. Complex systems (e.g., the participating team) seek challenge and move toward disequilibrium in order to maintain its highest level of organization (Juarrero, 2002). While participating in the event teams of students felt excited when they generated a new idea, learned something new or accomplished a level of success on an event or question within the competition. In this context, excitement seemed to operate as a *positive feedback loop,* which helped to keep the complex system on the brink of disequilibrium and was a condition that helped promote emergence of ideas and of more intense emotions. Positive feedback loops allowed for the amplification of small system perturbations. For example, when one student became excited, the entire team got excited and engaged, more ideas and expressions of emotions emerged from the collective. There are numerous examples in the video data of teams being re-energized in the final moments of a particular task or competition by a new idea, insight or expression of emotion. All students began talking at once, generating ideas, manipulating the equipment and trying to get their individual voices heard. The strong emotions experienced while participating in physics competitions provide support for literature that has called into question criticisms of competitions based on extrinsic motivation (Hidi & Harackiewicz, 2000), illustrating that students are intrinsically motivated to engage in the activities.

However positive feedback loops were not limited to amplifying positive emotions. The competitive atmosphere prompted the expression of strong feelings of **disappointment**. Feelings of disappointment were more prevalent in the PO than in the BCBM activities, most likely due to the amount of feedback (Hmelo et al., 2000) they receive throughout the day. Although PO participants usually did not know whether their efforts were ultimately successful for any particular task, they were often able to get a sense of their level of success from observing other teams or from how easy or difficult it was for them to complete the challenge. However, in the BCBM event students who completed the exam but didn't win did not have any prior gauge or hunch of how well they did. Thus, the same feelings of disappointment were not expressed, which this study considers as not evoked.

The same factors, prestige and competitive atmosphere, which evoked excitement also led to disappointment at the PO event. Students were motivated to prepare, which elevated their expectations and made them more vulnerable to disappointment.

Two PO teams out of the five that were studied, Summergrove High School (SHS) and St. Elizabeth Secondary's (SES) 2008 team, were particularly disappointed with their efforts. SHS ranked second overall in the PO the year before. Thus, they had really high expectations going into the event. Bob and Cam were on this winning team so they expressed disappointment very frequently. SES's 2008 team also had high hopes. The team consisted entirely of Grade 12 students, who had attended the event the year before as Grade 11 students. Earlier in the school year, some of them had also been on a team that had placed second in a similar competition (that was not examined in this study and which had activities that covered all the school sciences). Thus they were confident going into the 2008 Physics Olympics, but were disappointed, in their words, disheartened, by their performance.

Therefore the venues (a large local university (UBC) and an amusement park) coupled with a competitive atmosphere evoked feelings of excitement (primarily), but also disappointment. In the Physics Olympics the main features of the venue and atmosphere were the prestige of the event and its challenging nature. Students experienced feelings of excitement when they had a new idea to try or when they achieved some minor or major successes during the event. They felt disappointed when their high expectations of success were not achieved. These emotions were evidence that the students were intrinsically motivated and that meaningful learning was occurring. In the BC's Brightest Minds competition the general context of writing a competition in an amusement park seemed to be the primary source for students' feelings of excitement. The next theme will describe some of the structures of the events that made them challenging and thus emotionally evocative and the specific expressions of emotions that were expressed as a result.

Structures of the Events

Several structures of the Physics Olympics and BC's Brightest Minds events emerged as important and essential to the evocation of emotion. Two structures in particular, time constraints and proscriptive (open ended) instructions, were integral to moderating the level of difficulty of the competitions and thus evoking strong emotions, usually of **frustration**. Strict time constraints were part of the general context of both events and are thus discussed in detail here within context evoked emotions, whereas the nature of the proscriptive rules used to craft particular tasks will be described in more detail under the theme of task evoked emotions.

While students prepared their pre-built designs for the Physics Olympics, they often described time as a significant issue. Teams were observed while they prepared for the competition, designing their pre-built projects. Most groups worked late into the night, sometimes overnight trying to create a working prototype of their project. During both the PO and BCBM events, limiting the amount of time provided for completing particular tasks always increased the challenge for students. Students on all three BCBM teams found that obtaining accurate measurements, such as height of the rollercoaster, was very time consuming. Strict time constraints prompted students to devise efficient methods for taking measurements and to plan and strategize their use of time so that they could complete as many of the competition questions as possible.

> Laura: It's going to take all the time to do the measurements, we don't have time to do the calculations. [BCBM, CVS]

> Jane: For example we had, eventually we stopped using the tape measure, we started using our feet because it took too long, because we kept doing really dumb things, it took too long so we just measured our feet. Which probably explains some of our answers. [BCBM, QHS]

> Paul: We kind of spent, wasted about 45 minutes thinking about one question. And then we decided we have to move on, we have to move. So we worked on the next question. [BCBM, KHS]

The tasks in the PO were typically between 20-45 minutes long and students felt the stress and pressure of time constraints during the vast majority of the tasks they worked on. An example of a team of students struggling with a particularly tight time constraint during the PO occurred for SES in 2006 who had to make some last minute changes to their pre-built design. In the video clip Brad and Tom were frantically working on their catapult car to change both the elastic, which powered it, and the mass they were expected to launch. They were both hunched over the small car, making adjustments. "We don't have much time", Brad said to Tom. Finally the car was ready just in time to do a trial, but neither trial worked. Brad kicked the car before he picked it up and sat down in his seat with a very unhappy look on his face for the remainder of the task. His lapel microphone captured what he said to his teammates later, "That was so annoying, three minutes, two and a half. Oh my God. After all that it didn't even get to launch. I had to switch the elastic band which took a while." In his post-event interview, his non-verbal expressions were probed, and he described his feelings as "Happy but a little bit annoyed with my car." This description is also a good example of how audio, video, and interview data were used to construct rich descriptions and to interpret students' emotional experiences during the events.

From audio and video data it was apparent that emotions were particularly strong and more frequently expressed as time ran out on a particular task. For example, in the Boat Design task in the 2008 PO, the SES team planned and worked on their design for their entire time allotment and did not take the time to test it. Barry was very frustrated by this: "Test it! Just put it in the damn water". He frequently asked Glen how much time was left and when time was up he put his head in his hands. In several instances throughout both competitions, individual students were observed putting their head in their hands during moments of difficulty. This was interpreted as an expression of frustration.

Most students described their frustration evoked by strict time constraints in their post-event interviews. However, several students also recognized this particular structure as generating strong emotions such as excitement and providing the challenge that motivated them.

Elyse: I mean those 15 minutes [in the Optics task] were probably the fastest 15 minutes of my life. Like we were all panicking, and before we know it was like halfway done and we'd just started. But after the stress, I think it was so much fun though. [PO, SES 2007]

Greg: I liked the boat one. But I think we should have been given more time, but I guess that really adds to the challenge of it so. [PO, SES 2008]

Glen: Even during the multi-meter, we all did something, mostly because of the time limit. I mean if we had an hour, we would have just let Henry get it perfect, but we all were frantically typing in things on the calculators and stuff. Even though that didn't go that well, it was so fun, I learned from that. [PO, SES 2008]

Cam: Well for me, it's like when I learn things in school sometimes I don't get as interested. But that when you're telling me oh you get to compete with all these people and there's time limit, there's scores that gets me excited it just like want to participate. [PO, SHS]

According to Anderson, Thomas, and Nashon (2009), awareness of time constraints is a feature of task awareness, which is an important mediating factor in how students manage social dynamics in group work settings. Strong emotions evoked by time constraints provide further support for these findings by providing indicators of how prominently students are aware of or motivated by the tasks.

In post-event interviews, students often cited frustration and stress due to time constraints as a negative part of their experience. Most students also said that they would start working on their pre-built projects sooner so that a working prototype could be developed before the competition. Similarly, BCBM students said they would have liked to have made the time to prepare before the competition, to study their formulas and review concepts relevant to amusement park physics.

Strict time constraints required students to communicate and problem solve (Watts, 2003) within the team environment and significantly increased the challenges they faced in both events. The emergence of emotions (both positive and negative), is evidence that the complex system of learning was robust enough to handle these stresses and are catalytic to the emergence of new ideas (Watts, 2003). These moments of challenge and emergence were also examples of states of what Capra (2002) describes as *critical points of instability* that are characterized by "chaos, confusion, uncertainty, and doubt" (p. 117). In the PO and BCBM, testing goes awry, materials are hard to find, ideas clash with one another and time is of the essence. Emotions that emerged during critical points of instability are beneficial to learning when the degree to which students are challenged is carefully managed. Data from this study suggests that the challenge level of the events was mediated (in part) by carefully controlling the time constraints. The venue, competitive atmosphere, and structure of the events have been described to establish their role in evoking students' emotions. The next, and final, sub-theme within the general context of these kinds of competitions, describes the impact of working as a team or in a pair, on students' emotions while they participated.

Social Nature of the Events

Both competitions were opportunities for students to work on physics challenges in a social/teamwork context. At the Physics Olympics students worked on each task in a group of five, which was often a sub group of the larger Physics Olympics team. Students also prepared their pre-builts in social, collaborative settings. For the BC's Brightest Minds event, students worked in pairs to complete the measurements and competition questions. Working as part of a group evoked several emotions. Most of the time students described the experience of working with others as **fun**.

Before the event, the majority of students who were preparing for the Physics Olympics described the experience as a fun opportunity to work with others. And for some, the chance to work as part of a team was a motivating factor to participate:

> Bob: Well I think group work, team work with other students, seeing what they think about, especially the pre-built one. That was pretty interesting. Everyone has different ideas to make the musical instrument. [PO, SHS]

Henry: And it's fun too, just a bunch of friends hanging out, well we're not really hanging out, we're working, I enjoyed it [last year]. [PO, SES 2008]

Colin: Well I just heard that the whole experience with your friends, getting to do something, that's somewhat involved with physics, it is. It is completely a physics event. But more so I heard about the different things, all the great experiences people had with their friends. And well the fact that you're learning something too. [PO, SES 2007]

Observations of students while they participated showed that the experience of working with a team was enjoyable and fun for most of the students, and provided a context where, although they were participating in a challenging and stressful competition, they could still joke and laugh. In post-event interviews students were asked about the experience of working in groups and for most the experience was very positive.

Diane: Just getting to know more people and I don't know it was just a lot of fun and kind of a feeling of working towards, in a team and being successful at the end and realizing that you actually did something right. [PO, SHS]

Ian: I don't know, it's a fun thing to do with people from your school. I mean I didn't really come out with money or prizes or scholarships, textbooks whatever, it's just a fun thing to do. [PO, SES 2008]

Allen: I really enjoyed working with the team, just in general. [PO, SES 2007]

Elyse: We did all end up working together in the end and we put all of our knowledge together, just cause we accomplished something. That felt good. [PO, SES 2007]

However, working together in the team environment also evoked feelings of **frustration**, annoyance, anger and confusion:

Elyse: Yeah it was pretty bad. Me and Ian were so frustrated, but in the end we agreed on stuff and we ended up kind of collecting ourselves and refocusing. [PO, SES 2008]

Elyse: I mean obviously during the task when like you have, you're stressed out, you only have couple of minutes, people interrupt each other, they get frustrated. [PO, SES 2007]

Barry: I told you we should have maxed it out [added more weight], but no, no one listens to me. Told you. [Student is frustrated during the Boat Design task.] [PO, SES 2008]

Fun and frustration were the dominant expressions of emotions evoked by the social nature of the Physics Olympics and BC's Brightest Minds contexts. The strong emotions expressed by students during critical moments of instability illustrated that the system, the learning collective, was undergoing changes, adapting and learning. You (2007) and Roth (2001) also provide reasons why negative emotions may not negatively impact learning. You (2007) found that teams of students working on projects during a competition experienced negative emotions, but that they did not necessarily negatively impact student motivation and argued that emotional intelligence counter balanced negative emotions. Similarly, Roth (2001) theorized that the situated and social nature of group problem solving on a design task provided the support that students needed when the task was extremely challenging.

The impact of general context on the emotions of students participating in competitions such as the Physics Olympics and BC's Brightest Minds has been discussed under three sub-themes: the venue and competitive atmosphere, the structure and the social nature of the events. Teams of students expressed emotions interpreted as fun, frustration, excitement and disappointment before, during and after the events because of the particular context created by these kinds of science outreach activities. Emotions were also evoked because of the nature of particular tasks within the events. Thus, task evoked emotions are discussed next.

Task Evoked Emotions

Data analysis revealed that some specific tasks within these events were more emotionally evocative than others. Discussion within this theme will illustrate the types of emotions that were expressed because of the nature of particular tasks within the events. In the Physics Olympics there were several different types of tasks and some evoked strong emotions of **fun**, **frustration**, **surprise**, and **disappointment**. Before the event, preparing the pre-built projects (e.g., instrument made of food (edible material), catapult car) was described as **fun** and/or **frustrating** by most students:

Res: What's it been like preparing for the Physics Olympics?
Rob: Oh frustrating at times, sometimes enjoyable. [PO, SES 2006]

Diane: Because everyone has different ideas. And people sometimes can't see what other people are seeing so once everyone is on the same page it kind of works out. And then I find that when you have more people working on it, it's sometimes slower than if you have just a couple of people working on it together. It's been a little bit difficult. [PO, SHS]

Res: What's it been like preparing the lifter and the submarine?
Allen: Very glorious at moments and very hard at others. You feel a great sense when you accomplish something but when you realize you find something better it's like oh we have to do that again. Recalculations and in some ways it's stressful, in some ways it's very lax. I guess. I'm very good friends with a lot of them so you see us fooling around a lot which isn't very good. But I mean other than that it's very nice. [PO, SES 2007]

During the PO event, the moments during which the most emotion was expressed were while the pre-built projects were being tested. While the preparation for the pre-built projects was emotional, they were equally or more emotional to test during the competition. During tests, students were often **surprised** to find that they had misinterpreted the rules or something happened that they did not expect. For example, in 2006 students had to design a musical instrument made out of food. Phil had to perform the instrument and he was surprised and shocked to find that he would have to perform *Twinkle, Twinkle, Little Star* in front of a full lecture hall of judges, participants and spectators. In his pre-event interview he said:

> Phil: Well I don't see how anybody could be doing super on this, especially on this instrument. I don't see how anybody could actually be like head and shoulders above anybody else like we're all kind of fumbling around in the dark with this one so I think it'll be pretty even you know. [PO, SES 2006]

On the video, his expressions were captured as he watched other teams perform. After the first team performed very well, he looked around at his fellow team mates with a shocked expression.

While surprise was an emotion that was expressed by the students when something happened that they didn't expect, more often **disappointment** was the prevalent and dominant emotion. In 2007, Summergrove's leaky submarine was a good example of a task where the students were incredibly disappointed when their prototype failed. Ellen sat watching with her head in her hands. Another teammate comforted her by putting their arms around her. This team's second pre-built, the lifter, also didn't work. Bob said:

> Bob: The team's performance was a disaster. The two pre-builts failed completely. [PO, SHS]

When their lifter failed to lift the amount of mass that they thought it could, the team exclaimed 'No!', Diane said to herself "I don't understand why it's not working", and Bob was particularly upset. He was sitting on the ground with his head in his hands. He exclaimed 'Shit!' when it didn't work. His student teacher comforted him. One of the judges said "Don't worry, you're not the first team to have random stuff happen." Later

Bob ranted:

> Bob: But it [the pulley on the lifter] always turned. Yesterday it turned too, no it didn't turn yesterday, well how could it not turn yesterday, but turn today? Oil - I thought you added it already! [PO, SHS]

St. Elizabeth Secondary also experienced problems with their lifter. They misinterpreted the rules and had to make some last minute adjustments, which resulted in their design not working at all.

> Barry: That's a big punch in the face again. [PO, SES 2007]

> Allen: I am actually the saddest man on Earth right now. It did everything we wanted it to do, not as well as we wanted it to do it, but.... we came, we saw, we lost. [PO, SES 2007]

Their submarine's performance also surprised and disappointed them. When they put it in the water it didn't sink at all.

> Elyse: Ah - too much foam. I told you, you put too much, there was a perfect amount there yesterday. Oh my god, you have got to be kidding me, I knew the magnets were there for a reason. I told you not to take them out! [PO, SES 2007]

The pre-built projects weren't the only activities that prompted students to feel disappointed when they did not succeed. Other design challenges or hands-on activities that were part of the Physics Olympics event were also emotionally evocative. For example:

> Barry: Ah! Yeah! Ah! No! No! Go! Go! Dammit. [laughing][He is watching the Boat Design task.] [PO, SES 2008]

Elyse: She hits the table and puts her head in her hands when the laser doesn't hit the target in the Optics task. [PO, SES 2007]

Bob: Oh my God, give me a pencil. Oh my God, if we had reversed everything...how come I didn't see that [diagram] earlier. Are you serious? [He realizes his mistake in the Electric Maze task, puts his hand on his head.] [PO, SHS]

In post-event interviews, students described their disappointments. The students who put the most work into the pre-built designs had the highest expectations and felt the most intense feelings of disappointment.

Bob: I was really disappointed. When Mr. Patrick said, "It's OK guys, let it go," I felt even sadder because it was not OK. Three week's work for nothing! The two groups put so much effort into the pre-builts. It really sucks to fail when you put that much effort into something. [PO, SHS 2007]

Allen: Just like, you know after working so hard on your pre-builts, watching it just, it's like your baby and watching it fail at something. You just want to cry. [PO, SES 2007]

Colin: But overall it was funny, the pre-builts did work when we tried them here, the next day everything just fell apart. It was too bad, the things that we felt were working there was something small that wasn't working, we tried to fix it, but everything we did to fix it made it worse! It was too bad. [PO, SES 2007]

Thus pre-built and design tasks evoked strong positive and negative emotions. Gläser-Zikuda et al. (2005) also found that social interactions and student-centered design projects elicited strong emotional responses from students. In fact, when students were asked about their favourite activities, they usually chose these kinds of tasks. Design tasks carry with them expectations for the students and thus the students have an agenda, usually of success, going into the event. Agenda fulfillment and affect each have strong influences on the vividness of student memories (Anderson & Shimizu, 2007). These results agree with observations from post-event interviews where students cited design activities and pre-builts as their favourite (and most vividly remembered) tasks. Students who participated for two years in a row were asked what they remembered about the previous year and they always provided rich descriptions of their experiences with the pre-built activities. Electric Maze and Optics tasks were less design oriented but still captured students' attention because they were hands-on activities, where university lab equipment was used.

Unpopular tasks also provided evidence of the importance of evoking emotions while learning. The 2006 and 2007 Physics Olympics competitions, each had a task called Intuitive Physics, which required the students to use a computer simulation to determine the identity of mystery forces. Most students did not enjoy this task. It was not interactive enough and was difficult for five students to engage with. For most teams, the video data of this activity shows that one or two students are working with the simulation on the computer and answering the questions on the handout and the remainder of the team is standing behind them, watching. In a couple of cases, some members of the team left before the activity was even over. Some students expressed emotions of **boredom**:

> Rob: I didn't care too much for that one where you use the computer.
>
> Res: How come?
>
> Rob: It was kind of boring just a computer program. It would be different if it was actually objects in front of you to do some testing. [PO, SES 2006]

Although this task was challenging, it did not provide students with feedback about their progress and thus there were no evoked emotions (emotional feedback loop) to keep them motivated. In other words, since they didn't have any information about their progress, they didn't get excited or even frustrated throughout the task.

Another task that was unpopular with some students was the Mystery task in the 2007 PO. To complete this activity students were asked to move a tray in front of a motion detector in order to match a velocity-time graph. Many students did not consider this task to be 'physics'. The students also found this task less challenging. Despite the fact that all were successful in it, to some degree, they were not very excited about their success in post-event interviews. However, during the activity the students appeared emotional and visibly excited when their motion graphs matched the one on the computer. This suggests that enough feedback about their progress was provided for students to stay motivated, but it wasn't challenging enough to sustain their excitement. Therefore, this activity was missing the elements capable of creating critical points of instability or sufficient ambiguity to evoke strong emotions. The two most unpopular tasks illustrate important characteristics of emotionally stimulating PO tasks: they must provide feedback for students and secondly they must be sufficiently challenging. Little research in the area of competition and design activities has attempted to determine the appropriate level of challenge. At the PO and BCBM's competitions, challenge was moderated using strict time constraints and proscriptive rules. This study of emotions in these contexts reveals some useful aspects to pay attention to when evaluating whether projects or activities are emotionally and cognitively evocative or debilitating.

Design activities such as the pre-built projects in the PO provided feedback loops built in where students worked through multiple iterations (Linn, 1995). Each attempt provided information that helped point towards an idea for the iteration that followed. This characteristic of design activities, especially when it was embedded in a competitive context, created a positive feedback loop where students' emotions were amplified. Positive feedback kept the complex system (team working on pre-built) in a state that was far-from-equilibrium so that it continued to generate ideas and remained dynamic and adaptive, rather than being stagnant and unmotivated. Without emotional highs and lows, successes and failures (i.e., iterations), I believe the teams would have run out of ideas and been unable to sufficiently improve their prototype.

