They Blinded me with Science!:
Promoting a Community View of the Nature of Science for Science Education

Kamran Shaikh

A Dissertation

In the Department

of

Education

Presented in Partial Fulfilment of the Requirements
For the Degree of
Doctorate in Philosophy (Educational Technology) at
Concordia University
Montreal, Quebec, Canada

March 2014

CONCORDIA UNIVERSITY

School of Graduate Studies

This is to certify that the thesis prepared

By: Kamran Shaikh

Entitled: They Blinded me with Science!: Promoting a Community View of the Nature of Science for Science Education

and submitted in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY (Educational Technology)

complies with the regulations of the University and meets the accepted standards with respect to originality and quality.

Signed by the final examining committee:

______________________________ Chair
Dr. Roberto Viereck-Salinas

______________________________ Examiner
Dr. Richard F. Schmid

______________________________ Examiner
Dr. Robert M. Bernard

______________________________ External Examiner
Dr. Anila Asghar

______________________________ External to Program
Dr. Sandra Chang-Kredl

______________________________ Supervisor
Dr. Vivek Venkatesh

Approved by ______________________________
Dr. Ann-Louise Davidson, Graduate Program Director

____
March 19, 2014 Professor Joanne Locke, Dean of Faculty

Abstract

They Blinded me with Science!: Promoting a Community View of the Nature of Science for Science Education

Kamran Shaikh
Doctorate of Philosophy (Educational Technology)
Concordia University, 2014