Thus activities such as the pre-built projects and other hands-on, or design activities evoked strong emotions of frustration and disappointment because of their particular characteristics. These kinds of activities provided students with a lot of information about whether or not they were achieving success through the iterations they went through as part of the design process. A second characteristic that most of these activities had was that the parameters of the challenges were outlined in terms of proscriptive rules. Proscriptive rules are a set of parameters that students must work within, but which allow for a large array of possible solutions by outlining the constraints (don'ts) instead of step-by-step instructions (dos). These kinds of rules also introduce an element of ambiguity, which prompts the system to develop effective communication and problem solving skills (Watts, 2003). Similar to the time constraints that were typical of both competitions' general contexts, proscriptive rules introduced a significant element of challenge. Students struggled with the ambiguity of proscriptive instructions and the unpredictable outcomes. They also noticed the variety of products that emerged from these conditions.

BC's Brightest Minds Tasks

The BC's Brightest Minds event was perceived by students as one activity as a whole, instead of being a series of separate activities or tasks. Although in the competition students answered questions about three different rides, the event as a whole was what students meant when they described their experience. From video and microphone data, most students appeared to be having more fun and expressed stronger emotions of **excitement** and **frustration** when they were taking measurements and participating in the more hands-on component of the competition.

> Jane: Don't you love it! We don't have it [the altimeter]. Oh! Here it is. They just put it back to back, smart! [BCBM, QHS]

> Stacy: [She is laughing as she gets off the amusement park ride.] What did you get? Do you realize what this means, we're going to have to measure this again, lie down, watch it again. Let's do it! [BCBM, QHS]

> Jared: It's hard to find the period of this thing...because it changes. [BCBM, CVS]

The aspects of the competition that were the most challenging for students were the questions that asked students to measure the height, period and forces applied during the rides. Other parts of the competition resembled typical physics questions that they had likely encountered in the classroom context. The measurements that students were asked to take were similar to Physics Olympics tasks since they were not given step-by-step instructions or many materials to complete their task. They had to figure out, using simple materials, how to obtain the most accurate measurements.

> Paul: Well the height measurements we got that figured out eventually just by using the altitude meter but the acceleration we had no idea how to figure out the free fall acceleration. [BCBM, KHS]

The challenges presented by measurements also promoted teamwork during the BC's Brightest Minds event. In several instances, and for all three teams, microphone data illustrated that students believed that it was necessary to have a partner to complete the measurements, whereas strictly calculation questions could be, and often were, completed individually.

> Laura: I wouldn't want to time it there myself. [BCBM, CVS]

> Jane: There's nothing I can do without you here. I'll be waiting for you. [BCBM, QHS]

> James: You have to come help me man. It's too far. [BCBM, KHS]

Therefore when considering specific task evoked emotions for BC's Brightest Minds, the measurements students were required to take, and the procedures they had to design in order to take them, were the tasks that evoked the most emotions because of the challenge and teamwork involved.

In this study, task evoked emotions illustrated the characteristics of activities which evoked strong emotions for students. Tasks, which are design oriented or which ask students to use hands-on materials evoked the most emotions for students. However, these activities were particularly emotional if they used proscriptive instructions or rules to provide the appropriate amount of challenge. Activities which provided students with feedback about their progress or success, through successive iterations, amplified expressions of emotion, and resulted in more heightened emotions than activities that didn't. Finally activities that students spent a lot of time on or that they felt they were prepared for, generated strong feelings of disappointment if things didn't work out as they expected. The pre-built activities at the PO, in particular, embodied all of these characteristics and for most students they were the most emotional aspect of participating in the event. Another reason why these activities evoked strong emotions was that the students were unfamiliar with these kinds of projects. The novelty of the tasks in these competitions and the uncertainty students felt as a result, was a significant source of emotion and will be discussed as a separate theme.

Novelty Evoked Emotions

Something must get the students' attention. Since these events were a diversion from the regular routine of a provincially examinable course (usually content and test driven) the novelty of the Physics Olympics and BC's Brightest Minds competitions injected an element of aliveness (Capra, 2002) into the physics community as a whole. Aliveness was evident in the strong emotions of fun and frustration that students experienced which were evoked by novelty. In the case of the Physics Olympics, novelty was provided through the nature of the hands-on and design activities that are not usually included in the curricular expectations for typical physics courses as expressed by one of the participants, Elyse.

> Elyse: I actually enjoy physics. I love to think of something like how could this work. It's like physics but it's on a different level. It's not classroom physics. [PO, SES 2007]

During the competitions, many student emotions were expressed because things happened that they didn't expect. For example, in the BC's Brightest Minds event, students demonstrated emotions of **frustration** while they carried out and tried to explain unfamiliar measurements and apply physics to real life:

Paul: We tried. It was pretty tough. We're not used, we haven't really done any lab work in the physics AP course. [BCBM, KHS]

Jane: It's all about showing the work that's hard. [BCBM, QHS]

Stacy: Geez I never thought of it that way. [BCBM, QHS]

Researchers have discussed the value of experiences such as science outreach activities for broadening students' experiences with science (Baker & Leary, 1995).

Fear was another commonly expressed emotion that was expressed within the BC's Brightest Minds context since some students were extremely afraid of amusement park rides. Jane and James described their feelings about going on the rollercoaster:

Jane: I'm terrified, not afraid, afraid is an understatement. [BCBM, QHS]

James: [negative emotions occurred] when I went on all the rides, a little bit scared but still have to take measurements and yeah. That didn't feel good. [BCBM, KHS]

At the PO, the Electric Maze and Optics tasks captured student's attention and capitalized on the concept of novelty to evoke students' emotions through the use of unfamiliar equipment and university facilities. The Electric Maze task in particular was challenging for most teams who were unfamiliar with the use of a multi-meter and circuit components such as diodes and capacitors, which evoked emotions of **frustration**.

Phil: What the hell is it? Is it a diode? [PO, SES 2006]

Allen: We could have done it if we'd known how a multi-meter works. [PO, SES 2007]

Student comments in post-event interviews confirmed impressions from video and microphone data that students were unfamiliar with the equipment they were expected to use.

Allen: Pretty much, the Electric Maze, that one we came in unprepared. Other groups looked like they knew how to use a multi-meter. Like we were unsure what to do exactly so that took us a while and cost us. [PO, SES 2007]

Glen: I'm pretty confident about how to do the calculations but I wasn't sure about how to get the measurements [in the Optics task]. The thing that really bothered me was that it was up on a higher table so in order to get a precise measurement if you didn't know how to use that thing you had to climb up. We weren't really sure which measurement to take, but some students agreed with me so we went with that. [PO, SES 2007]

In post-event interviews students talked about being surprised by particular aspects of the events, confirming that these were indeed novel contexts and that novel contexts evoked emotions of **fun**. These feelings were widespread among individual participants and teams.

Colin: Well a lot of the things that we experienced at the Physics Olympics were really very different from what we learn from the text book. We're so used to coming into the classroom, learning equations and then manipulating those equations. Overall it was totally different from what I expected. That made it interesting. That made it fun. [PO, SES 2007]

Beth: It [the Physics Olympics] was fun. It was surprisingly, amazingly fun. A lot of different projects. [PO, WHA]

Ellen: It was very intense competition and very emotional for us, because we experienced something that we didn't expect. But it was fun overall, I really liked it. [PO, SHS]

Laura: There were a few [BC's Brightest Minds questions] that I like oh that's a tricky way of asking the question. Never thought of it that way before. But it was still interesting. Kind of cool to try to figure it out. [BCBM, CVS]

Thus novelty was key to evoking emotion in the students and the most common emotions were those of fun and frustration when students encountered novel contexts. Since these strong emotions are expressed in novel contexts associated with science they are likely to become part of the series of memories and experiences students will draw upon when their science identities are activated (Damasio, 1999).

Chapter Summary

Emotions expressed while participating in science outreach contexts have been characterized according to how they were evoked. Emotions were evoked by the general context of the competitions, the tasks students were asked to participate in, and the novelty of the experiences. By paying attention to expressions of fun, frustration, excitement and disappointment, characteristics of science outreach contexts that can evoke strong emotions were identified. The venue and competitive atmosphere were important for creating emotions of excitement and fun. However, expectations of success in the competition also led to feelings of disappointment. Specific aspects of the venue and atmosphere included being around many people interested in physics at the Physics Olympics, or being at an amusement park with all the excitement, noise and distraction for BCBM. Structures of effective competitions were identified as strict time constraints, which elevate the level of challenge of particular activities. Time constraints in both competitions led to the expressed emotions of frustration and stress, but also motivated students by challenging them. The social nature of both events also made them fun and frustrating for students and provided support for students during challenging tasks. Task evoked emotions included frustration and fun and occurred most often while students were preparing and testing their pre-built activities in the PO or taking measurements in BCBM. Hands-on and design tasks that were appropriately challenging evoked strong emotions. These kinds of tasks provided the students with enough feedback to keep them motivated and the opportunity to change or adapt their ideas through multiple iterations. Novelty was an important characteristic of both the context and the tasks in these events. There was lots of evidence that these experiences were novel for students, which generated interest and emotions of fun. While the emotions presented in this chapter represent trends observed across students and teams, individuals and teams experienced and expressed different emotions depending on their existing and emergent science identities. In the next chapter, the role the emotions evoked by the context, tasks and novelty of the Physics Olympics and BC's Brightest Minds events in the manifestation of science identities will be explored.

CHAPTER FIVE

Science Identities Manifest in Evoked Student Emotions

In Chapter Four emotions expressed while participating in the Physics Olympics and BC's Brightest Minds events were interpreted and characterized as evoked by context, tasks, and novelty. Expressions of emotions of fun, frustration, disappointment, and excitement were experienced by most students and teams participating in the events. Other expressions of emotions, such as confidence and apathy, were expressed by individual students depending on their past experiences with science, expectations, and specific roles in the events. By paying attention to these types of expressions of student emotions their role in the manifestation of perceived science identities will be explored. Therefore, this chapter responds to the challenge presented by the second research question: How do the student emotions evoked by participation in science outreach programs contribute to the manifestation of students' perceived science identities? Expressions of emotions contributed to the emergence of different types of student perceived science identities including team science identities, individual student science identities and stereotypical student science identities. These types of science identity represent different units of analysis where the emotions expressed by both individuals and groups (teams) were studied.

In this chapter, manifestations of perceived science identities were identified, interpreted and understood depending on the conditions mitigating their emergence: 1) Identities manifest in diversity, 2) Identities manifest in redundancy; 3) Identities manifest in neighbour interactions; and 4) Identities manifest in decentralized organization. These conditions were drawn from literature in complexity thinking (Davis & Sumara, 2006) and emerged from the data which was coded as pertaining to identity. These four themes do not represent a complete list of conditions of emergence, instead during winnowing of the data, signs of identity were associated with the conditions in which emergences are manifest. Thus a frame was not imposed on the data, instead, the literature cited above provided a suitable language for describing the conditions.

However, as an overarching perspective that frames the current study, complexity thinking did influence the range of interpretations for manifestations of science identities.

Emergence occurs when a coherence arises from a group of autonomous entities (Johnson, 2001). The new, coherent unity is greater than the sum of its parts and represents a higher level of complexity than its components. Examples include the emergence of a hive from a group of bees, a city from clusters of neighbourhoods and a living organism made up of cells (Johnson, 2001). A complexity thinking perspective, employed in the current study, which frames emotions as a complex system, has provided an interpretive toolkit to identify and describe particular conditions under which emergence can occur – in this case, the emergence of identities. Damasio (1999) theorized that emotions were part of the fundamental data that define our identities. Thus, identity is an emergent unity and evoked emotions manifest or are manifestations of its emergence. Conditions of emergence include, but are not limited to, diversity, redundancy, neighbour interactions and decentralized control (Davis & Sumara, 2006). Therefore, analysis of data that sought to elucidate the nature of perceived science identities manifest in student emotions, differentiated the identities based on how they were manifest.

Identities Manifest in Diversity

Emotions were expressed while participating in the Physics Olympics and BC's Brightest Minds events in part because of the internal diversity of the system. In a learning system, internal diversity refers to the variety of backgrounds, interests, knowledge, and personalities that individuals contribute to the collective. Diversity contributes to emergence by providing a richness that expands the learning space with a variety of ideas, emotions and experiences to draw upon.

Diversity contributed greatly to the emergence of a team science identity from a group of individuals on a team. Mr. John from St. Elizabeth Secondary described his students as "a range of students for sure". The following students were also aware of the value of diversity in their learning experience.

Tom: I like working with people, it's good to have a bunch of ideas to come up with and refine. [PO, SES 2006]

Fred: I think it's fun, it's good experience [to work in a group]. It's like a conglomerate of thoughts; it's good to see other people's perspective as well. [PO, SHS]

Diane: Because everyone has different ideas. And people sometimes can't see what other people are seeing so once everyone is on the same page it kind of works out. And then I find that when you have more people working on it, it's sometimes slower than if you have just a couple of people working on it together. It's been a little bit difficult. [PO, SHS]

Thus, the existence of a diversity of opinions contributed to an array of emotions that were experienced, particularly as a result of working within a group. Expressions of annoyance, anger and confusion were common during stages of the competition where the entire group was grappling with a particularly difficult question or problem, which was illustrated in Chapter Four.

However, usually frustration and anger arose because of communication difficulties. Diversity is not only a possible source of conflict, it can also promote coherence and emergence. In complex systems, communication is necessary to capitalize on diversity and to allow the ideas to bump up against each other and intermingle to produce a grander idea (Davis & Sumara, 2006). Most teams recognized the importance of communication:

Barry: We were discussing everything. I would sit there verifying what other people found, contributing my own ideas. [PO, SES 2007]

Ellen: But we all kind of helped each other. We stand by the side of the table and say well you could do this....With all of our knowledge put together we'll obviously if someone realizes something one of the five didn't then it works out. [PO, SHS]

Brad: Could have had a bit more group discussion other than that I guess it was OK. [PO, SES 2006]

Alex: Where one person would step back another person would step in. And I think we did a great job. We didn't learn about physics, we learned more about each other. [PO, WHA]

Laura: Yeah we had to give and take, sometimes he'd have one view of doing it and I had another. That's just how we work. I like to write things down a lot and he does it in his head. I can't do that, I need to write it down, I need to have something right in front of me so I can see it. [BCBM, CVS]

Team science identity appeared to manifest in positive emotions of enjoyment and fun, which promoted teamwork or a sense of coherence. Two teams, Summergrove High School (2007) and St. Elizabeth Secondary (2008), had a particularly strong sense of coherence, illustrated below:

Ellen: I would say [my favourite] was the Optics task, because, not just because we did well in it, but because it's actually something that we practised a lot on and then like something that we actually enjoyed. We worked together really well on it as a team. [PO, SHS]

Elyse: We did all end up working together in the end and we put all of our knowledge together, just cause we accomplished something. That felt good. [PO, SES 2007]

Glen: I thought, yeah, it was pretty good I think. No one was really that mad at each other. We were able to work together. Everyone contributed something. Some more when we were building the pre-builts and some more in the actual tasks. But we all did something. [PO, SES 2008]

Thus, diversity among team members in the PO, and even between the pair of students working together during BCBM allowed for the expression of emotion and thus the manifestation of a team science identity. Diversity was an important component of a team science identity where different types of people each have contributions to make in order for a team to be successful in these kinds of science competitions. For example, students talked about two types of participants: those who are good at theoretical problems and those that are skilled at using scientific equipment, building things and hands-on challenges.

Diane: There are some people who are way more, like hands-on, so they kind of know how to put a circuit together and other people are like, well, why doesn't the battery look like it does on the page? [PO, SHS]

Adam: So basically a variety of people. For example Bob knows about electricity so I let him on [the team] and Fred is good at like making things so I got him on. [PO, SHS]

Elyse: If you look at the students, there are some that are academically smarter but there's people like me who I'm not like all formula, this equals that, I'm more of a logical thinker so it's like, yeah that works, but wouldn't it technically you know work better if you were to do it this way? And so I think that's why we all have something to contribute and then we all make it work really well. [PO, SES]

Therefore, particularly in the PO, a team science identity emerged as a group of students who have a variety of skills and strengths. Specifically, several students said that two types of students must be represented on an effective team: those with a strong, theoretical knowledge base and others who can apply physics in experimental, real world situations. These findings complement those of Shanahan (2007) who used role identity theory to explore students' perceptions of being a science student in classroom contexts. She found that students had consistent perceptions, which included acting scientifically (serious, focused and objective) and having high levels of intelligence. It is interesting that in informal learning contexts, students emphasized different types of skills such as the ability to build things and apply physics to real world contexts.

Individual student perceived science identities were also manifest through diversity. Students who participated in the PO were asked what their role or contribution to the team was and most described a positive way in which they contributed to the team, either in preparation or during the competition. Students often described their role in the event in terms of their unique contribution to the team, identifying what they had to offer that others didn't bring to the table. Students also reflected on their strengths and weaknesses as a result of participating as part of a diverse team:

> Diane: I'm not the kind of person who's totally focused on science, so I'm not the type of person who always gets the best marks in science but I'm still interested in science. I just have like a more wide range of interests. [PO, SHS]

> Allen: What got me interested is people always say that I'm a creative person, I'm not exactly maybe the smartest person.
>
> Res: What makes you say that?
>
> Allen: It's just people's opinions. So what they say. Over a period of years I guess I've realized I'm not the brightest of students I guess I am but I just don't apply myself the same way. But whenever I do some sort of contest or competition I seem to push myself to some sort of new limit that seemed unachievable before. [PO, SES 2007]

> Cam: And on the other ones, even though I'm not the leader, I try to offer more insight cause some of these topics I try to go deeper. [PO, SHS]

Bob: This is kind of weird. Most of the time in a group project, I would feel that I am not good enough. But this time, I actually felt that I was pretty good. I realized that I was very organized. I could make plans for the group to follow. Where my teammates were not very organized. They lost a bunch of stuff. Physics-wise I was pretty happy about how hard I contributed to the lifter. [PO, SHS]

Laura: It was a lot of fun and it helped me figure out what I need to work on and study, if I don't know it and it also helped me realize where I'm good at stuff. [BCBM, CVS]

Res: Did you learn anything about yourself from the Physics Olympics?

Glen: I learned that I'm not a very fast thinker. I'm a very slow thinker, but I get it right. [PO, SES 2008]

Thus, the diversity represented among team members, helped each student to see, through the emotions that they felt, that they each had a contribution to make and what their individual contributions were. Theorists and researchers in the field of science identity have often identified that students are not subject to wide range of discourses about science (Hughes, 2001) or provided with diverse identities that they can identify with (Brickhouse et al., 2000). The emotions students expressed allowed them to store memories about their experiences in science. Given the data above, some of these emotions will be attached to their sense of team and individual science identities, thus enabling these identities to emerge.

Identities Manifest in Redundancy

Internal redundancy provided the common ground that students both started from and kept coming back to as they tried to negotiate the unfamiliar space of learning at the PO and BCBM events. Coherent team science identities relied heavily on redundancy. In the Physics Olympics, teams were comprised of both Grade 11 and 12 students. Some of these students had the opportunity to participate in the PO for two years in a row. In interviews, these students said that it was helpful to participate for a second time because they had a better idea of what to expect during the event.

Phil: I think we were a little better prepared this year because we, I know I was, because I knew what to expect. I mean [this year] everyone else was kind of in the same boat that I was in last year. I think it was probably a good thing to have a little bit of following through from year to year.

Res: Having an idea of what the day is like even can help?

Phil: Can help yeah. You know what to expect, as opposed to kind of being in awe when you get down there, looking around, things like that. It's kind of nice to know what you are going to be doing. [PO, SES 2006]

Barry: We knew more, we were more ready for what was coming instead of like just like last year we had no idea what was going to happen.

Res: So was being more ready, was it good, did it help out?

Barry: Sort of, we didn't exactly win, but we sort of knew what was coming. [PO, SES 2008]

Elyse: We can work together, this group, that's the thing, these people, we did [the PO] last year, and [another competitive event], and now the second Physics Olympics so we kind of all know how to work together.

Res: Comparing the two years what would you say is different?

Elyse: This year, not only are we all in Physics 12 so we all know a lot more, but I think that since we were all together for, this was like our third competition, we did get along, we did realize oh she knows what she's talking about or she's good at this. Or he's good at that. So it's kind of...we worked better together. [PO, SES 2008]

One of the roles of redundancy in the system is that individuals can compensate for the lack of experience of others (Davis & Sumara, 2006). Thus, having participated in the event before, or a similar type of event (where they had worked as a team in a competitive context), allowed some students to help their team members cope with the unfamiliar or novel aspects of the events.

A second role of redundancy allows members of the system to interact (Davis & Sumara, 2006). Since students couldn't participate in the BCBM event more than once, students instead drew on shared experiences of either attending an amusement park physics event before or of having solved similar types of questions before.

> Jane: Some of the questions, the beginning questions for the Drop Zone ride, were what we needed to do in our normal amusement park physics booklets. Right and some of them were totally out there. [BCBM, QHS]

> Stacy: Yeah and also a lot of the questions were already in the physics booklet that we had done before, we had gone over how to get the radius and stuff like that. [BCBM, QHS]

> Jared: Well you didn't really have to do any calculations [in regular amusement park physics event]. Like some of the stuff we had to do actually was a benefit for the BCBM thing, like finding the radius of something and we're like oh yeah we did that last week, just coincidentally. That was good. [BCBM, CVS]

Participating in events with students from their school and in their classes also helped students to share and interact so that they could tackle difficult physics concepts during events that had strict time constraints.

> Elyse: I enjoyed, well I did like the Intuitive Physics task because we did the unit, torque, we already did that in class. So everybody was in the room and you knew somewhat what you were doing so it was kind of like, yeah we

double checked everything so it was like, it was good to know something. Being familiar with what we're being asked. So that was good. [PO, SES 2008]

"A complex system's capacity to maintain coherence is tied to the deep commonalities of its agents" (Davis & Sumara, 2006, p. 139). In a robust and coherent system, changes don't necessarily destroy the system, but instead prompt it to respond intelligently. Emotions play a large role in the redundancy of shared experiences. Chapter Four described how students experienced similar emotions of fun and frustration (for example). Observations of the teams while they prepared for the Physics Olympics were conducted and students often talked about their past experiences. Often their memories were of the most emotional moments in the events, such as when pre-built projects failed. These results echo those from a long term study of world fair visits (Anderson & Shimizu, 2007) where a relationship between affect and memory vividness was found. These shared experiences allow students to interact and also to embody the history of their school's participation in the competition. Stories and impressions of these events were passed down from year to year, as different students participated and older students graduated. This sharing allowed the system to be more robust. For example, students were not devastated by failures since they had heard stories of previous failures. They were also prepared to spend a lot of time preparing and expected the experience to be fun because they had heard stories from previous years' participants. The expressions below are examples of shared memories of emotional events that enhanced the emergence of team science identities.

Elyse: You know what's funny is last year the same thing happened with the submarine [that failed]. [PO, SES 2008]

Phil: No it was like this last year, it was like this last year when we were here. I remember it. [PO, SES 2006]

Colin: Our teacher was telling us last year that they spent four hours working on their pre-builts on the last night. We only had about two hours and 15 minutes of that was cleaning up. [PO, SES 2007]

Redundancy was also used by students to define their perceived individual science identities. While students recognized the importance of having a diversity of skills and talents represented on their teams, there were also qualities and characteristics that most students believed all scientists or students participating in these kinds of events should have. Students expressed that being good at math and calculations was important accompanied by the ability to apply those skills to new situations.

Phil: Well a lot of it is learning how to apply the math you've learned which has a lot to do with you know manipulating formulas to achieve what you want. And then you kinda you have to be able to wrap your head around the questions for a lot of them figure out what exactly you need to calculate. [PO, SES 2006]

Res: What do you love about physics compared to other sciences or subjects?

Fred: I just like to solve stuff. Looking around the environment, I want to see why that is that way.

Res: What do you like better about it [physics]?

Fred: I think more logically and systematically, about calculations.[PO, SHS]

Jane: Well it's definitely more practice of how to handle real scenario questions. Because most of the time you're not going to have a sheet and numbers all laid out. You have to know how to measure and all that. You need to know what you need to know in order to get to where you want to go. So I think that's what's so good about these kinds of questions is that it prepares you for more reality things. [BCBM, QHS]

Res: Why do you prefer physics and chemistry to biology?

Barry: Physics is mostly calculations stuff and I'm quick with math so it's simple. [PO, SES 2007]

Glen: Physics is logic, and it's really, in everyday life. It's everywhere, it makes sense. I'm good at physics cause of logical thinking skills. I'm a good learner for the most part. [PO, SES 2007]

Thus, there were lots of incidences where logical, mathematical problem solving was an essential part of how students defined and accounted for their ability and interest in physics. Most of the quotes above were taken from pre-event interviews and reflect students' ideas about the necessary skills to succeed in classroom physics. After participating in the Physics Olympics and BC's Brightest Minds events, the students talked about different types of characteristics that are part of doing science. In post-event interviews, many students talked about the unpredictable nature of science:

Bob: From this experience, I learned that physics is not just about doing questions in class because in reality it is always different than expected. Just like in our lifter, we calculated the efficiency of our machine. We expected that was what we were going to get. However, things did not come as planned. Therefore, I learned that in real life, you cannot make the physics perfect like in class. There will be much uncertainty. [PO, SHS]

Cam: [The musical instrument made of bread] is not something solid and concrete like wood, it's always changing depending on the room temperature and everything, so that was pretty interesting. [PO, SHS]

Diane: We haven't really figured out a strategy. We just kind of like are thinking about it, and hope something comes up. We've solved a few problems we still have a few more. [PO, SHS]

Ellen: We didn't really learn new concepts just by participating in it, maybe preparing for it, it's more like, we learn more preparing. Participating, it showed me how physics, some of the things require really accurate calculations and a thorough understanding of how everything works. Sometimes it doesn't work all the time. [PO, SHS]

Res: Are you glad you participated or do you wish you were just doing the amusement park physics that day?

Stacy: Well it's good to try these application things you know. It's more real life physics.

Jane: I think it's good to see the more difficult applications, not just on paper. If it's on paper you don't have to, it's not problem solving so much, you just have to remember the formula, know how to use it. Here's a piece of string, tell me how high the empire state building is, it's more like a puzzle, like a challenge. [BCBM, QHS]

Ian: I don't know, kinda, felt like it [physics] requires more on your toes thinking, rather than just sitting there. [PO, SES 2008]

Derek: So it's not so much just math and calculating, you actually get to do stuff, research, and I found that cool. [PO, WHA]

Being able to work with others within a group was another key characteristic that students learned was important as a result of participating in PO and BCBM. Surprisingly, few students talked about working with others in pre-event interviews, even though they had been working as a team on the pre-built projects in the weeks leading up to the PO event. However, in post-event interviews many students said that they learned from each other in their groups and that the ability to work with others was key to success in the events.

Res: What did you learn about yourself by participating in the event?
Felix: I can work with people. [PO, WHA]

Cam: And just that team work is really important too. You need to be really cohesive. You can't be arguing. I think that could be one of our downfalls in [another competitive science event] because we were sort of arguing over one concept, we couldn't really agree. [PO, SHS]

Ellen: Besides knowledge of physics, we learn to work together as a team and to be supportive. [PO, SHS]

Res: What did you learn about physics by participating in the event?
Colin: Physics. That it's as much of a team effort I suppose you need the help of people, just as much as hitting the books and yeah trying to learn yourself. You need to be group oriented. You need to be able to work with people because otherwise you won't be able to be successful. [PO, SES 2007]

Thus, in some cases (e.g., Cam), students saw conflicts between members, and the emotions evoked, as interfering with task completion. Students recognized the value of diversity but they did not want that diversity to give rise to conflict. Ideally well balanced diversity and redundancy allows for increased communication and a good group work dynamic to emerge. Students valued this quality when they observed and experienced it in their teams and conditions in events such as the PO and BCBM can be optimized to allow this to occur.

By participating and learning in the Physics Olympics and BC's Brightest Minds events, both complex learning systems, students became familiar with another side of science, where the answers are not predictable and calculable using formulas and textbooks. According to how emotions were defined in this study, strong emotions that were evoked by participating were, in part, responsible for shaping, students' perceptions of what it means to do science. Thus, participation in science outreach contexts that evoke strong emotions, contributed to student learning in science by broadening their perceived individual science identities which has been shown to include skills such as getting good grades, remembering ideas quickly, and being objective (Shanahan, 2007). The emotions students experienced also gave them clues about how well their perceived individual science identity matched with their perceived stereotypical science identity. This match has been shown to play an important role in student decision making and motivation in science (Hannover & Kessels, 2004) and was particularly elucidated through neighbour interactions.

Identities Manifest in Neighbour Interactions

Neighbour interactions allow for the intermingling and sharing of ideas among members of a team and between teams. These kinds of interactions do not necessarily mean that participants or teams need to share the same space, but that there are opportunities for ideas among members of the complex system to 'bump up' against each other (Davis & Sumara, 2006). When ideas are allowed to interact, new ideas and possibilities are created that are more powerful than what one person could have generated on their own.

> Res: Where do the ideas come from?
>
> Dean: Mostly [from] all of us, just in. It's a group of people, someone throws in an idea and then other people who are doing it work together. We are always sitting in a circle and ok why not add this to it to make it better. Usually it's a combination of us, it's not really just one person. [PO, SES 2007]

For example, while students worked in groups or pairs at both events, they also learned from the other teams participating, whom they often did not explicitly interact with, or even talk to. In post-event interviews, students frequently expressed that participating in a large physics event, and competing against lots of other schools, was a valuable learning opportunity, which evoked emotions of excitement.

Phil: I kind of thought that was pretty cool you know get together with all the other people see what everyone else is doing. [PO, SES 2006]

Fred: I learned that there's actually a lot of people who are interested. All those students, they were really enjoying the competition. That was interesting. [PO, SHS]

Dean: I liked going to the university and seeing all the people and looking at their… looking at what other people built as well and how different minds when they come together they make really interesting things. [PO, SES 2007]

Diane: But we learned, I learned a lot from hearing about the other groups and what they had to do. I thought oh that's kind of difficult. I don't think I would have been able to do that. But I learned a bunch just from talking to other people.[PO, SHS]

Cora: It will be really exciting to see, how everyone else's will work. [PO, WHA]

Res: Was the day what you expected?
Fred: It was surprising to me, it's a lot of schools that I've never heard about that did so well in physics. [PO, SHS]

Emotions were evoked by exposure to a large physics community context and were often expressed in terms of excitement and surprise. When students' emotions were allowed to be expressed and experienced in a public environment, a positive feedback loop was generated. When students saw other teams getting excited, they were more likely to express excitement themselves. This excitement was usually shared by team members and contributed to the emergence of team science identity.

Individual student science identities also emerged when students had the opportunity to compare their work with other students' achievements. This was particularly true for the pre-built projects in the Physics Olympics. Several students said that they learned about how well they fit into the physics community that they were experiencing:

Barry: It was pretty interesting to see some other people's work. I saw some other teams' cars, some of them have like pretty cool designs, they also had like laser cars and stuff like that.

Res: Did you ask some teams how they got their stuff built?

Barry: Yeah we asked one or two, [..] design, theirs actually worked, ours was basically made from me and Ian's Lego collections. [PO, SES 2008]

Ian: You go there and you look at other people's stuff and you're like, wow, totally would have never thought of that and they just and overall it's good to see how you stack up. [PO, SES 2008]

Res: What are you expecting the Physics Olympics to be like because you haven't been?

Greg: Interesting to see what other people can think of and see how bad we look, compared to others. [PO, SHS]

Res; Did you learn anything about yourself? How do you do physics?

Fred: It shows me, my place in the physics world.

Res: And where is that? Is it more in than you thought or less in?

Fred: Less. [PO, SHS]

Derek: By the end of this whole experience I really want to be an engineer.

Res: That's awesome.

Derek: Yeah, I just feel I have the creative mind for it and the smarts I guess. [PO, WHA]

Res: What did you learn by participating?

Eddy: To read the instructions better. And I guess that you put it into perspective, we don't really know much about physics you know.

Res: Did you learn that you didn't know as much as you thought you knew.

Eddy: Yeah. [PO, WHA]

Thus, students participating in the Physics Olympics learned about themselves (individual science identities) and the physics community (stereotypical science identities) while competing in the large event. The structure of the event allowed for neighbour interactions where they learned from and shared ideas with physics students from other schools. Their observations and impressions of other students, their designs and behaviour impacted their own ideas. This kind of event is an example of an open system that is "constantly exchanging information with its context" (Davis & Sumara, p. 94, 2006). The physics learning environment for most students, is usually closed. It is limited to their teacher and their peers in their physics courses at school. After participating in an event like the PO or BCBM, students observed large groups of students excited about and enjoying working on challenging physics problems. They also had the opportunity to see themselves participating alongside highly successful teams. This experience in particular contributed to the emergence of individual science identities, where some students learned, from sharing ideas with others, that they don't know as much physics as they thought they did, while others learned that they can thrive in this context.

Identities Manifest in Decentralized Organization

In a system with decentralized organization, there is no clearly defined leader. Each member of the system (participants and teacher included) participates and contributes to the emergence of a collective learning experience, but often in different ways. What emerges is unpredictable and cannot be precisely controlled. In the case of the Physics Olympics, teams usually emerged without a leader or top down control as typified by the excerpts from interviews from St. Elizabeth Secondary's teacher and team members:

> Mr. John: Everyone in Physics 11 or 12 is welcome to join. We sort of lose some due to who's available on the day and I don't make any cuts. I've been trying to do project based physics all year, to get them on board with the idea that these sorts of things are fun and that's drawn them in a little bit. [PO, SES 2006]

> Elyse: For the most part we seem to be working together perfectly fine. It's not like we have a leader or anything. Everyone contributes their ideas. It's really good it depends how it is, it's really good for our case, not to have a definitive leader. I guess, the teacher kind of is, but not really. [PO, SES 2007]

In this case, Mr. John allowed for decentralized control when he gave students a high degree of independence and control over their projects and preparation for the event. By being proscriptive instead of prescriptive the teacher allowed both the team and the individuals' roles to emerge. Mr. John's teams were studied for three years and each year the team emerged differently. For example, in 2006, students divided themselves up and worked on different pre-built designs, and in 2007 the entire team worked collaboratively on both designs. Mr. John's method of creating his PO teams allowed for a much more natural social dynamic that was mediated by student emotions and motivations; one where students chose what they wanted to work on and who they wanted to work with based on their preferences, not on instructions. This also led to a stronger influence and role for emotions in their experience than would have been present in a more prescriptive activity.

Research into emotions and the brain speaks to the value of providing a space for student emotions to mediate their actions, largely due to the role emotions are believed to play in decision making (Damasio, 1994). In post-event interviews students were asked about their roles within the team and they often answered, not by describing their actions, but by describing their individual characteristics that contributed to the team dynamic. Many of these characteristics were those that emerged as components of individual or stereotypical science identities through the expression of emotions such as stress, frustration and fun.

Res: What was your role?

Frank: I don't know, just like the thought person, think things through.

Res: Did you learn anything about yourself from participating? How you respond in these kinds of environments?

Frank: Yeah it was a high stress thing again.

Res: Were you good under stress?

Frank: Yeah, I'm getting better under stress, it's becoming more common now. [PO, SES 2007]

Res: What did you learn about yourself from participating?

Adam: I get too nervous. In this stuff. [PO, SHS]

Res: Did you learn anything about yourself by participating?

Cam: I tend to like take more of a leadership role when I'm understanding the thing. But then when I'm not clear, I tend to contribute, but I'm not very assertive about my own opinions.

Res: So were you assertive in any of these tasks?

Cam: Yeah like the Optics task. I've been leading the practices. And the Intuitive Physics task, because, last year I think we used the same computer software, but this time it was different forces or something. I think the questions are different. So I certainly knew how that works, so I was like, being more assertive in that. [PO, SHS]

Ellen: I don't know. I also found that I really have a really strong-

Res: -positive attitude?

Ellen: Yeah. I try to be optimistic. Most of the time. [PO, SHS]

Res: What did you learn about yourself by participating? What are some of your strengths?

Laura: I learned that I don't speak up when I think I have the right answer. Like sometimes you'd be like I think it's this and I'd be like unhuh, unhun, and I'm thinking, no I don't think it's right. And sometimes it would end up that what I thought was right, and I think if I had spoken up I wouldn't have wasted all this time doing this stuff, because I figured I was wrong. I just need to voice my opinion more I think. And then I second guess myself a lot too. [BCBM, CVS]

The nature of the Physics Olympics event allowed for different levels of decentralized organization. In 2007, three teams from three different schools were studied and each used a different method to create a Physics Olympics team. Mr. John (whose teams were studied for three years) encouraged any student who was interested to participate in the creation of the pre-built projects in the weeks leading up to the event. Depending on which students worked on the pre-built projects, and who was available to attend the event, he would choose up to 10 students to make up a team. From these 10 students he would choose the five students (the maximum allowed) who would participate in each of the tasks at the competition. This model is an example of decentralized organization, where students who were interested and passionate about creating the pre-built designs could participate. It is interesting that each year a team of enthusiastic students who were excited to take on the challenge of the Physics Olympics, emerged from the pool of students in his classes. The dynamics of the team, especially with regard to preparation of the pre-built was different each time.

At Water Hill Academy, the physics teacher used a very different method of organizing his students for the event. He chose five students from his Physics 12 class and one Grade 11 student and expected them to participate. These students had not necessarily expressed an interest or desire to participate. After being assigned to the team, these students were left to their own devices to prepare for the event and since there were only six of them, they worked on both pre-builts as a team. This team of students was the least enthusiastic of the teams that were studied, likely resulting from the top-down form of organization which didn't allow the team to naturally emerge depending on students' interests and emotions.

Res: What's it been like preparing for the event?

Alex: I had trouble I think building enthusiasm for it. I think I jumped at the aspect when I first heard about it. But I guess from the preparation, the brainstorming hasn't quite gone as I expected. So I haven't come up with the ideas that I expected. I think it's been I guess alright. Like there has been a lot of team work, we have collaborated a lot. [PO, WHA]

Beth: The idea sounded kind of interesting but sort of odd and sketchy at the same time. Just cause Physics Olympics, you really don't hear about it. But now that we're actually doing it it's really fun, but really frustrating. [PO, WHA]

Res: What's it been like preparing for the event?

Eddy: It's OK, I guess. [PO, WHA]

Summergrove High School organized their Physics Olympics teams by assigning one student leader to each of the six tasks. This leader was expected to prepare a team of five students who would complete the task at the Physics Olympics. Often more students were interested than could participate. In this case the student leader usually allowed more than four students to participate in the training/preparation activities and chose from among this larger group depending on their performance on these activities. Sometimes students even submitted to writing tests to be selected to be on the team!

Res: And what are you doing to lead the Optics task?

Cam: Right now I'm just preparing, sort of studying the material more so that you know more of what's going on. Other than that it's like mostly coordinating, meeting times with teachers and just sending out emails and stuff. And on the other ones, even though I'm not the leader, I try to offer more insight cause some of these topics I try to go deeper. [PO, SHS]

Res: Are you the leader on this one [submarine pre-built task]?

Ellen: I'm the co-leader. The second in command. Basically what I did was organize all the meetings, getting everyone together. And then the design we worked on, everyone worked together to build it and test it. So that was really good team work and [...] we just had some slight modifications to the design and by now we're pretty much done everything. [PO, SHS]

Mr. Patrick, their teacher described his philosophy on preparation for the Physics Olympics:

Res: What kinds of things do you do to prepare the team?

Mr. Patrick: The students work on their own, I do give them some organization guidance. I stress heavily that the students are to come up with their own ideas, and not the teacher guiding them on how to build or what to study. I'd rather the kids take it from their own initiative and come up with their own ideas. But if I notice that they are too far off then I will give them some suggestions or tell them they are too far off base.

Res: I mean one thing that is very interesting about the way you do it is you also give them leadership roles. Not over just the ideas, but also over the organization, training, things like that, which is pretty unique I think.

Mr. Patrick: I'd rather the kids, the objective is not to win anything. My objective is for the kids to come up with plans and make their plans work or modify it. So there's a learning experience for them to accomplish something and not so much, can we have a good winning design, so my emphasis is on the growth of the student I guess. [PO, SHS]

His organizational style encouraged his students to self-organize and allowed for the emergence of an extremely strong sense of team science identity. Individual student science identities also emerged, particularly if they were leaders of a part of the team.

Working within a decentralized system can be an uncomfortable space, particularly for students who are used to clear rules, instructions and expectations. Bottom up emergence and self organization is difficult to control and to predict. Some students talked about how, although they didn't have a clear plan, that something emerged anyway.

> Res: When you guys get stuck what do you do?
>
> Greg: We just do trial and error I guess, we don't like look ahead, we just do it and see if it works. [PO, SHS]
>
> Diane: We haven't really figured out a strategy. We just kind of like think about it, and hope something comes up. [PO, SHS]

An example of an emergent possibility enabled by the conditions that have been described was the pre-built design, where the product created by the collective was capable of more than what could have been designed by any one individual. It was impossible to attribute an idea, component of the design, or particular success to any one individual. In addition, by relying on bottom up organization, emotions such as frustration began to play an important role in bootstrapping the system; disrupting it into a generative space.

Thus, decentralized organization is a condition of emergence that allowed teams, particularly at the Physics Olympics, to emerge. Emotions that lead students to choose to participate in particular tasks were evoked by a complex interplay of factors including social dynamics, nature of the tasks, attitudes about science and self-efficacy. By paying attention to connections between emotions and identities, the role of students' perceived strengths and weaknesses emerged as important factors in the manifestation of perceived science identities in teams with decentralized organization. This open space to develop their own role and contribution according to their interests and emotions allowed their science identities to emerge.

Chapter Summary

In this chapter, emotions evoked while participating in the Physics Olympics and BC's Brightest Minds competitions contributed to the manifestation of perceived science identities. Diversity, redundancy, neighbour interactions and decentralized organization were conditions of emergence that existed in the complex system of learning where emotions were expressed. Diversity between team members allowed team science identities to emerge, where students recognized that they needed individuals with different skills and abilities to succeed in the events. This led to an awareness of different types of science identities: those who are skilled at theoretical problems and those who can build and design. At the same time, redundancy in the system helped to make teams robust and able to respond intelligently to challenges. Students who had participated before and the emotions students experienced together were shared understandings that helped coherent team science identities to emerge, which can lead to powerful impacts on student attitudes, motivations and decision making about physics as will be discussed in the following chapter. While valuing a range of science identities in recognizing diversity, students also described a standard skill set a participant should have. Stereotypical science identities broadened after participating, from perceptions that are common in the literature such as having strong mathematical skills, to include the ability to work with others and to apply physics to real world situations.

Neighbour interactions between teams at the Physics Olympics generated strong feelings of excitement and students learned about their strengths and weaknesses by observing other teams. Paying attention to their emotions and feelings allowed perceived individual science identities to emerge as students compared themselves to other teams and students. This system is more open than typically closed physics classrooms and thus students' science identities shifted as they learned from observing others. These findings recognize the dynamic and adaptive nature of identity called for in recent literature (Nieswandt, 2007; Roth & Tobin, 2007). Finally, the condition of decentralized organization was used particularly successfully by one team (SHS) which was allowed to self-organize. This team had a strong, coherent sense of team science identity because students were allowed to participate according to their interests and emotions.

Manifestations of science identities were noted under four key conditions of emergence through student emotions. Science identity has been shown to be an important construct to consider in the exploration of student attitudes, motivations and decision making. Thus, the next chapter describes how science identities impacted these affective constructs as students participated in the Physics Olympics and BC's Brightest Minds competitions. These results are used to provide recommendations for designing and creating meaningful learning opportunities in science outreach contexts. These recommendations will be discussed in the Chapter Seven.

CHAPTER SIX

Attitudes, Motivations and Decision Making about Physics

In Chapter Five, conditions of emergence - diversity, redundancy, neighbour interactions, and decentralized organization - were used to describe the manifestation of student perceived science identities. These science identities, as emergent unities, were interpreted and elucidated through a complex thinking framework. This chapter aims to illuminate further the dynamics of these science identities in the context of participating in the Physics Olympics and BC's Brightest Minds competitions, by addressing the final research question: How do student perceived science identities influence their attitudes, motivations and decision making about science?

Several sources of data were collected to probe student attitudes about physics and to explore their motivations and decision making. Student attitudes, motivations and their past and future decision making about physics were probed in pre- and post-event interviews. Several themes emerged around characteristics of student perceived individual, stereotypical and team science identities. The three themes which will be explored in this chapter are 1) Influence of science identities on attitudes about physics; 2) Influence of science identities on motivations about physics; and 3) Influence of science identities on decision making about physics.

Influence of science identities on student attitudes, motivations and decision making about physics were interpreted in terms of what students said they *learned* by participating in the events. In Chapter Four, complexity thinking was used as a perspective to describe the complex qualities of the learning contexts and activities at the Physics Olympics and BC's Brightest Minds competitions, and to establish parallels between these science outreach contexts and complex systems, paying particular attention to the emotions that students expressed. Conditions of emergence in complex systems were used in Chapter Five to describe how perceived science identities emerged as unities while students participated in the events. Emergent unities from complex systems are considered to be organized (rather than disorganized) (Hebb, 1949; Johnson, 2001) because they are able to adapt and learn. Learning in this sense is understood as "ongoing, recursively elaborative adaptations through which systems maintain their coherences within dynamic circumstances" (Davis, 2004, p. 151). In other words, as Rasmussen (2005) simply puts it, learning is "handling complexity" (p. 214). The unities that emerge from organized complex systems display forms of higher order behaviour that their constituent components cannot achieve. Higher order behaviours can be defined as adaptations or changes in behaviour that occur in response to external and internal stimuli which ultimately make the entire system more successful at the goal it is pursuing (Johnson, 2001). Thus, as developed in Chapter Two, complex systems can be described as learning systems (Capra, 2002).

In this chapter, student reflections on their learning as a result of participating in the events will be used to describe how perceived student science identities influenced student attitudes, motivations and decision making about physics. In other words how perceived science identities, both emerged and adapted, as a result of participating, and thus necessitated adaptations in attitudes, motivations and decision making about physics. These adaptations move the complex system (learning) closer to the goal of creating meaningful learning experiences in physics.

Influence of Science Identities on Student Attitudes about Physics

In Chapter Five, three types of perceived student science identities were manifest through diversity, redundancy, neighbour interactions, and decentralized organization. Particularly influential on their attitudes about physics were students' perceptions of stereotypical science identity. Characteristics of what students perceived as stereotypical science identities were expressed by students when they described their experiences in their physics course, their past experiences with physics outside of school, and their experiences with the Physics Olympics or BC's Brightest Minds competitions. In Chapter Five, some common themes in what students perceived to be stereotypical student science identities were presented along with supporting data. They included having strengths in the area of mathematics and calculations and the ability to apply these skills to new and real life situations. Students recognized the importance of having specialized skills, but participating in the events also highlighted the power of working in teams of individuals with diverse talents and backgrounds. Specifically, two types of stereotypical science identities were described by students: those who are skilled at hands-on, applied challenges and those whose strengths include understanding and applying abstract, theoretical concepts. After participating, student perceived stereotypical science identities changed somewhat from a narrow view to a more broad view. This was the lens through which students' attitudes about science were interpreted.

Before participating in the events, students described physics using topics they had studied in their classes or with big abstract ideas. In some cases students were at a loss for words and had trouble expressing their conceptions of what physics was. They rarely described the subject of physics as being relevant to everyday life or real life situations and contexts.

Res: If I were to ask you - What is physics? - what would you say?

Barry: Study of the physical world or something like that. [PO, SES 2007]

Allen: Physics is the application of science, according to.... no seriously, what is physics? Physics to me is what helps everything, you know, without physics where would we be today? Without laws and theories, everything is related to physics in some way, I guess you could say that also about chemistry or not necessarily biology, but in every aspect, physics just makes the world go round. [PO, SES 2007]

Res: If you were to say what physics is, what would you say?

Paul: It's the study of matter and the behaviour of basically everything in the world. [BCBM, KHS]

Tom: It's kind of like the laws of the universe. Why things happen the way they do. [PO, SES 2006]

Diane: Well I like physics as a class, but some of the material is sort of oh, kind of boring and you don't see how it's relevant to anything so I thought that doing the Physics Olympics would be better so that you can kind of see how it applies in the real world. Obviously you're not going to be making submarines, probably, but it seems more tangible than just having the notes and just doing problems on the page. So it's a lot more interesting and fun. [PO, SHS]

Res: So if I ask you - What is physics? - what would you say?

Ellen: Well it's really hard for me to say, because it's such a vast area of everything. [PO, SHS]

Res: If I were to ask you - What is physics? - what would you say?

Beth: I'd probably say that I have no idea because all I've been learning is formulas. No clear idea. [PO, WHA]

However, after participating students described physics as being applicable in a wide range of situations and as useful for solving everyday problems. They also emphasized the difference between idealized classroom physics and messy real world physics.

Laura: I don't know. Physics, well it can be applied to a lot of stuff. Biology can really only be applied to like living things. Physics can be applied to lots of things, I find. It's more technologically advanced I guess. [BCBM, CVS]

Jane: I think just that since the competition I want to learn more about applying what we've learned than just learning what it is. Also I guess to be actively involved with how things behave in physics. Theoretical physics is complicated enough we couldn't really do it yet, so there's no point trying to apply it. I guess we're not really that ready. [BCBM, QHS]

Stacy: It's not just about technical work, not about formulas. It's about how you can actually solve real life problems. [BCBM, QHS]

Bob: From this experience, I learned that physics is not just about doing questions in class because in reality it is always different than expected. Just like in our lifter, we calculated the efficiency of our machine. We expected that was what we were going to get. However, things did not go as planned. Therefore, I learned that in real life, you cannot make the physics perfect like in class. There will be much uncertainties. [PO, SHS]

Res: So do you think your attitudes or ideas about physics have changed as a result of participating?

Ellen: I think I like physics better, even better, because it's so cool to be doing, applying what we learn to real life situations and then use them and compete with it. [PO, SHS]

Res: What did you learn about physics by participating?

Greg: I didn't really learn anything new, but just improved upon what I already knew and more about its application into the real world. [PO, SHS]

Allen: I learned, I guess I broadened my perspective on things like how to apply physics. When I'm doing physics in class they give you this sort of pre-built question that you don't understand. I was even doing one today that is talking about a 200 kg car moving at 100 m/s. It makes no sense, but if you put stuff to reality and how stuff really works that's probably what I learned the most. [PO, SES 2007]

Shifts or adaptations in student perceived stereotypical science identities and thus student attitudes about physics were a trend across the majority of students who participated in the Physics Olympics and BC's Brightest Minds competitions. In some individual cases, the shifts were particularly evident. For example, when Derek was asked to define physics he said:

> Derek: What is physics? That's a tough one, I don't know. It's just applying math and formulas and concepts to find, to achieve something. [PO, WHA]

However, after participating in the Physics Olympics, he described physics differently. He was asked if his attitudes about physics had changed as a result of participating:

> Derek: I've seen how physics is [...], and what it does and what it incorporates. So it's not so much just math and calculating, you actually get to do stuff, research, and I found that cool. [PO, WHA]

Cam's comments also clearly reflected a shift towards a view of physics as applicable to a broad range of situations and real world contexts. Before participating in the Physics Olympics, he was struggling to see how physics concepts could be applied:

> Cam: Physics I find at our level, some of the concepts we can't really apply that much. [PO, SHS]

But after participating, he agreed that his attitudes about physics had changed:

> Cam: Yeah, because you can kind of see where all the things are applied, you can kind of see them in real life instead of just looking at a textbook and seeing like oh well this is how this circuit works. [PO, SHS]

Thus, after participating, students described physics as being more than the application of math and the skillful use of formulas and abstract theories. For many, stereotypical science identities, and thus their attitudes about science, shifted to a broader perspective after participating. In other cases, some aspects of stereotypical science identities were very stable. Some students were surprised that there weren't more calculations at the Physics Olympics event.

> Colin: Well I expected a lot more calculations. I expected more of the quantitative side of physics to be involved, not really the qualitative. And there were a lot of things that I had never seen before. Both the Mystery task and the Intuitive Physics task were totally, nothing that I expected. They were a lot different. But overall it was totally different from what I expected. That made it interesting. That made it fun. [PO, SES 2007]

In particular, one PO task, the Mystery task in 2007, garnered many responses from the three teams that were studied at the competition. Their perceived stereotypical science identities led them to believe that the skills they used to solve it did not involve physics. In this task students held up a tray in front of a motion detector and were asked to match the motion described by the position-time graph displayed on a computer. They could keep conducting trials (by walking back and forth at particular speeds) until they produced a match that they believed was the closest they could achieve. This task was easy for most students to understand and complete and did not involve any calculations or explanations using physics concepts. As described in Chapter Four, the task evoked strong emotions in students because of the feedback they received during the event, however it was not challenging enough to push the team towards a critical point of instability where emotions contribute to the emergence or adaptation of science identities.

> Adam: Mystery is just fluke. You know what it is, it's just moving the plate, it involves no physics, it's just moving stuff. [PO, SHS]

> Cam: Yeah. And also the Mystery task. This year it was less, I don't know I thought it was based on fluke, I don't see too much physics in that. Other than you know you try to break the time interval into smaller ones. Like someone who has previous music experience, like one and two and three and four. [PO, SHS]

Allen: It just seems like dexterity. Well it doesn't seem like you're really applying physics. It's not really a very interesting Mystery task. If the paper tower was a Physics Olympics task that would be very interesting. [PO, SES 2007]

Colin: My favourite task was actually the Mystery task. And that's the one too that I think had the least to do with physics, the most to do with luck. Once you've figured out how you had to move this metal tray in front of this motion detector, you know what you had to do. [PO, SES 2007]

Frank: The Mystery task was less than I thought it would be. It was hardly physics at all, it was basically just like, you know motor skills. [PO, SES 2007]

Res: And the Mystery task, you were in the Mystery?

Henry: Yeah, that was kind of dumb, it wasn't really physics, it was dexterity. Right, but still it was kind of cool to see a machine that was able to gauge an object's velocity theoretically irrelevant from its position. [PO, SES 2008]

Although students required a basic understanding of kinematics and motion graphs to complete the activity correctly, they still attributed their success to practice and dexterity, which are not, according to their stereotypical science identities, skills necessary for learning physics. Therefore, student perceived stereotypical science identities, influenced student attitudes towards physics through their judgments about (and hence emotions evoked by) particular tasks or activities that they participated in during the competitions. Science identity literature (e.g., Draw a Scientist Test) is rife with findings which describe the largely negative, stereotyped images students have of scientists and hypothesizes that these poor images discourage students from choosing science courses or hobbies (Losh et al., 2008). Hannover and Kessels (2004) found that a poor match between students' self-concept and the image they have of a subject leads to poor attitudes about that subject. The results of this study confirm the stereotypical attitudes that students carry about scientists, particularly physics, but also show promising ways to impact these attitudes. By experiencing a wider range of activities, including those in the Physics Olympics and BC's Brightest Minds competitions, students are able to draw more connections between themselves and the subject of physics, such as the ability to work with people or the ability to apply physics to real life situations. This improves the likelihood of a good self-to-scientist match that Hannover and Kessels (2004) found to be influential in student course choices.

Influence of Science Identities on Motivations about Physics

The influence of science identities on motivations in physics is discussed in two areas. Firstly, students' intrinsic motivations to volunteer to participate in these events and sustained efforts during preparation and participation are illustrated using comments from interviews and observations of their behaviours. Student emotions while participating are drawn upon to show the obstacles that they encountered as well as were motivated to overcome. Data supported the claim that perceived individual science identities were influential in helping students to sustain their motivations despite difficult challenges and disappointing failures. Secondly the influence of team science identities on maintaining focus, coherence and motivation while participating is presented.

Emotions expressed by students showed that motivations to volunteer to participate and to engage deeply while participating in both competitions was very high. Students described several motivations to participate. When they were asked in pre-event interviews why they participated, they said it was because: 1) they had positive attitudes about physics, were interested and thought it would be a fun, enjoyable experience,

Stacy: We were just doing it for the experience and to have fun. [BCBM, QHS]

James: Yeah. It will be a fun experience, after the AP [exam]. To actually go have some fun. [BCBM, KHS]

Res: Why did you choose to be on the Physics Olympics team?

Phil: Well my teacher suggested it last year and it kind of sounded like fun you know, building these things outside and kind of applying the knowledge you're learning in physics class. And then after I had so much fun last year I thought I'd do it again this year. [PO, SES 2006]

Colin: Well I just heard that the whole experience with your friends, getting to do something, that's somewhat involved with physics. It is completely a physics event. But more so I heard about the different things, all the great experiences people had with their friends. And well the fact that you're learning something too. [PO, SES 2007]

Greg: I thought it would be interesting to see what goes on, interesting engineering applications. [PO, SHS]

Res: Why did you want to be on the Physics Olympics team?

Dean: I like physics. [PO, SES 2007]

2) they were motivated to learn physics more deeply than they had been able to through classroom experiences,

Brad: Well, I really - well physics is interesting for me I really want to start - how should I put this - well I guess right now at the moment it's to redeem myself for a whole bunch of failed projects during class.

Res: Yeah?

Brad: So yeah I think Physics Olympics is a good way to get my – I don't know- mojo going. [PO, SES 2006]

Res: Now why did you want to be on the Physics Olympics team?

Bob: I just love physics. I want to explore more physics with other students. It's interesting. [PO, SHS]

Res: That's great, so why did you want to be on the Physics Olympics team?

Ellen: Because I think it's really, really interesting and it's a really good opportunity for me to apply the physics that I learned at school to real life situations. I think it's because I just want to learn about more things in physics, not just the stuff we learn about at school. The more modern physics. [PO, SHS]

Res: What makes you want to be on the Physics Olympics team on top of it all?

Elyse: I actually enjoy physics. I love to think of something like how could this work. It's like physics but it's on a different level. It's not classroom physics where you know. [PO, SES 2007]

and, 3) some were motivated by the competitive context. The novelty and expectations of success captured the students' attention.

Res: Why did you want to be on the Physics Olympics team?

Adam: Well I want to win. Last year we won second place. So, yeah, cause of last year. Cam is always saying we won. So if I win this thing then I have proof that I'm better. [PO, SHS]

Res: Any other reasons for participating in the Physics Olympics?

Cam: Well for me, it's like when I learn things in school sometimes I don't get as interested. But that when you're telling me oh you get to compete with all these people and there's time limits, there's scores that gets me excited I just like want to participate. [PO, SHS]

Res: Why did you want to participate again this year?

Barry: I like building things right so it seems interesting, fun and I want to win I guess this year. [PO, SES 2007]

Ian: The competition was held earlier and yeah. But this year I'm kind of more into it because I want to do better. [PO, SES 2008]

However they expected the competitions to be difficult:

Res: What are you expecting the Physics Olympics to be like?

Rob: Very difficult. [PO, SES 2006]

Jane: It was challenging as I thought it was going to be. [BCBM, QHS]

Beth: It's going to be I don't know wiping brows thinking hard. But it should be fun, this is surprisingly fun. [PO, WHA]

In Chapter Four the competitive atmosphere was an important source of context evoked emotions. Frequently expressed context evoked emotions of disappointment and task evoked emotions of frustration illustrated that many of the tasks were indeed extremely challenging and difficult. Particularly in the case of the Physics Olympics, students invested hours of time outside of class to design the pre-built projects. Participants from each team experienced intense emotions of frustration and disappointment when their pre-built designs didn't work or when they weren't able to complete a task or a question to the level of success that they expected. Despite these failures and frustrations, most students said that they would participate again in the Physics Olympics or that they wished they could participate again.

It is noteworthy that students would choose to participate twice and devote so much time and effort to a competition in which they have little chance of succeeding (i.e., competitions that are well known to be prestigious and challenging). As well, after participating, they all said that they had fun and enjoyed the experience despite the difficulties they faced in preparation and during the events. For example, students encountered the most difficulties during the Physics Olympics pre-built events, but still chose them as their favourite tasks in the competition. Many students commented about simultaneously experiencing both fun and frustration. (See task evoked emotions in

Chapter Four.)

Strong and robust individual science identities may be the source of these seemingly contradictory messages. The emergence of strong individual science identities was discussed in Chapter Five. Since these students had strong individual science identities, it is possible that they were more resilient in the face of failure and frustration. In fact some believed that it is part of the process of being a scientist.

Paul: You definitely have to have the motivation to do it, same with math because if you do something and you mess up, you get frustrated and just stop, that's not like a good physicist. If you mess up, a good physicist, should be like OK whatever, I made a mistake I'll figure it out and I'll keep trying. So you have to be able to just keep trying. [BCBM, KHS]

Res: So did you get any impressions of engineering do you think?

Brad: It's going to be a tough, tough, tough journey. It's going to be hard, but I hope it's going to be satisfying in the end. I just want to build some buildings. [PO, SES 2006]

Therefore, students who typically participated in these kinds of events had strong individual science identities, which influenced their motivation to participate in physics activities such as competitions. They seemed to anticipate associated difficulties and challenges but still that did not dissuade them. Furthermore, the experience of failure did not taint their experience and memories of the event. Several students were interviewed before participating in the event for the second time. They were asked about their experiences the year before. They did not forget their failures. Chapter Five described how emotional memories of failure helped students create a shared history and story of participating in these kinds of events. Therefore, they were still optimistic and excited to participate again:

Elyse: I think we're going to do well. I'm confident. And I think we're going to work together well. [PO, SES 2008]

Henry: Yeah a little bit, it's just that the pre-builts are always so ridiculous, it's a little daunting. And the Intuitive Physics task - I think will be interesting and pretty fun, I think I'll do alright on that. [PO, SES 2008]

Thus strong individual science identities seem to have influenced student motivations in physics and allowed them to engage in activities where they risked (and experienced) failure without negatively impacting their attitudes about physics and motivations to participate in physics related activities in the future. In fact, in most cases, participating appeared to have strengthened their individual science identities, which could motivate them to participate in more events. This could, in turn, strengthen further their science identities. This positive feedback loop likely plays a role in the development of elite students in the sciences, who are extremely motivated to succeed and who participate in a wide variety of science related experiences, both as part of their education and outside their formal educational experiences. These findings are in tandem with Linnakylä & Malin's (2008) study results which showed that students who were highly engaged (involved in many curricular and extracurricular activities) also had high self-concept and aspirations for further study. This study adds to this work by looking at a particular science context and by using emotions and science identities to explore student engagement, attitudes and decision making. Thus this chapter concludes with a discussion of the influence of science identities on student decision making about physics.

The Influence of Team Science Identity on Motivations About Physics

Team science identity emerged while students participated in the Physics Olympics and BC's Brightest Minds competitions. Students participated in both competitions in teams. A team of about ten students usually represented a school at the Physics Olympics, but during each task teams of five students worked together. At the BC's Brightest Minds event, students worked in pairs to complete the challenge. Since the Physics Olympics teams were larger, the emergence of team science identity was more prevalent in that context. Team science identity emerged through student ideas and experiences of working together on a science related task. The skills, knowledge, emotions and experiences that emerged as necessary or important to succeeding at working as a group on a science task (usually a design project or a problem solving activity) were identified as aspects of team science identity. In Chapter Five, team science identity manifested through diversity was discussed. Students attributed their successes, in part, to the wide range of skills and experiences of their team members. Redundancy among members also facilitated the emergence of team science identity. Students who attended the same classes and had common background knowledge and experiences were able to build on them. Students also perceived some benefits to having previously attended the events, or something similar, so that they knew what to expect and were more prepared. Decentralized organization provided more flexibility for students to group themselves into effective teams depending on their interests and emotions, which according to this study, resulted in strong team science identity. Other factors such as social dynamics, school culture, and gender (for example) also play key roles in the complex system of how students form groups (Ciani, Summers, Easter, & Sheldon, 2008) but were not examined in this study.

In student pre- and post-event interviews and from observations preceding and during the events, students appeared to be motivated to participate. Some of these motivations appeared to stem from a sense of team science identity. Students saw themselves as part of a whole or of a separate entity, which they were committed to contributing to. As long as the team stayed motivated, its members did too. This was an example of a property that the emergent entity, which in this case is the team and its team science identity, embodied but was not necessarily present for each individual member. Student motivations which stemmed from their sense of being a member of team are conveyed in the interview excerpts below:

Res: How did it feel when the pre-builts didn't work?

Bob: It sucked. It made me want to swear. I was really disappointed. When our teacher said, "It's OK guys, let it go," I felt even sadder because it was not OK. Three weeks of work for nothing! The two groups put so much effort into the pre-builts. It really sucks to fail when you put that much effort into something. [PO, SHS]

Diane: I think it [the teamwork] was good, everyone was really supportive and they were there to oversee all the other activities. I thought everyone would kind of go off on their own but everyone kind of stuck by everyone else for moral support. So yeah that was good. [PO, SHS]

Elyse: And also because it's like a team thing, so once we do really bad on it, we kind of think oh we've brought the team morale down. So it's really down. [PO, SES 2008]

Elyse: Well we worked together really well I think, everyone did their part and then we supported each other. I think that was really great. [PO, SES 2008]

Res: How did it feel when the pre-builts didn't work?

Greg: It was harsh knowing that both team efforts had failed, even though we had spent so much time on them. I felt sorry for the teammates that we failed them. [PO, SHS]

The comments above mostly came from students who were on the same team, Summergrove High School, for the Physics Olympics in 2007. This team was described in Chapter Five because of the particular form of decentralized control that their teacher, Mr. Patrick, used to allow the team to emerge from his classes of students. His process of allowing student leaders train and choose other members of the team allowed for a particularly strong team science identity to emerge. But this was only one factor in the emergence of their strong identity. This team also represented a school that had won second place overall at the PO the year before. The majority of the students who participated were enrolled in IB physics and were particularly high achieving high school science students. This shared background, also a useful redundancy, which contributed to a strong team science identity, where the students were very motivated to succeed because they wanted to improve on, or at least match, last year's efforts. Their strong team science identity, led to a group of very motivated students, who supported each other throughout the competition and who felt badly for the entire team when they failed at their particular tasks.

Summergrove's team science identity included a sense of trust in other members. They had the same strong education in science and they were each trying their best. Data from other teams also indicated that when students worked in teams and talked about working with their team, the motivations that they displayed while participating became evident. Students described their teams as focused and competitive and that all members contributed by trying their best.

James: We tried, we tried our best. I think that basically it's like what we are, how quick we are is kind of a reflection but anyways we tried our best. [BCBM, KHS]

Res: I noticed during the tasks you guys were very focused, almost pretty serious. What was going on there?

Brad: Well tried to be, tried to concentrate on getting it done because time constraints were pretty tough so hard to get it done. Actually I think sometimes we were just stumped. [PO, SES 2006]

Res: Yeah I noticed that you guys looked a little intense during the activities.

Tom: We're all kind of … competitive. [PO, SES 2006]

Glen: Everyone contributed something. Some more when we were building the stuff and some more in the actual tasks. But we all did something. [PO, SES 2008]

Res: Can you describe a positive experience from the day?

Cora: How we managed to get the force thing all done, that was pretty cool. And like how everyone chipped in their opinion and how everyone was trying to help. [PO, WHA]

Ian: I guess they [the team] pushed me various times to keep working on the car and sometimes I did [give up] and in the end I kind of did. [PO, SES 2008]

In the BC's Brightest Minds competition, working with a partner was also motivating:

Res: What about the benefits of working with someone else?

Laura: Definitely like if you are both on the same page kind of thing it just goes much faster. And it's like, if I can't remember something, he'd probably remember it, or if he couldn't remember something, I could remember it. That was good so. [BCBM, CVS]

Res: And then what do you think it will be like working on a competition with somebody else?

Paul: That's definitely a good thing, because everybody has mental blocks sometimes and having another mind is like having another hundred formulas ready for you right? [BCBM, KHS]

Thus embodied in perceptions of team science identity is a sense that the members shared common values about the importance of science in general and the competition specifically, in other words they all appeared motivated. Members also shared similar perspectives on how to tackle a challenging problem: share the work, generate lots of ideas, try your hardest and remain focused on the problem. Some of these skills are specific to the project of science and are thus components of a team science identity as opposed to a general group identity or team identity.

Therefore, team science identity emerged and appeared to influence students' motivations during the Physics Olympics and BC's Brightest Minds events. It helped to maintain the team's coherence so that they could overcome obstacles and challenges that they encountered. Davis and Sumara (2006) describe how emergence is facilitated by a balance of coherence (focus of purpose/identity) and randomness. In this case, meaningful learning emerges from a team with a strong sense of science identity but includes randomness in the form of the diverse personalities and the unknown nature of the challenges that they will encounter. Their ability to adapt and change, while maintaining coherence, allows the team to respond to challenges during the competitions. Some of the challenges arose because the students were in teams and sometimes had conflicting ideas and opinions. Chapter Four described the emotions that were evoked in those situations. However, the emergence of team science identity provided a common framework for students to fall back on and provided a goal for them to focus on as individuals who were part of a larger project. Some teams had more clearly defined team science identities. This was the result of the varying constraints that were applied to create the teams or which allowed for teams to emerge. This evidence provides a basis to make recommendations for teachers, in Chapter Seven, so that participating in events such as the Physics Olympics or BC's Brightest Minds are meaningful learning experiences for students. But, to end this chapter is the section below which examines the influence of science identities on student decision making.

Influence of Science Identities on Decision Making about Physics

Decision making about physics, in the context of the current study, differs from motivations about physics. It refers to the process by which students made decisions about their future career possibilities and the steps they took (or planned to take) towards those career goals, including the courses and university programs they decided to enroll in. Motivations about physics incorporated students' interests and their likelihood to volunteer or choose to participate in physics related activities such as competitions. Often, students allowed their emotions and interests guide their motivations. Statements such as "I want to participate in the Physics Olympics because I like physics" occurred frequently in student interviews. Student motivations for participating in the events were summarized above in the previous theme. Thus, while motivations about physics were more closely linked to student interests and attitudes about physics, decision making about physics tended to be more pragmatic. The role that science identities, emergent from emotions evoked by participating in Physics Olympics and BC's Brightest Minds, played in decision making is the third theme which will be explored in this chapter. Two types of perceived science identities emerged as playing a role in the decision making process: individual science identities and stereotypical science identities. Through the emotions they felt during their participation in the Physics Olympics and BC's Brightest Minds events, students learned how closely their perceived individual science identity matched with their perceived stereotypical science identity.

Students tended to analyze their interests, backgrounds, resources, strengths and weaknesses in order to decide on a course or career. In other words they drew upon their perceived individual science identity. For example:

Res: Now what makes you interested in engineering? Why do you think you want to go into that?

Bob: My dad works in engineering, well kind of, not really. But his company does that kind of thing so I always go there and I'm really interested in doing that. [PO, SHS]

Res: What are you hoping to do next year?

Cam: Next year? Well I sent out my applications to UBC, McGill, and U of T.

Res: What kind of program?

Cam: Science, life science. because I want to pursue medicine hopefully in the future. [PO, SHS]

Res: Why do you want to be a doctor?

Diane: Just because I really enjoy helping people and I have other skills I can use like I've been learning a whole bunch of languages too, so that will help me travel around. The major languages like French, Spanish, Chinese, English. I guess those are ones that hit major groups of people. [PO, SHS]

Ellen: Chemistry well I really like, maybe not chemistry as in chemistry but food sciences and nutrition.

Res: So how did you get interested in the nutrition stuff? Sounds like there's a story there.

Ellen: Because my dad is a nutritionist. And then he used to work in a company and he's like part of the research and development of nutritional foods. So he would always bring home these new samples. And then also because my mom, is not very healthy, so I want to become a nutritionist and make everyone healthier. [PO, SHS]

Res: How come you chose physics and chemistry over biology/chemistry [in high school]?

Colin: Well I am interested in all the sciences and I think in university I'm going to go into all the sciences but I thought that biology would be easier than chemistry and physics because it's more memorization than anything else. I wanted to get a good grasp of different concepts in physics and chemistry. You go into a great deal of depth when studying chemistry too, so those are the ones I wanted to get a good grip on before moving on to university. [PO, SES 2007]

Res: How come you chose to take physics and chemistry and not biology?

Dean: Because for whatever I do in the future I'll need those for sure. [PO, SES 2007]

Phil: I decided to take Physics 12 because I want to go into engineering next year so it's a requirement I need to get in and I don't really like biology very much so I said chemistry and physics I'll go with that. It's kind of always interested me how things fit together and work, rocket science that sort of thing. [PO, SES 2006]

Thus, students were influenced by their parents' professions, course prerequisites and to an extent, their interests, strengths and weaknesses to make decisions about what careers to pursue and what courses to take. All of the above statements were made during pre-event interviews where students were asked about why they chose their current science courses and about their future career and/or post secondary plans.

In post-event interviews students were asked what they learned about themselves by participating. Students learned about their strengths and weaknesses.

Res: What did you learn about yourself from participating? Did you surprise yourself at all?

Allen: Sometimes I - no not really. I know who I am, I do what I do, I'm not really special or anything. I just give whatever. I guess I'm sort of the average guy who does what he can. [PO, SES 2007]

Jane: I just thought I should stick to biology.

Stacy: Yeah, [physics] it's not my strongest subject. I didn't learn that because I knew it. I learned that I can think of, remember formulas if I'm given enough time to remember them from like the depths of my brain. [BCBM, QHS]

Laura: It was a lot of fun and it helped me figure out what I need to work on and study, if I don't know it and it also helped me realize where I'm good at stuff. [BCBM, CVS]

Res: What did you learn about yourself from participating?

James: I'm not that good.

Res: Not that good at what?

James: Physics I guess, like just generally. I always thought mechanical stuff, that I'm pretty good at all that. But I think that's just a way that Chinese teachers teach their students. You have to be good at.

Paul: I'd say that we still need to learn to apply the theory we've learned to real life, actual situations. Not just situations that we're given on paper because everything behaves differently, the angle is such and such and something is traveling at this velocity. It's really different when you have to approximate values before you can work with it.

James: I was never, when I was in China and we learned physics we didn't do any labs. There's no labs period. So application is really my weakest thing. [BCBM, KHS]

When students learned about their strengths and weaknesses while competing in a physics competition, their perceived individual science identities adapted accordingly. Student perceived individual science identities were described in more detail in Chapter Five. Through neighbour interactions, student individual science identities emerged through comparisons with the larger physics communities that they became a part of when they participated. In Chapter Five, data was presented about what students learned about themselves and the physics community while participating. Chapter Five also described how students' perceived stereotypical science identities adapted as they participated. Their perceptions became more broad. For example, students recognized that different types of science learners are useful on a team and that doing physics does not only involve skill in calculations but also the ability to work with others. In several cases this learning led students to reflect, not only on their physics knowledge and skills compared to other students, but on their future career goals and course choices.

Res: Did you learn anything about yourself? How do you do physics?

Fred: It shows me my place in the physics world.

Res: And where is that? Is it more in than you thought or less in?

Fred: Less. [PO, SHS]

Eddy: To read the instructions better. And I guess that you put it into perspective, we don't really know much about physics you know.

Res: Did you learn that you didn't know as much as you thought you knew.

Eddy: Yeah. [PO, WHA]

Res: Were there any good moments in the day, any positive experiences?

Felix: Yes because we went to UBC and alumni pass by and we talked to them.

Res: Yeah that was interesting, what did you learn from them?

Felix: [about] Interesting jobs and good paying ones. They are really top students.

Res: You don't think you could do that?

Felix: No I don't think so.

Res: Why?

Felix: Lack of self confidence. [PO, WHA]

For one particular student, participating in the Physics Olympics event was very influential on his future career choices. Derek expressed very strong positive attitudes about physics and a firm plan to become an engineer before participating in the event:

Res: Great so you're pretty motivated in physics.

Derek: Yeah I want to be some sort of engineer.

Res: Engineering, Why engineering?

Derek: I've always been strong in math, I like math. More than English and all the other courses. [PO, WHA]

After the event, he again expressed a strong desire to become an engineer:

Res: What did you learn about yourself by participating?

Derek: That I really want to be an engineer. By the end of it I wanted to be an aeronautical engineer. I don't know how I got that, I thought that was cool. By the end of this whole experience I really want to be an engineer.

Res: That's awesome.

Derek: Yeah, I just feel I have the creative mind for it and the smarts I guess. [PO, WHA]

Therefore, while participating in the Physics Olympics and BC's Brightest Minds competitions, students learned about themselves and thus their individual science identities adapted and changed over the course of the competition. Secondly they learned about their physics community, which was informed by the dynamic and adaptive stereotypical science identities as described in the first theme in this chapter. The coherence between their perceived individual science identities and their perceived stereotypical science identities led them to draw conclusions about their possibilities of success in similar fields in the future. Previous work has shown the importance of science identity and attitudes on student decision making (e.g., Robertson, 2000; Woolnough & Guo, 1997). At the same time, Damasio (1994) described the key role emotions play in guiding rational thought, particularly decision making. This study has drawn connections between emotions, science identities and attitudes to explore the implications for decision making about science. It seems that emotional learning events aid in the emergence of science identities, which can help provide students with a framework from which to draw upon to develop attitudes and motivations about physics and ultimately to make decisions about their future in physics.

Chapter Summary

After participating in the Physics Olympics and BC's Brightest Minds, student perceived science identities continued to progressively emerge. Stereotypical science identities impacted students' attitudes about physics, where students' ideas about physics and its applications shifted from narrow to broad. Strong individual science identities also helped students to sustain their motivations to participate throughout the competitions and in subsequent years, despite experiencing strong negative emotions due to difficult challenges and disappointing experiences. Team science identity provided a source of coherence to an often messy complex system, which motivated individual students to work together as a team to achieve success on activities such as the pre-built designs. Finally students drew on their individual science identities and stereotypical science identities to gauge how well they fit into a larger physics community while making decisions about physics. In this chapter, science identity proved to be a particularly important and useful construct to pay attention to in order to better understand the complex system of learning that existed at the Physics Olympics and BC's Brightest Minds events. Emotions were evoked, identities emerged and adapted and adaptations were played out by influencing student attitudes, motivations and decision making about physics. Implications of these findings and recommendations for creating emotional, meaningful learning experiences in these kinds of contexts will be offered in the next chapter.

CHAPTER SEVEN

Conclusions, Implications, and Recommendations

Chapters Four, Five and Six have provided data and detailed analysis to support findings to the three research questions that framed this study. This chapter summarizes and discusses key findings for each research question and implications and recommendations for 1) teaching and learning physics, and 2) the study of emotion. The limitations of this study are addressed and further questions to study are also offered.

Discussion of Key Findings

Key findings are discussed and synthesized within each research question given what has been presented about previous research in the field. Whereas gender was noted in the literature as a possible factor shaping students' perceived science identities, it did not emerge as such in the current study. Therefore, this section concludes with a discussion of possible reasons for this.

Research Question One: How can the emotions experienced during science outreach programs be characterized and understood?

Employing a complexity thinking framework, emotions were defined as a level of analysis in the complex (learning) system of participating in science outreach experiences. Data from pre- and post-event interviews were supported with video and lapel microphone data and observations of students participating in the Physics Olympics and BC's Brightest Minds competitions. Expressions of emotions were organized into three themes according to how they were evoked: context, task, and novelty evoked emotions. In conclusion, this study demonstrates that: 1) experiencing strong emotions can enhance motivation and learning; 2) structures of the context appeared to evoke strong emotions; 3) competition evoked emotions of excitement and disappointment; 4) tasks with the appropriate level of challenge have the potential to evoke feelings and expressions of emotions; 5) tasks that provide feedback about success and failure have the potential to evoke feelings and expressions of emotions; and 6) novelty of events have potential to evoke strong emotions of fun and sometimes frustration.

Experiencing strong emotions can enhance motivation and learning.

Students were observed to experience very strong emotions while participating. Four emotions were frequently observed through verbal and non-verbal expressions: fun, frustration, excitement and disappointment. Often positive and negative emotions were expressed simultaneously. Emotional experiences were remembered frequently and, interestingly, favourably. Connections between emotions and learning were made in this study by drawing on Damasio's (1994) findings that memories are accompanied by emotional 'stamps' and that stronger emotional 'value' increases the likelihood that an experience will pass through sensory filters and be committed to memory. Thus, students at the Physics Olympics and BC's Brightest Minds events were engaged in meaningful (and memorable) learning. Similar results have been observed in informal learning contexts where students became emotionally charged while interacting with issues-based exhibits (Pedretti, 2007) and emotionally stimulating exhibits were discussed more deeply and frequently than other exhibits on visitor comment cards (Pedretti, Macdonald, Gitari, & McLaughlin, 2001).

However, this work raises questions about claims that pleasurable memories are favoured over unpleasant ones (Damasio, 1994; Sylwester, 1995). This dissertation surmises that negative emotions experienced in particular types of science contexts, do not necessarily lead to negative attitudes. This is, in part, due to students' perceptions of stereotypical and individual science identities, where challenge and the resulting frustration and disappointment is perceived to be part of science – a notion that was explored in research questions two and three.

There was also evidence that students were intrinsically motivated to participate in activities that shared characteristics with flow activities (Csikszentmihalyi & Hermanson, 1995) where their minds and bodies were completely immersed in the task.

Structures of the context appeared to evoke strong emotions.

Context evoked emotions were usually experienced by teams as a whole. Structures such as the social nature of participating and the voluntary, novel, out-of-school contexts were key agents in evoking emotions. This study was situated within informal education literature. Informal learning contexts have been advocated as ideal locations to explore relationships between affect and cognition (Dierking, 2005) because participation is voluntary, learners are guided by their interests, and social and group learning are emphasized. The Physics Olympics and BC's Brightest Minds contexts shared these qualities. Moreover, the social nature of both competitions created feelings of fun and motivated students to participate. Shared emotions emerged and provided indications of a learning collective. Informal education literature has found that conversations are key tools, which lead to higher understanding (Baxandall, 1987) and that explaining to others (e.g., parents to children in museums, or one team member to another in the Physics Olympics) is one strategy in socially mediated learning. Peer interactions, such as those at the PO and BCBM, have not been studied as closely as mentor-novice interactions in informal learning settings but studies have described how students form their own communities of learning as they discuss and engage with new learning experiences (Astor-Jack, Whaley, Dierking, Perry, & Garibay, 2007).

Competition evoked emotions of excitement and disappointment.

The competitive atmosphere and novel nature of the venue created expectations in students, which led to context evoked emotions of excitement and also disappointment when they did not succeed. Ozturk and Debelak (2008a) recently advocated for academic competitions to provide differentiated learning for gifted children, as they are meaningful learning opportunities. They also described affective benefits of participating in competitions, including increased motivation and self-concept (Ozturk & Debelak, 2008b). Exposing students to competitions can also help them to learn to cope with subjective judgments and psychological effects such as anxiety and stress (Davis & Rimm, 2004), especially when students are mentored through the process under the guidance of an educator who encourages the rigor of competition while gauging stress levels and helping students to manage them (Ozturk & Debelak, 2008b). The results of the current study support these observations, that strong emotions are experienced in the context of competitions, and that these feelings must be attended to. The current research contributes to the field by exploring the kinds of emotions that were experienced by students and describes healthy competition structures such as those in the Physics Olympics where a coach (teacher) and team dynamic (illustrated through an emergent team science identity) helped students to cope with strong emotions.

Tasks with the appropriate level of challenge have the potential to evoke feelings and expressions of emotions.

Students' level of success and frequent feelings of frustration and disappointment were also closely linked to the nature of the tasks in the events, in particular the level of challenge. Proscriptive tasks which moderate the level of challenge were very emotionally evocative. Challenge was usually moderated through carefully planned time constraints and proscriptive rules which, through positive feedback loops, pushed the system (the team) closer to critical points of instability where emergence (emotions, identity, ideas) can occur. Sadler et al. (2000) wrote about successful design challenges in middle school and recommended that students start with an initial 'cookbook' design which must be tweaked to reach a particular goal. The results of this study show that, for senior high school physics students, a more proscriptive approach can be used to create appropriate challenges. In the Physics Olympics and BC's Brightest Minds competitions, students were not given step-by-step prescriptive instructions to complete their challenges. Instead, they were given a list that limited the possibilities (usually in terms of materials, space, and time) but that didn't provide much information about how to achieve the goal. Few studies have emphasized this important feature of design activities and what students learn about the process of science by experiencing the difficulties and the possibilities that emerge from working within strict constraints.

Tasks that provide feedback about success and failure have the potential to evoke feelings and expressions of emotions.

In this study, tasks with feedback about students' successes and failures evoked the strongest and most frequent emotions. The quality of feedback is a factor that causes extrinsic motivators (such as competition) to lead to intrinsically motivated behaviour (Butler & Nisan, 1986). These results support literature which advocates for the use of design activities and which cites multiple iterations (Linn, 1995), feedback (Hmelo et al., 2000) and reflection (Schön, 1983) as key characteristics that lead to meaningful cognitive and affective outcomes.

Novelty of events have potential to evoke strong emotions of fun and sometimes frustration.

Novelty was ensured through the use of unfamiliar equipment and the out-of-school, competitive context. These results must be tempered with findings from informal education, which demonstrate that familiarity encourages engagement in exhibits and hands-on activities during museum visits (Allen, 2007). In the context of the Physics Olympics and BC's Brightest Minds, it is the competition that captures participants' initial attention, thus unfamiliar contexts and equipment can be presented to participants. However, a balance must be struck between familiarity and novelty (similar to the necessary balance between diversity and redundancy), so that students' curiosity is peaked but where multiple entry points for engagement are also provided. In the second half of this chapter, results from examining the different ways in which emotions were evoked at the Physics Olympics and BC's Brightest Minds events will be used to extrapolate what we have learned about these meaningful and emotional learning experiences in science outreach contexts, to applications in physics classroom contexts and physics teaching and learning in general.

Research Question Two: How does participation in science outreach programs and the emotions evoked by these experiences contribute to the manifestation of students' perceived science identities?

Three types of science identities (team science identities, stereotypical science identities and individual science identities) were located and described based on the conditions of emergence in which they were manifest. In particular, identities manifested under the following conditions: 1) diversity, 2) redundancy, 3) neighbour interactions, and 4) decentralized organization.

Diversity evoked emotion and broadened students' perceived science identities.

In a complex system, diversity enlarges its range of possible responses to external circumstances (Davis & Sumara, 2006). While participating, students described their team science identities to include the notion of a diversity of skills. They described two types of people that they wanted to work with on these kinds of challenges: those with strong theoretical physics skills and those who could design and build, or who could apply physics principles to real life. Carlone and Johnson (2007) employed a model of science identity that encompassed three dimensions: performance, competence and recognition. Findings in this study suggest that students' recognition of the role of a scientist has been broadened somewhat. More students may be able to recognize themselves as scientists or be able to advocate to others to be recognized based on skills and attributes that they learned they had and/or needed while participating in the Physics Olympics or BC's Brightest Minds events. The nature of emotions evoked has the potential to make students aware of and broaden their individual and collective conceptions of science identities.

Before participating, students talked about skills that all scientists must have, including good mathematical problem solving skills. This expression of stereotypical science identity is consistent with existing literature (e.g., Brickhouse et al., 2000; Flinson, 2002; Shanahan, 2007), but shifted and broadened with participation in the events to include the ability to work with others and apply physics concepts to real world situations. Therefore participating in events such as these increases the number of discourses or science identities that are available for students to draw upon in order to develop their attitudes about science (Brickhouse et al., 2000; Hughes, 2001).

Emotions shared in redundancy promote communication and coherence.

Redundancy complemented diversity and provided a common ground for students as they negotiated the unfamiliar learning space at the competitions. Within their teams, students benefited from having members who had attended the competition before and from participating with their fellow classmates. These shared understandings enabled them to communicate, which improved the team's coherence and ability to respond to difficult challenges. Memories shared from past events, which were usually emotional, helped contribute to team science identities as students strove to improve on past failures or to maintain past successes. Neurologists have demonstrated that emotional memories are stored differently than other memories (Johnson, 2004) and long range studies of visitors to world exhibitions (Anderson & Shimizu, 2007) have established relationships between emotions and memory vividness. Thus experiences where emotions are being evoked and expressed are more likely to be recalled and retold and are thus more likely to influence students' science identities.

Interactions and shared emotions between teammates and other teams allowed perceived science identities to emerge.

When ideas were shared between individuals on teams or between teams, neighbour interactions were said to be present in the complex system. At the Physics Olympics in particular, observing and competing alongside other schools generated strong feelings of excitement and surprise. Teams and individual students learned about their own strengths and weaknesses compared to a larger student physics community and hence their emotions, particularly related to their successes and failures, helped them to see where they fit within this student physics community. Therefore, perceived individual science identities emerged in the interactions between their teammates and with other teams. Student perceived individual science identities are malleable and dependent on emotions manifest in the event and the collective. The emotions students experienced provided clues about how well their perceived individual science identity matched with their perceived stereotypical science identity. This match has been shown to play an important role in student decision making and motivation in science and was particularly elucidated through neighbour interactions.

Calabrese Barton, Tan and Rivet (2008) recently wrote about creating hybrid spaces for science engagement where student identities were renegotiated and learning communities were expanded. They introduced several different practices into the science curriculum, such as story telling and songs. The results of their study suggest that hybrid spaces of science engagement can be created by bringing together different groups of students engaged in meaningful learning activities such that they can observe and learn from each other. Science outreach competitions, such as the Physics Olympics and BC's

Brightest Minds events, can be interpreted as hybrid spaces where neighbour interactions allow notions of teams and competition and the expression of emotions to be associated with the application of physics concepts and skills.

Strong team science identities emerged under conditions of decentralized organization.

The condition of decentralized organization was present in some instances more than others. For the Physics Olympics, some teams were allowed by their teacher to emerge from groups of students depending on their interests and emotions. The teams of students who worked within decentralized organizational structures appeared to produce a collective with stronger team science identities than those whose members were assigned by teachers to the event or to particular tasks within the event. It is important to note that advocating for decentralized control is not meant to imply that teachers or coaches relinquish all control of the system (Davis et al., 2008), rather to recognize the important role of teachers to be knowledgeable enough to recognize and choose from possibilities that are presented and to impose constraints that sufficiently limit the system so that emergent ideas can be pursued and developed. Decentralized organization also recognizes the role of students' own strengths and interests in the process of developing teams and privileges them by allowing groups to form naturally or organically from some initial constraints (such as grade level, time and space to meet).

Science identities are dynamic and adaptive.

Student perceived science identities broadened and shifted as a result of students' experiences in the Physics Olympics and BC's Brightest Minds competitions. The results of this chapter contributed to literature that has advocated for a more dynamic and adaptive perspective on identity (Nieswandt, 2005; Roth & Tobin, 2007) and introduced emotions as an important construct to consider when exploring how identities emerge or are constructed (Damasio, 1999). This study has also contributed to the field by presenting science identity as an important construct to use to study learning in a science outreach context where most of the literature in science identity has been conducted from a critical theory standpoint and has focused on case studies to illustrate gender and race issues in science learning. Complexity thinking can contribute a new lens for studying science identity and how science identities can influence affective learning constructs such as attitudes, motivations and decision making about physics.

Research Question Three: How do students' perceived science identities influence their attitudes, motivations and decision making about physics?

This study examined the impact of science identities on these affective constructs through a complexity thinking framework. Complexity thinking draws attention to how aspects of a complex system (in this case students' emotions and science identities) are constantly adapting in dynamic interactions between itself and the environment. In an intelligent complex system, these adaptations are moments of learning. Thus, the influence of science identities on attitudes, motivations and decision making about physics were interpreted by reflecting on what students said they learned by participating in the events.

Shifting science identities led to shifts in attitudes about physics.

Stereotypical student science identities were particularly influential on student attitudes about physics. These results support previous findings (e.g., Shanahan, 2007) which have also drawn connections between science identities and attitudes about physics. Students' attitudes shifted after participating to a more broad perspective which included different skills than are currently included in the literature portraying students' stereotypical ideas about science (e.g., Losh et al., 2008). However, some aspects of stereotypical science identity were very stable, such as strong mathematical abilities (Shanahan, 2007).

Emotional tasks impact attitudes about physics.

Results suggested that tasks that evoke emotions, particularly those which employ hands-on activities with an appropriate amount of challenge, have the potential to shift students' attitudes about science. These emotionally evocative tasks share characteristics with 'flow activities'. Flow theory suggests that appropriate level of challenge and meaningful feedback are ideal ways to engage students (Csikszentmihalyi & Hermanson, 1995). These findings also reinforce further the complexity of learning systems, since complex systems must always seek challenge and critical points of instability in order to maintain a high level of complexity (Juarrero, 2002).

Science identities promote motivation.

Students were intrinsically motivated to participate and maintained strong motivations throughout the competitions. Strong individual and team science identities, emergent through the emotions evoked, helped to sustain their motivations during unexpected challenges, obstacles and failures. There was indication that strong team identity was an important source of motivation for students, which is consistent with literature on student group projects (You, 2007). Students' individual science identities were also revealed through strong positive attitudes and emotions that students expressed about the events in post-event interviews, despite experiencing strong negative emotions while participating. These results support models in the literature, which have connected self-concept and self-efficacy to attitudinal and motivational constructs (Gungor, Eryılmaz, & Fakıogleu, 2007).

Emotions have the potential to make students more aware of coherences between their perceived stereotypical science identities and individual science identities and to inform their decision making about physics.

Finally, there was an indication that emotions expressed during students' experiences at the Physics Olympics and BC's Brightest Minds events helped students learn about their strengths and weaknesses and the coherences between their perceived individual science identities and stereotypical science identities. These coherences have been shown to be important in student decision making in science, from courses to careers (Hannover & Kessels, 2004). Thus, science identity proved to be a particularly important construct to pay attention to and understand in the complex system of learning that existed at the Physics Olympics and BC's Brightest Minds events. Emotions were expressed, identities emerged and adapted and adaptations were played out in the form of changing student attitudes, motivations and decision making. This study contributes to a body of work that has already demonstrated impacts of participating in extracurricular activities on decision making (Hofstein et al., 1990; Milner et al., 1986; Resnick, 1987;

Woolnough, 1994) but extends it into physics outreach contexts. These findings will particularly inform directions of future research in the field of science education where pedagogies and curricula are continuously being designed and studied in order to try to improve student attitudes about physics and increase secondary and tertiary level enrollment in this subject area.

The Gender Factor

In the current study, gender did not emerge as a key factor, perhaps due to the nature of the competitions and the types of students who participated. This is despite the fact that many of the studies reviewed in attitudes, motivations and decision making about science, science identity and learning in informal contexts have observed differences between male and female students. Theoretical perspectives and research into science identity perceive gender as a significant component of science identity (e.g., Brickhouse et al., 2001, Carlone, 2003, Lee, 1998). Low enrollment in physics is a problem for both male and female students (Nashon & Nielsen, 2007). Research has suggested that girls' decision making is impacted by positive attitudes related to extra-curricular activities (Baker & Leary, 1995) and many science outreach programs are initiated to recruit women and other underrepresented groups into the sciences (AAUWEF, 2004). The important impact physics competitions could have on girls was recognized in the beginning stages of design of the current study, however only a small number of girls participated and the gender factor did not emerge as significant for several reasons. Firstly, students volunteered to participate or were selected based on their prior interest in physics. In addition, participants were from senior physics classes, which meant that they were already disposed to doing physics.

There is generally low enrollment of girls in Grade 12 (and to a lesser extent Grade 11) physics courses, let alone those who offer to participate in competitions such as the PO and BCBM. This is consistent with Jones' (1991) observation that gender trends in science fairs and Olympiad events closely match the numbers of women who choose science courses and careers. It is well established that attitudes about science of girls are lower than those of boys (e.g., Osborne et al., 2003), but these results are from studies of large, general populations of students. The participants of the current study are a self-selected group of high achieving and motivated students in the area of science. The vast majority of students, both male and female, were very positive about physics in pre-event interviews and all students (except the team from Water Hill Academy) volunteered their time and efforts to participate in the event. The context and activities were novel and challenging for all participants and thus, it is not surprising that there was not a strong gender trend in the key findings of this study. Thus, strong gendered identities did not emerge in the data.

Given that this study involved tracking students' behaviour and conversation before, during and after participating in the competitions, it was not possible to initiate gendered centered questions since interviews were meant to probe further and clarify students' actions and what they said, their feelings and emotions, none of which exhibited any gender specific characteristics. Perhaps, a longitudinal study of these students would be able to detect gender differences in student decision making about science in the years following their participation in these events, especially the nature of post secondary education they will choose to engage in. More limitations and suggestions for further study are elaborated on in the next sections.

Limitations of the Study

While this case study research observed trends across several schools (6), students (35), events (2) and years (3), the findings are still considered to be particular to the contexts that were studied. The contexts, science outreach competitions (Physics Olympics and BC's Brightest Minds), were very specific types of science outreach events and do not represent science outreach contexts on the whole. However, two of their characteristics (voluntary, informal) were essential parts of their structure, and contexts that share these qualities will likely generate similar types of learning experiences. This study has attempted to provide enough detail in its descriptions and data to allow readers to judge the applicability of the results for themselves and their contexts.

Students from six different schools participated in this study and while the events occurred outside of the school context, the culture of the schools (Lortie, 1975) likely influenced the results. The types of schools included private, public, small, large, inner city and country schools, however a large enough sample was not taken in order to be able to generalize across schools to describe how students typically experience the BC's Brightest Minds and Physics Olympics events. Each team's experience was different depending on the role of the teacher, the past history of the school at the event, resources available to the students and much more. However, since there was variation in both the contexts and the schools studied, the ability to generalize the results in these areas was improved since it is more likely that the results will apply to another particular context similar to ones described here.

The biggest limitation of this study concerns what it can say about individual students' experiences at an event such as the Physics Olympics or BC's Brightest Minds. Most of the students who participated in this study were high achieving, motivated students who already had positive attitudes about physics. This is a self-selecting group which does not represent the majority of secondary school students taking physics or considering taking physics in this region, or country. For example, the girls in this study did not exhibit the gendered identities different from boys that have been observed in previous work (e.g., Brickhouse, 2001). Therefore, the results of this work are limited to the ways in which participating in these kinds of events can influence the science identities and attitudes, motivations and decision making about physics of students who already have strengths in these areas.

Finally, the study of emotions is fraught with methodological issues (Zembylas, 2007). Emotions are deeply personal, dependent on many factors including individuals' experiences, gender, and social-cultural background. This study was not able to explore or recognize the complex interplay between all these factors. Interpretation of students' emotions was dependent on the perspective of the researcher. By using multiple collection methods (interviews, videos, microphones, observations) and using a complexivist and phenomenological theoretical frame for analysis, an attempt has been made to interpret students' emotions and science identities as adaptive and dynamic. Thus, what was captured in this study was temporal and is not presented as universal truth. These limitations raise questions of possible improvements and elaborations on this study, which will be discussed in the final section of this chapter.

Implications and Recommendations

The results presented above suggest implications and recommendations in two important areas of educational research: 1) teaching and learning physics, and 2) the study of emotions in education.

Implications and Recommendations for Teaching and Learning Physics

The results of this study suggest that emotional learning experiences are meaningful learning experiences. Emotions were part of a complex system of learning where science identities emerge and adapt, influencing attitudes, motivations and decision making about physics. In the science outreach contexts that were studied, several characteristics and structures were observed which were powerful evocations for emotion. Considered broadly these included the social nature of the activities (working in teams or pairs) and the challenge and novelty of the experience. In ordinary physics classrooms students often work in groups on challenging activities that they have not encountered before, so why are Physics Olympics and BC's Brightest Minds contexts different? I believe that the bar is raised higher in these contexts: students are more social (forming themselves into groups and meeting and engaging with teams from other schools) and spend their own personal time working on these projects. The activities are more challenging than those that most teachers risk presenting in their classes and finally the experience is particularly novel because it is a competition, held outside of class in a larger physics community than they have likely seen before. These elements are all powerful sources for emotion and can not necessarily be repeated in a physics classroom but some elements might be useful for thinking about teaching and learning science.

Tasks from both the Physics Olympics and BC's Brightest minds events that were most enjoyed by students were those with a hands-on, design component. Students found designing pre-built challenges difficult but rewarding. These types of activities significantly influenced their attitudes about physics by broadening their notion of the skill sets needed to succeed. They learned about the unpredictable, emergent nature of science. The strongest emotions were expressed when the challenge was difficult, which was usually moderated through strict time constraints and proscriptive rules. An important lesson learned from observing students learn at these events was that it does not necessarily take a lot of time (which is always an issue for classroom teachers) and that they don't need to succeed to learn something from it. Students take a lot away from simply experiencing the uncomfortable space of trying to negotiate a difficult design challenge with their peers. Secondly, teachers should not shy away from creating emotionally evocative, challenging learning experiences in their classrooms. Students often reconstruct negative experiences positively, they feel a special sense of accomplishment from being challenged in a particular way, or from being brave enough to even try. Thirdly, building on findings from Anderson and Shimizu (2007), strong affect improves memory vividness, thus emotionally evocative activities are more likely to be memorable and be reflected upon as students make decisions about physics. This research suggests that if students are sufficiently motivated, Physics Olympics and BC's Brightest Minds types of activities can evoke strong emotions and influence student perspectives on physics in new ways. To create this kind of motivation, outside of a large regional competitive event, it would be necessary to create a particular culture within the school, where students can compete without being solely extrinsically motivated (i.e., risk free competition). Currently, many schools hold science fairs, bridge building competitions or robotics competitions all of which have the potential to become meaningful learning experiences such as the Physics Olympics and BC's Brightest Minds, even if they are held in a school or course context.

The results of this study offer support for specific recommendations to be made for competitive events such as these. According to complexity thinking, proscriptive rules or enabling constraints are more generative than recipes or instructions and thus the following recommendations are made using this structure:

1. Participation must not be mandatory or have defined or prescribed roles.

In the case of the Physics Olympics and BC's Brightest Minds events, students who volunteered to participate and were able to choose which events to participate in were more engaged in the event than students who were assigned to the event. Their roles within the team emerged depending on their interests and perceived strengths and weaknesses. Positive emotions of fun and excitement were evoked while they participated and negative emotions of frustration and disappointment when they experienced failure indicated that they were invested in the outcome of the event. From experiencing these emotions students learned about themselves and were able to manifest their individual science identities and particularly strong team science identities. In the case where students' participation was not voluntary, incidents of emotions were experienced less often by the participants, team science identity did not emerge and they did not have the opportunity to explore their interests and build on their skills and knowledge in optimal ways.

2. The activities should be rule bounded and flexible.

The activities designed for the Physics Olympics and BC's Brightest Minds teams were proscriptive in nature in that they were not step-by-step instructions to creating a project or completing a task on the day of the event. Parameters were set and students had to work within them but often there was a large array of possible solutions. Strong emotions were evoked during these types of activities, and shared failures and successes allowed a team to emerge from a group of students, and for individual science identities to emerge from within the team. Thus, this study has illustrated some of the characteristics of design activities that make them particularly generative learning opportunities and complexity thinking has helped to illustrate why these activities stand out in the Physics Olympics and BC's Brightest Minds events.

3. Do not isolate the team in preparation or competition.

Providing an open space where students and teachers interact around the pre-built projects promoted neighbor interactions and opportunities for students' ideas to bump against one another. It also raised awareness of the shared community of practice (Wenger, 1998) of the Physics Olympics team among other levels of complexity that existed within the school such as the physics class and school as a whole. Similarly during the PO and BCBM events, teams should compete alongside each other so that their emotions can interact and amplify each other in the exciting and engaging learning context.

One of the most common observations that students made about participating in the Physics Olympics event was the numbers of students attending. On a Saturday in March, over 500 high school physics students, some of whom had traveled for more than 12 hours, were in attendance. Similarly 50 students work for three hours at an amusement park on challenging physics questions, when they could be simply going on the rides for fun. Students become energized by an awareness that they are part of a larger (complex) system of physics learners by participating in a community of practice (Wenger, 1998). In their high school, physics students usually represent a small group, with only one or two teachers who teach physics and few resources (due to low enrollment) (Neuschatz & McFarling, 1999). One way to make events like the PO, BCBM, and high school physics in general, even more powerful, would be to find ways for teams to interact with each other, either at the event or during preparations for the event. Students stand to learn much from each other's ideas and experiences of physics. This would strengthen the informal community of practice of participating in these events and allow students to make more enduring connections within it, perhaps leading to an increase in the number of students who choose to remain involved in physics beyond high school.

Implications and recommendations have been offered for teaching and learning physics generally (i.e., what can be brought into the classroom context) and more specifically for teachers who are currently, or thinking of, engaging their students in these kinds of competitions, or who are considering creating a competition within their school or district. Emotionally stimulating learning contexts must be carefully created and an awareness of the dynamics of complex systems has many pragmatic recommendations for how to create or manipulate some of the qualities of the system.

Implications for the Study of Emotions in Education

This study employed a theoretical framework, complexity thinking, that has been used implicitly by neurologists to understand the brain and the role of emotion in the emergence of consciousness and identity (Damasio, 1999; LeDoux, 2002). Educational researchers are beginning to recognize complex systems in their classrooms and learning environments (Davis & Sumara, 2006). This study brought together neurological perspectives on emotion and a complexity thinking perspective on learning to contribute to the literature in affective learning in science education. This is timely, given recent calls for new perspectives that are more holistic than constructivist or social constructivist perspectives (Zembylas, 2007). The complexity thinking frame recognized qualities of complex systems and used them to describe the emergence of science identities from expressions of emotion in science outreach contexts. The framework viewed identity as dynamic and adaptive, an idea that has also been proposed from socio-cultural and cultural-historical perspectives (Roth & Tobin, 2007). In the future, complex systems such as these will be more easily recognizable and their qualities can be tinkered with to create generative learning spaces.

This study can particularly contribute to the study of emotion in educational contexts by emphasizing the important role of science identity. An immense amount of research is being done in the area of attitudes and motivations towards science, but this research should be undertaken through a lens of science identity as an overarching construct from which student attitudes emerge. Thus, this work may lead to the development of an analytical model for studying affective learning where emotions, science identities and attitudes, motivations and student decision making are interactive attributes of a complex cognitive-affective learning system. They may exhibit nested structure, where emotions give rise to emerging science identities, which in turn influence other affective constructs. Thus, one construct (e.g., attitudes about physics) cannot be studied in isolation from the others.

The methodology of this study, where emotions were studied using several different data collection methods, is also a significant contribution to the field. Recently Zembylas (2007) called for the use of multiple data collection methods in the study of emotion. This study made connections between the work of psychologists and neurologists who quantify and measure instances of emotion and educational researchers, who observe and describe emotions. Combining these perspectives allowed for the creation of holistic, rich descriptions of the role(s) emotions play in learning.

Future Research Directions

This study has laid the foundation for many different avenues of future research. Building on current work in competitive science outreach contexts, it would be interesting to study non-competitive contexts such as summer camps or co-op work experiences in science-related fields in order to observe the different types of emotions that are evoked and the influence they would have on student science identities and other affective constructs. Similarly, the tasks that have proven to be emotionally stimulating in these contexts should be tested in classrooms to see if there are differences in the emotions expressed, student motivations and engagement. An interesting study would take recommendations from this work to design tasks for classrooms that embody some of the qualities of Physics Olympics and BC's Brightest Minds tasks and test them in classrooms, looking for student emotional responses and evidence of the emergence of perceived science identities.

While the current study intimates that male and female students seemed to experience the same types of emotions, a longitudinal study that systematically follows these students into their post secondary education and participation in related competitions could elucidate any gender factor in evoked emotions and manifest identities.

Calls in the literature for more work in the field of emotions and education (Zembylas, 2007) or affective learning in education (Alsop, 2005b) often argue for the use of mixed methods including both qualitative and quantitative methods. An important extension of this study would be to complement qualitative data with surveys which require students to describe their emotions in a quantifiable way. The interpretations of the researcher would still be present in data analysis but an additional perspective from the students would help to identify the sources and the strength of emotional expressions. It would also uncover emotions that students did not express but which were important aspects of the experience. A study that combines qualitative and quantitative methods could also be designed to probe student awareness of their emotions. If indeed the evocation of emotions is as important as this study suggests, then student awareness of their own emotions and those of their classmates or teammates during learning would be interesting to study in both classroom and informal contexts. This research could lead to the development of techniques for students to track and interpret their emotional responses for improved learning experiences.

The data and analytic framework of complexity employed in this study could lead to the development of assessment tools for stakeholders in science outreach programs to examine the impact of their programs. The results of this work advocate for recognizing the interconnectedness of emotional and cognitive outcomes and emphasize looking at emotion evocation as one way to measure the effectiveness of a program. A longitudinal study to discover what students remember most and which requires them to reflect on their decision making throughout their education and career path would also provide important data for determining the role science outreach programs play in influencing student decision making in physics.

Final Comments

This study undertook the challenge of observing students' emotions while participating in science outreach competitions and drew conclusions about their role in students' science learning. An important aspect of the complex system of student science learning is the construction of science identities and how these identities influence their attitudes, motivations and decision making about science. Science outreach contexts such as the Physics Olympics and BC's Brightest Minds competitions are emotional learning contexts where students' perceptions about stereotypical and individual science identities shift and adapt as they participate in challenging tasks. Future research in science education must pay attention to and value the emotions that students experience and express as they learn science. Currently emotional learning experiences happen primarily in informal learning environments, but classroom experiences can also be developed to nurture the affective domain of learning.

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APPENDIX I

Detailed Descriptions of Physics Olympics Events

Physics Olympics 2006 – St. Elizabeth Secondary

In 2006, a team of four students, Phil, Rob, Brad and Tom, from St. Elizabeth Secondary were studied as they participated in the Physics Olympics. All four students were in Grade 12 and Phil had participated in the event the year before. Table 3 lists descriptions of the activities the team participated in and the order in which they occurred. Since the team was so small, all four students participated in each of the six tasks during the event. However, for the pre-built tasks they assumed different roles. In the weeks leading up to the event Brad did most of the work designing and building the catapult car. Tom helped him with his efforts, but did not contribute many of his own ideas. Phil and Rob focused on the other pre-built challenge, to build an edible musical instrument. At the Physics Olympics event, Phil had the responsibility of performing *Twinkle, Twinkle, Little Star,* for a crowd of judges and fellow participants.

The team's PO experience began with the Electric Maze where they skillfully used a multi-meter to identify the components of a circuit. When their maze was tested at the end they successfully chose two terminals which, when connected, would complete the circuit. The second task was to perform with their edible musical instrument. The whole team, especially Phil who had to play the instrument, were surprised to find that the testing would take place in an auditorium full of people. They were also surprised to find that many teams had an instrument that worked much better than theirs. Phil was extremely anxious about performing, but he did. One other student (who did not consent to the study) helped him by handing him the pieces of macaroni cut to particular lengths, for particular notes, at the right times.

During the next task, Intuitive Physics, the team worked with the computer program to answer the assigned questions for most of the time given. However, most of the team, particularly Phil, became frustrated at the end and left before it was over, since they did not think they could finish it. Tom stayed until the end to answer as many questions as he could. The fourth task, Angular Momentum, asked the students to build an apparatus that would roll the fastest down a ramp by conserving angular momentum.

They did not struggle with this task and tied several other teams for the second fastest design of the group of 10 teams that they competed against in this timeslot.

Table 3: Physics Olympics 2006. St. Elizabeth Secondary.

	Task	Description of activity
1	Electric Maze	Students identify components of an electrical maze with a multi-meter.
2	Pre-Built: Musical Instrument	Pre-built task: Students perform *Twinkle, Twinkle, Little Star* in the key of G on a musical instrument that is entirely edible.
3	Intuitive Physics	Students use a computer simulation program to explore relationships between some unknown variables, to determine the nature of the variables and the relationships governing their behaviour.
4	Angular Momentum	Students have 20 minutes to design an apparatus that conserves angular momentum and travels the fastest down a ramp.
5	Pre-Built: Catapult Car	Pre-built task: Design a catapult car that will travel 3 m and hit a target with a projectile launched using only the energy from two elastic bands and a falling 1 kg mass.
6	Mystery Task	Students use their knowledge of magnetism to use several magnets to propel a small iron ball a maximum distance.

The testing of the catapult car, the fifth task of the day, was an emotional and stressful task for the team. Brad and Tom were surprised to find that they would have to replace the elastic and weight in their design with ones supplied by the judges of the competition. They had five minutes to make the switch and the entire time a judge counted the time down. It was difficult to make the change, but Brad was able to do it in the last few moments. The catapult car did not launch on the first trial, but did on the second trial, unfortunately only moving several centimeters (not the 3 m required by the rules). Brad kicked the car after the second trial and was extremely disappointed that his design did not at least travel 3 m. Brad and Tom knew that they did not have a fully working prototype, but were shaken by having to change the elastic and weight. Finally the last task, the Mystery Task, did not receive the team's best efforts. They were tired and disappointed by their results from the rest of the day. They played with the magnets and ball bearings but did not make a serious effort to answer the questions or complete the challenge. At the end of the day some of the students attended the awards ceremony and found that they actually placed sixth in the Angular Momentum task. They attributed this success to the fact that they tried to answer the written questions that they submitted along with their design, which had tied for second fastest in their timeslot.

Physics Olympics 2007 – St. Elizabeth Secondary

Table 4 describes the tasks, their order during the day and which students participated in particular tasks for St. Elizabeth Secondary's 2007 team. Seven students from a total of ten team members participated in the study, thus not all students participated in each task. Similar the SES's 2006 experience, their PO event began with the Electric Maze. However, their experience with the task was much more challenging since none of the participating students was familiar with how to work a multi-meter. After they worked out how to complete basic measurements with the multi-meter they identified some parts of the circuit, but were not successful at the end when they attempted to complete the circuit and make the diode light up. Their second task, testing their pre-built submarine, was also disappointing. They were shocked when their submarine, which had worked fairly well during its last test at the school, did not sink at all. Some team members admitted to adding some extra foam and to removing one magnet, which contributed to its change in mass. The team was very disappointed with this result.

Next they participated in Intuitive Physics, where the five students who worked on it remained engaged for the entire 45 minute timeslot. In the fourth timeslot, the team tested their lifter, which did not go smoothly. When they brought their prototype to the judges to be measured and tested they discovered that its height exceeded the specifications. The team tried to make adjustments but they altered the lifter's capability to transform the work from 2 L of falling water into energy to lift a weight. They worked very hard to make appropriate adjustments but in the end their lifter did not complete its task.

Table 4: Physics Olympics 2007. St. Elizabeth Secondary

	Task	Description	Participants
1	Electric Maze	Students identify components of an electrical maze with a multi-meter.	Allen, Dean, Glen
2	Pre-Built: Submarine	Pre-built task: Design a submarine that will sink, pick up nails and rise to the surface again without polluting the water that it is in.	Allen, Barry, Elyse
3	Intuitive Physics	Students use a computer simulation program to explore relationships between some unknown variables, to determine the nature of the variables and the relationships governing their behaviour.	Colin, Dean, Frank
4	Pre-Built: Lifter	Pre-built task: Design an apparatus that can perform the maximum amount of work (by lifting a mass) using the potential energy released by 2 L of water falling from a height of 0.75 m.	Allen, Barry, Colin, Glen
5	Optics	Students use principles of optics to design a course of optical elements (lenses and mirrors) to direct a light beam to hit a target.	Barry, Elyse, Glen
6	Mystery Task	Students use a motion detector and computer graphing program to match a velocity time graph.	Colin, Dean, Frank

The final two tasks were more successful and enjoyable for the students. The Optics task had two parts and the team successfully completed the first part before the time limit. They did not successfully align the optical components to hit the target for the second part of the challenge but were still proud of their efforts. The final task, Mystery task, was fun for the students who competed. They understood the motion graph and used their time wisely to fine tune their movements to get an excellent match using the motion detector. Most of the team attended the final awards ceremony and were overjoyed to find that they placed sixth in an optional task, paper tower building, which several students had participated in while they were not competing in other tasks.

Physics Olympics 2007 – Summergrove High School

The events and participating students for Summergrove High School's 2007 Physics Olympics team are summarized in Table 5. This team had few successes during their PO experience. They too did not know how to work their multi-meter and could not get the diode to light at the end. Their pre-built submarine sank, but did not rise again because of a leak in the plastic bag. The team was devastated to see the leak because they were very confident that their submarine would work. They weren't as surprised when their pre-built lifter didn't work. It turned out that they had not measured the 2 L of water precisely enough and required more water to lift the weight. They worked well during the Intuitive Physics task but enjoyed the Optics and Mystery tasks most. During the Optics event they completed the first part of the challenge very quickly and were able to get very close to the target in the second part. The team had practiced and studied optics concepts to prepare for the event and felt that their preparation had paid off. This team too was successful in the Mystery task and appeared to have fun while moving in front of the motion detector to match the graph.

Table 5: Physics Olympics 2007. Summergrove High School

	Task	Description	Participants
1	Electric Maze	Students identify components of an electrical maze with a multi-meter.	Adam, Bob, Cam
2	Pre-Built: Submarine	Pre-built task: Design a submarine that will sink, pick up nails and rise to the surface again without polluting the water that it is in.	Ellen, Fred
3	Intuitive Physics	Students use a computer simulation program to explore relationships between some unknown variables, to determine the nature of the variables and the relationships governing their behaviour.	Cam, Fred
4	Pre-Built: Lifter	Pre-built task: Design an apparatus that can perform the maximum amount of work (by lifting a mass) using the potential energy released by 2 L of water falling from a height of 0.75 m.	Adam, Bob, Diane, Greg
5	Optics	Students use principles of optics to design a course of optical elements (lenses and mirrors) to direct a beam of light to hit a target.	Cam, Diane, Ellen
6	Mystery Task	Students use a motion detector and computer graphing program to match a velocity time graph.	Adam, Cam

Physics Olympics 2007 – Water Hill Academy

The team from Water Hill Academy was selected by their teacher and assigned to participate in the event. Six students participated, thus most students were able to participate in most events. Cora couldn't attend for the whole day, so she did not participate in the afternoon events. Table 6 lists their tasks and participants throughout the day. This team did not do enough preparation for the Physics Olympics in the weeks leading up to the event, thus they had to work all night to complete their pre-built tasks. Secondly their teacher was away the week before the event and the team did not have much assistance interpreting the rules. This led to some problems with their lifter, which contravened many of the specifications when they presented it to the judges. They made major modifications in the five minutes of set-up time that they had, but were not able to create a working prototype. They wanted to test it regardless and when they poured 2 L of water into their design it spilled all over the floor. They expected their pre-built submarine to be more successful as it had worked in their testing at home, however they ran out of the vinegar they were using to create a chemical reaction and the new vinegar that they bought reacted differently. Thus, their submarine was not able to rise to the surface carrying its load of nails.

In the Intuitive Physics, Optics and Electric Maze tasks at least two team members were engaged for most of the activity timeslot, but there were also one or two members who watched from the sidelines. The did not have any successes in any of these three events and by the time they tackled the Electric Maze at the end of the day they were exhausted and unmotivated to participate. Like the other teams in 2007, they were able to complete the Mystery task and appeared to enjoy working on it.

Table 6: Physics Olympics 2007. Water Hill Academy

	Task	Description	Participants
1	Pre-Built: Submarine	Pre-built task: Design a submarine that will sink, pick up nails and rise to the surface again without polluting the water that it is in.	Alex, Beth, Cora, Derek, Eddy, Felix
2	Intuitive Physics	Students use a computer simulation program to explore relationships between some unknown variables, to determine the nature of the variables and the relationships governing their behaviour.	Alex, Cora, Derek, Eddy, Felix
3	Pre-Built: Lifter	Pre-built task: Design an apparatus that can perform the maximum amount of work (by lifting a mass) using the potential energy released by 2 L of water falling from a height of 0.75 m.	Alex, Beth, Cora, Derek, Eddy, Felix
4	Optics	Students use principles of optics to design a course of optical elements (lenses and mirrors) to direct a light beam to hit a target.	Alex, Beth, Derek, Eddy, Felix
5	Mystery Task	Students use a motion detector and computer graphing program to match a velocity time graph.	Alex, Beth, Derek, Eddy, Felix
6	Electric Maze	Students identify components of an electrical maze with a multi-meter.	Alex, Beth, Derek, Eddy, Felix

Physics Olympics 2008 – St. Elizabeth Secondary

Finally, a team from St. Elizabeth Secondary was studied in 2008. Table 7 contains descriptions of the events they participated in. The entire team consisted of students who had participated in the Physics Olympics the year before and three of them were participating in the study for the second time. The day began with the Intuitive Physics task which comprised of several experiments exploring concepts of torque and static electricity. The team split up into two groups to work on the different aspects of the activity, checked each other's work before handing it in, and completed the task before their time was up. The next activity was the Boat Design task. The team was given simple materials to build a boat to transport oranges. They spent most of their 20 minutes planning their strategy and quickly built the boat at the end. They did not test their boat before they had to complete their time trials. Some team members thought that they did not maximize their points by only choosing to transport just three oranges. In the end, the boat did not complete the course because it simply spun in front of the fan. The team was disappointed by this result and agreed that they should have spent less time planning and allotted more time for testing. The third activity before lunch was the team's opportunity to test their first pre-built, a home-made multi-meter. Henry essentially designed the multi-meter on his own. He took several other students into the event with him to help him with the measurements. The apparatus was able to perform the measurements but at the end the results were compared to the known values and Henry found out that his multi-meter was way off. He was very upset and walked away to be on his own for a while. However he recovered quickly and participated in the rest of the competition.

Quizzics was the fourth task the team completed and they did fairly well. They tied several other teams for third place in their group and as they watched the tie-breaker between the top two teams they knew the answers to the tie-breaker questions. They were satisfied with their performance in the Quizzics task. Throughout the day, several members of the team in turn had been working on the second pre-built, the car. Ian, who had already invested a lot of time into the design, sat out of several events in order to work on the car. When he became frustrated and decided that it was useless to try to get it to work, other students stepped in to try something different. In the end, they concluded that it would not be able to complete the 90° turn in the course (powered only by elastics) and decided to remove the second stage of the car and just get it to move forward. The car launched in its two trials, but did not complete the course since it could not turn. The day ended with a Mystery task and for most of it the team had no ideas how to approach the problem. Finally, Elyse suggested something and they were able to build on that to hand in an answer, but they were not correct. After this event, they were quite discouraged that they could not think of an experiment to determine the specific density of a can of pop, but attributed it to being tired at the end of the day.

Table 7: Physics Olympics 2008. St. Elizabeth Secondary

	Task	Description	Participants
1	Intuitive Physics	Students complete several hands-on tasks related to torque and static electricity.	Elyse, Henry
2	Boat Design	Students are given 20 minutes to design a wind powered boat out of simple materials (paper, Styrofoam) that would carry the most oranges in the shortest time.	Barry, Elyse, Glen
3	Pre-Built: Multi-meter	Pre-built task: Design and build a multi-meter from common household materials (magnets, nails, wire etc…) that can measure voltage, current and resistance.	Glen, Henry
4	Quizzics	Students answer quiz style questions in a game show format.	Glen, Henry, Ian
5	Pre-built: Car	Pre-built task: Design a car that will turn 90° half way along a 3 m long course and which is powered by three elastics.	Barry, Elyse, Ian
6	Mystery Task	Students design an experiment (using simple measuring tools and water) to measure the specific density of a can of pop.	Barry, Elyse, Glen, Henry, Ian

APPENDIX II

Sample BC's Brightest Minds Contest Questions

Example 1: The Enterprise

1. Determine the radius of the path followed by a rider on the ride. Explain the steps you followed. (2)

2. Determine the minimum period (T) of the ride. (1)

3(a). What is the speed you would need to prevent riders from falling off the seats of the Enterprise Ride? Explain your answer. (2)

3(b). Is this speed a maximum or a minimum speed? Support your answer. (2)

3(c). What will happen if the ride significantly exceeds the speed from part (a)? What will happen if the ride's speed is significantly lower than the speed in part (a)? Support your answer using principles of physics. (2)

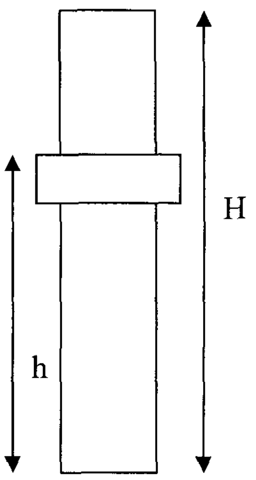
4(a). Determine the speed of the Enterprise ride. (2)

4(b). How do the values in 3(a) and 4(a) compare? (1)

5. Explain whether or not the mass of the rider affects the speed values in 3(a) and 4(a). (2)

Example 2: The Drop Zone

Before taking this ride decide on the kind of data you need to collect (1) from the ground, and (2) during the ride in order to answer questions 3 – 7 below. (**Make sure you don't eat any food right before riding this one! Have fun!**



1. Data from the ground (2)

2. Data during the ride (2)

3(a). Determine the height (H) of the Drop Zone (2)

3(b) Determine how high (h) the cart travels. In 3(a) and 3(b) explain in detail the steps you followed in order to determine the heights. (2)

4. Determine how long the cart takes to travel the height (h). (1)

5(a). In what portion of the ride is the cart accelerating upwards? Referring to the forces acting on you explain how you know. (2)

5(b). At what height relative to the ground does the cart stop accelerating upward? How do you know? (2)

6(a). Determine the time taken by the cart during the upward acceleration. (1)

6(b). Determine the corresponding vertical displacement. (1)

6(c). Determine the upward acceleration of the cart. (1)

7. Using the upward acceleration you calculated and your weight estimate the applied force on you while the ride is accelerating upward. (3)

APPENDIX III

Interview Protocols and Connections to Research Questions

[Relevant research question(s) in brackets.]

Student Demographics:

- What grade are you in?
- What is your favourite subject in school? Why?
- What science and math courses are you taking or have taken at the Grade 11 or 12 level?
- Do you participate in any team sports or extra curricular activities at school?
- What grade do you expect to get in your physics course?

Emotions: These questions will vary depending on whether they are asked during pre- or post-event interviews and depending on which event students participated in.

- Have you enjoyed preparing for the Physics Olympics? Describe some of your experiences. Try to include how you felt during these experiences. [1]
- Are you a competitive person? Can you give me some examples? [1,2]
- Do you like working with groups or as part of a team? Why or why not? [1,2]
- Did you enjoy preparing/participating in the Physics Olympics? [1]
- Tell me about some of your specific experiences? What was it like to do/or prepare for task x? [Go through each task and talk about it specifically. How did you feel when this happened?] [1]
- What was the best moment of the day? When were you happiest, or experiencing good emotions? [1]
- What was the worst moment? When were you experiencing negative emotions? [1]
- Reflecting back on the event, how would you summarize the *experience* in one sentence. [1,3]

Scientific Identity: These questions will vary depending on whether they are asked during pre- or post-event interviews.

- Do you think you *could* be a scientist? Why or why not? [2]
- Do you *want* to be a scientist? Why or why not? [2]
- What experiences do you have with science outside of school? [2,3]
- What characteristics do you have that would make you a good scientist? [2]
- What part of science are you particularly good at? What do you need to improve on? [2]
- What did you learn about being a scientist at the event? [2,3]
- Did you acquire any skills that would make you a better scientist, or did you discover skills you didn't know you had or that would be useful in science? [2,3]

- Has your idea of a physicist changed after attending the event and seeing so many physics students, teachers and professors? [3]
- What did you learn about yourself by participating? [2,3]

Attitudes, Motivations and Decision Making about Physics: These questions will vary depending on whether they are asked during pre- or post-event interviews.

- What kind of science do you like best? Why? [3]
- Why did you decide to take Physics? [3]
- What is your favourite topic in physics or in your physics course so far? Why?[3]
- Describe a really positive experience that you had with physics or with science in general. How did it make you feel? [3]
- Describe a really negative experience that you had with physics or with science in general. [3]
- What are your opinions about physics in general? [1,3]
- What do you like about physics? What do you hate about physics? [1,3]
- Do you think you will take physics next year or in university? Why or why not? [3]
- What did you observe about physics (both the content and the nature or processes) after participating in the activities and attending the event? [3]
- Do you think some of your ideas about physics have changed after competing? If so – how? [2,3]
- What did you learn from participating? About physics? About yourself? [2,3]

General pre-event Interview Questions:

- Why did you want to participate in the event? [1,3]
- Have you participated in a similar type of event? Tell me about it? [2]
- What has been your role in the preparation for the event? How did that come about (working on which pre-built etc....)? [2]
- What are you expecting the event to be like? [1,3]

General post-event Interview Questions:

- Which specific PO tasks did you participate in?
- What were the results? [1]
- Why do you think you were so motivated to participate? [1,3]
- What surprised you? [1,2]
- How did the team perform? [2]

Questions for students who participated in the Physics Olympics before:

- What do you remember about last year's event? [1]
- What was most challenging about last year? [1]
- What made you want to participate in the Physics Olympics again? [3]
- Did participating in the Physics Olympics last year help you at all in your physics course this year, or anything else you've done that's science related? [2,3]

Questions for the teacher/coach:

- Can you describe how you chose each student for the team? (What qualities did each student have that you thought would be beneficial to the team?) [2,3]
- During practices at school did you see any display of emotion related to participating in the event? [1]
- Are there any issues or relationships between the students that would affect how they work together and respond to one another? [2]
- At the event what emotions and attitudes did you see the students display as they participated? [1,3]
- Do you think each of these students will say that they want to pursue further studies in physics (either at high school or university)? [3]
- After the event did you have any relevant conversations (about their emotions and attitudes towards physics) with students about their experiences at the event? [1,2,3]

APPENDIX IV

Sample Interview Transcript

Event: Physics Olympics 2008, post-event interview
Student: Elyse
School: St. Elizabeth Secondary

Res: So thanks again for coming. I know you're tired. The Physics Olympics on Saturday - which events did you participate in?

Elyse: I was in the Boat task, the car (pre-built), Intuitive Physics and Mystery.

Res: Right so it was a busy day for you. What sticks out, what was your favourite out of the four?

Elyse: I enjoyed, well I did like Intuitive Physics because we did the unit, torque, we already did that in class. So everybody was in the room and you knew somewhat what you were doing. So it was kind of like, yeah we double checked everything so it was like, it was good to know something. Being familiar with what we're being asked. So that was good. But I actually did like doing the Boat task, even though we didn't have much time, we were scrambling and it was kind of stressful, but I mean it was fun task that we had to do, so that was good.

Res: What sticks out in your mind for the day?

Elyse: The pre-built car.

Res: What about the car?

Res: Because throughout the whole day we tried to fix it. Because the night before I guess. I mean our design, we realized, it was a really good design, great idea, but it you know really, you had to be really precise, it had to be, you know calculations had to be, lengths of strings had to be like perfect and you know. And we realized that you can't do that not with LEGO, LEGO pieces bend, LEGO pieces break of, the string wasn't perfectly measured out. We realized that it's not going to work so throughout the whole day we'd kind of adjust and see well if we put the peg in half way through, you know and this one full, just to kind of test it out. But I remember during lunchtime and after that it was how can we make this at least move kind of thing. And then when it actually came down to it, we could barely make it move the three meters we didn't wind up doing the two stage car [that turned 90°], we just did the bottom car just to get you know a reading. So we moved maybe like, not much, maybe a meter or something,

Res: So whose decision was that? To just make sure that it goes.

Elyse: I think it was Ian and Mr. John, I believe. They decided, let's just make it go, cause we knew that it wasn't going to execute, so we'd rather actually make a move than just stand still and blow on it go, go, go.

Res: Yeah so I mean, you wanted something to go.

Elyse: Yeah.

Res: What about the team, working as a team this year?

Elyse: It was good this year. I mean obviously during the task when like you have, you're stressed out, you only have couple of minutes, people interrupt each other, they get frustrated. But I mean this year was really good, I think everybody worked well together, and everybody had their word in, paid attention which I think was really important.

Res: Comparing the two years what would you say is different?

Elyse: This year, not only are we all in Physics 12 so we all know a lot more, but I think that since we were all together for, this was like our third competition, we did get along, we did realize oh she knows what she's talking about or she's good at this. Or he's good at that. So it's kind of...we worked better together.

Res: So with the boat, did you try, did someone try it afterwards?

Elyse: No, so the thing we worked so long to plan it out, what if this, what if that, that when we actually started building it, we didn't weigh it out. At all. Like we didn't put it into, we didn't realize how much weight or anything like that so that was I think a big problem.

Res: I found it interesting with the car, how you guys would take turns, kind of like you know at one point in would be so and so's car and at another point, it would be someone else's car.

Elyse: I mean that car, it was frustrating. But I mean, no one got that, we had maybe four people, so it was me, [name withheld], Ian and Barry. I mean we were basically doing the car. Where it was [name withheld] and Ian at the beginning so then [name withheld] took a break and was working with Barry, so I figured out how it works and I added some stuff on with Ian, and later Ian took it home and was working on it for a long time and he was completely frazzled with it and so then I took over and me and Barry took over and [name withheld] took over, you know we all just kind of last minute thinking, What if we do this? Yeah, I mean like we do work together and collaborate on it, but I think it was really at times, like stages where like one person did this, worked on it, ok didn't work, give it someone else. know what I mean.

Res: It probably speaks to you guys having worked as a team a few times, so that someone feels comfortable handing it over, or stepping in, things like that. Because usually what you see with this kind of stuff is that it's either everybody's or one person's.

Elyse: Like Henry with the multi-meter.

Res: Yeah like Henry with the multi-meter, because they've done most of it. What did you learn from this Physics Olympics?

Elyse: Um well I mean, in regards working with people you know. Well in the task I realized that you know you go with your first, simplest idea and go, don't take too long. That applies to the Boat task and also applies to I think the Mystery task because we were so stuck. And I think with Mystery like we were all, we had our ideas, and we were all kind of holding back and no one was saying . The only reason I started saying, well what if we did this, you know cause maybe someone could branch off from that. Like Henry was like yeah, if you do that, then I could calculate you know, and in the end it didn't work out but we had something. I realized that I have to talk and maybe my stupid idea, might be someone's brain wave of an idea. And so.

Res: Yeah that's awesome. Did you learn anything about yourself? I guess you learned that you need to speak up a little bit more. You said you were going to, and you probably did more.

Elyse: I did more. Like I know during the Boat task and stuff I did, but during the Mystery when I was completely stuck and I was kind of iffy, so I guess I still need to come out, don't be shy, don't be shy. Well it's kind of intimidating when you have the top people in your grade that are you know.

Res: You're like well if I've thought of it, they must have thought of it, and decided it's not the right thing. Do you think participating in the Physics Olympics has changed your attitudes towards physics?

Elyse: Every year it does, because every year I will be surprised like oh I didn't know that was part of physics or that's cool I'd like to do that more you know what I mean. Physics, you know, I enjoy classroom physics and doing the calculations, but I also like doing the hands-on cause you kind of apply physics to real life and I love that.

Res: That's great. What was a positive experience from this year's event?

Elyse: Positive experience. I would probably say, well I think that our, I think we all learned, I think this year we also learned like how to work together and I think that's really important because last year we did not have that. We did not have that at all. But this year everybody, I think that's number one what was really good this year, we all worked together.

Res: What was your least favourite event or which one didn't you like?

Elyse: You know what, after, no when the car, when it was the car's turn up, we all knew it wasn't going to go. I mean we did give up by making it just go that first three meters, in a way. Right. So we did that, but that was probably my least, it was fun working on it and designing it and building it but when we realized that it was too complicated, and that it wasn't going to work, I was like you know what, let's just get this event over with.

Res: Did you learn anything about being a scientist at the Physics Olympics?

Elyse: Not in particular, not like being a scientist, but no not really.

Res: Did anything surprise you this year because you went in expecting, like you knew what the Physics Olympics was about?

Elyse: I think the only shock we all had was when we were doing Intuitive Physics task and we all thought it was going to do with magnetism because we all studied that and Mr. John taught us about that, and we went in there and it was completely, it was torque which was good because we did torque, we did it before in December or something like that but it was like, we were all expecting it too and also.

Res: But then there was the static electricity, the other half.

Elyse: Right and we all thought it was going to be on computers right and all of a sudden it's like no you're not in that room. I remember realizing that and being like oh great. We're doing static electricity I think now, the next unit kind of thing and then we're doing electromagnetism. Upcoming. So we're all like, OK, let's use our Grade 10 knowledge and logic.

Res: The only other thing, just in the Intuitive Physics event, in the first part you guys split up, you were really.

Elyse: Yeah because, when Henry works on something he focuses and he knows what he's doing. It's kind of like, no one questions him because we all know that he is, he is probably out of all of us one of the smarter, with calculations and questions, so then me, [name withheld] and [name withheld] took half of the questions and he took the other part and I think Barry and [name withheld] were with him and then what we did is we switched them we kind of you know we fixed up our sentences we did this but yeah we did split that up, it makes more sense because five people working on one question right.

Res: And it looked like, how did you know you could do that like how did you know it didn't build on.

Elyse: I don't know.

Res: Cause it looked like it just kind of happened and then it worked, like you didn't need theirs and they didn't need yours.

Elyse: It was weird but I think cause I know that me and [name withheld] and [name withheld], well me and [name withheld] work well together we realize that you know early so I guess when Barry started doing his, like you know when Henry started working on some sheets, me and [name withheld] were like no we actually want to do something, so we pulled it apart, and he didn't stop us because he was going to check later. I don't know it just kind of happened.

Res: It was just doable I guess, you could do it without looking at what he was doing.

Res: That's all my questions, thanks for participating in the study.

Note: [name withheld] indicates that Elyse is talking a about a student that did not participate in the study.

APPENDIX V

Code Summary Report

Table 8 displays the codes that were used to mine student expressions of emotion in transcribed interviews, microphone data and video data. Coding was completed using NVivo8. Codes are listed in order of frequency of use (called *references* in NVivo8). Other data supplied by NVivo8 includes the number of sources, words and paragraphs. *Sources* is the number of sources (interview transcript, video file, audio file) that the code was found in, *words* is the number of words that were coded if the code was attached to a piece of transcript and *paragraph* is the number of entire paragraphs identified with the code.

References is the most significant count as it represents the number of expressions of a particular emotion. The number of sources represents the range of sources that contained expressions of a particular emotion. Sources range from a 30 sec video clip to a one hour audio clip. There were approximately 300 sources in total.

While four emotion codes appeared more frequently than the others, there were some similarity and overlap between some codes. Thus some codes were collapsed into one code. After collapsing some codes, the same four codes (frustration, fun, excited, disappointment) were much more frequently expressed than others and are summarized in Table 9. The next two most frequent codes are also included to show the comparison in frequency.

Table 8: Emotions Codes and Frequency

Node/Emotion	References	Sources	Words	Paragraphs
Fun	229	100	3616	138
Excited	165	79	2380	44
Frustration	159	80	2457	35
Disappointment	135	67	3927	125
Feeling time pressure	96	56	1510	23
Confident	96	55	2273	52
Enjoyment	96	64	1895	72
Annoyed	89	47	1382	12
Stress	76	53	1521	43
Pride	73	45	1600	48
Anger	69	39	1100	19
Surprise	63	50	1526	42
Confusion	60	38	1135	16
Apathy	52	29	968	11
Worried	51	33	737	6
Satisfied	44	27	1001	30
Fear	35	16	525	2
Nervous	30	21	394	8
Embarrassed	30	18	523	5
Optimistic	24	19	353	14
Regret	20	18	568	12
Sad	20	15	517	20
Concentrating	20	19	283	10
Despair/giving up	19	8	396	7
Ownership	16	10	364	4
Boredom	13	11	312	12
Calm	11	11	221	5
Head shake	10	6	75	0
Negative	9	6	211	6
Anxious	9	8	136	2
Relief	7	6	91	1
Left out	6	4	105	1
Relaxed	5	4	53	5
Comfortable	4	4	179	7
Tired	2	2	34	2

Table 9: Six most frequent emotions codes (after collapsing some codes together) and frequency.

Emotion	References	Emotion	References
Frustration Feeling time pressure Stress	159 96 76	Frustration	331
Fun Enjoyment	229 96	Fun	325
Excited	165	Excited	165
Disappointment	135	Disappointment	135
Confident	96	Confident	96
Annoyed	89	Annoyed	89

APPENDIX VI

UBC Ethics Certificate of Approval

The University of British Columbia
Office of Research Services
Behavioural Research Ethics Board
Suite 102, 6190 Agronomy Road, Vancouver, B.C. V6T 1Z3

CERTIFICATE OF APPROVAL - AMENDMENT & RENEWAL

PRINCIPAL INVESTIGATOR:	DEPARTMENT:	UBC BREB NUMBER:
Samson M. Nashon	UBC/Education/Curriculum Studies	H06-80021

INSTITUTION(S) WHERE RESEARCH WILL BE CARRIED OUT:

Institution	Site
UBC	Vancouver (excludes UBC Hospital)

Other locations where the research will be conducted:
All interviews (3 for each participant) will be conducted at their school. Schools will be from the Vancouver School Board and the CISVA (Catholic IndependentSchools of Vancouver Archdiocese). For Amusement Park Physics competitions students will be observered and video taped at the competition site (Playland, Vancouver, BC)

CO-INVESTIGATOR(S):

David Anderson
Rachel Moll

SPONSORING AGENCIES:

N/A

PROJECT TITLE:
The Impact of Participating in Physics Olympics and Amusement Park Physics Competitions on Student Emotions, Science Identity and Decisions about Physics

CERTIFICATE EXPIRY DATE: February 20, 2009

AMENDMENT(S):		RENEWAL AND AMENDMENT APPROVAL DATE: February 20, 2008
Document Name	**Version**	**Date**
Consent Forms:		
Parent Guardian Consent Form	6	February 6, 2008
Assent Forms:		
Subject Assent form	6	February 6, 2008

The application for continuing ethical review and the amendment(s) for the above-named project have been reviewed and the procedures were found to be acceptable on ethical grounds for research involving human subjects.

Approval is issued on behalf of the Behavioural Research Ethics Board
and signed electronically by one of the following:

Dr. M. Judith Lynam, Chair
Dr. Ken Craig, Chair
Dr. Jim Rupert, Associate Chair
Dr. Laurie Ford, Associate Chair
Dr. Daniel Salhani, Associate Chair
Dr. Anita Ho, Associate Chair

APPENDIX VII

Research Approval from Vancouver School Board

VSB Vancouver School Board
School District No. 39 (Vancouver)
LEARNING SERVICES
1580 West Broadway
Vancouver, B.C. V6J 5K8
Telephone: 604-713-5000
Fax: 604-713-5244

April 30, 2007

Rachel Moll
c/o Curriculum Studies
UBC Faculty of Education
2125 Main Mall
Vancouver, B.C. V6T 1Z4

Dear Rachel,

Thank you for your research proposal on "The Impact of Participating in Physics Olympics and Amusement Park Physics Competition on Student Emotions, Science Identity and Decisions about Physics". On behalf of the VSB Research Committee please accept this letter as approval for you to complete your research in Vancouver schools. You have permission to contact teachers and students in the Vancouver district. We request that you make your initial contact with the principal of the school to inform them of your study and provide them with a copy of this letter.

The VSB Research Committee would be very interested in learning of your results and its implications for students. When your research is completed please send us an abstract of the results.

Thank you for focusing your work within the Vancouver School District. I wish you the best of luck as you proceed with your inquiry.

Sincerely,

APPENDIX VIII

Research Approval from School District No. 36 (Surrey)

School District No. 36 (Surrey)

Superintendent's Department
14225 - 56th Avenue, Surrey, BC V3X 3A3 • Tel: (604) 596-7733 Fax: (604) 596-7941

May 17, 2007 File: 21000-01 (R&E)

Rachel Moll
[illegible]
Vancouver, BC
[illegible]

Dear Rachel Moll:

Re: The Impact of participating in Physics Olympics on Student Emotions, Science Identity, and Decisions about Physics.- additional venue "BC's Brightest Minds Contest Participants.

Please use this letter as confirmation of acceptance of your research project in principle. As you know, district level endorsement does not imply commitment of individual schools, students or other participants and you are required to seek consent, sequentially of those involved.

I wish you every success with your research and remind you that a final report is to be submitted to this department on completion.

Yours truly,

APPENDIX IX

Sample Consent Form

Department of Curriculum Studies

The Impact of Participating in Physics Olympics and Amusement Park Physics Competition on Student Emotions, Science Identity, Attitudes and Decisions about Physics

Principal Investigator: Dr. Samson Nashon, Assistant Professor, Department of Curriculum Studies, Faculty of Education, UBC, 604-822-5315
Co-Investigators: Rachel Moll, PhD student, Department of Curriculum Studies, Faculty of Education, UBC
Dr. David Anderson, Assistant Professor, Department of Curriculum Studies, Faculty of Education, UBC

Contact Information: Rachel Moll, 604-822-2302

Purpose of Research: To investigate the emotions, attitudes towards physics and scientific identities of teams of Grade 11 and 12 Physics students before and after participating in the Physics Olympics at UBC on March 3rd , 2007(three teams) and March 8th, 2008 (one team) and three teams of Grade 12 students participating in BC's Brightest Minds competition. The results will be published in academic journals and conferences and will comprise part of Rachel Moll's PhD thesis research.

Choice of Participants: The teams chosen for this study has been randomly chosen from teams volunteered by the teacher to participate in this research. Team members were chosen by their teacher to represent their classes and school at the Physics Olympics and BC's Brightest Minds.

Study Procedures:
1. Teams of Grade 11 and 12 students and their teacher will be chosen to participate in this study.
2. Your child will be interviewed three times, before the event, immediately after the event and one month after the event.
3. Your child will be interviewed individually. Interviews will take between 45 minutes to 1 hour, will take place at the school during school hours and will be video taped and transcribed.
4. Your child will be video taped during the event and field notes will be taken by the investigators.

5. Your child will be able to check and modify the transcripts of interviews and observations and will be asked to clarify meanings and interpretations.
6. Including all interviews your child will not spend more than 2 hours participating in this research.

Confidentiality: The identity of your child will be kept confidential. Publications of data and results will not identify the teacher, school or names of participants. All documents will be identified only by code number and will be kept in locked filing cabinets. Digital data records will be kept on password protected hard drives. Only the principle investigator and the co-investigators will have access to the data.

Contact information about the study: If you have any questions or desire further information with respect to this study, you may contact Rachel Moll at 604-822-2302.

Contact information about the rights of research subjects: If you have any concerns about your child's treatment or rights as a research subject, you may contact the Research Subject Information Line in the UBC Office of Research Services at 604-822-8598.

Consent: Your child's participation in this study is entirely voluntary and your child may refuse to participate or withdraw from the study at any time without jeopardy to their standing in Physics 11 or 12 or participation in the event as a member of the team. Members of the team who do not consent will not be interviewed and will not be videotaped at the event. They will still be able to participate fully in the competition event.

Your signature below indicates that you have received a copy of this consent form for your own records.

Your signature below indicates that you consent to your child's participation in this study.

I consent/I do not consent (circle one) to my child's participation in this study.

____
Subject Signature Date

____
Printed Name of Subject

____
Parent or Guardian Signature Date

____
Printed Name of Parent or Guardian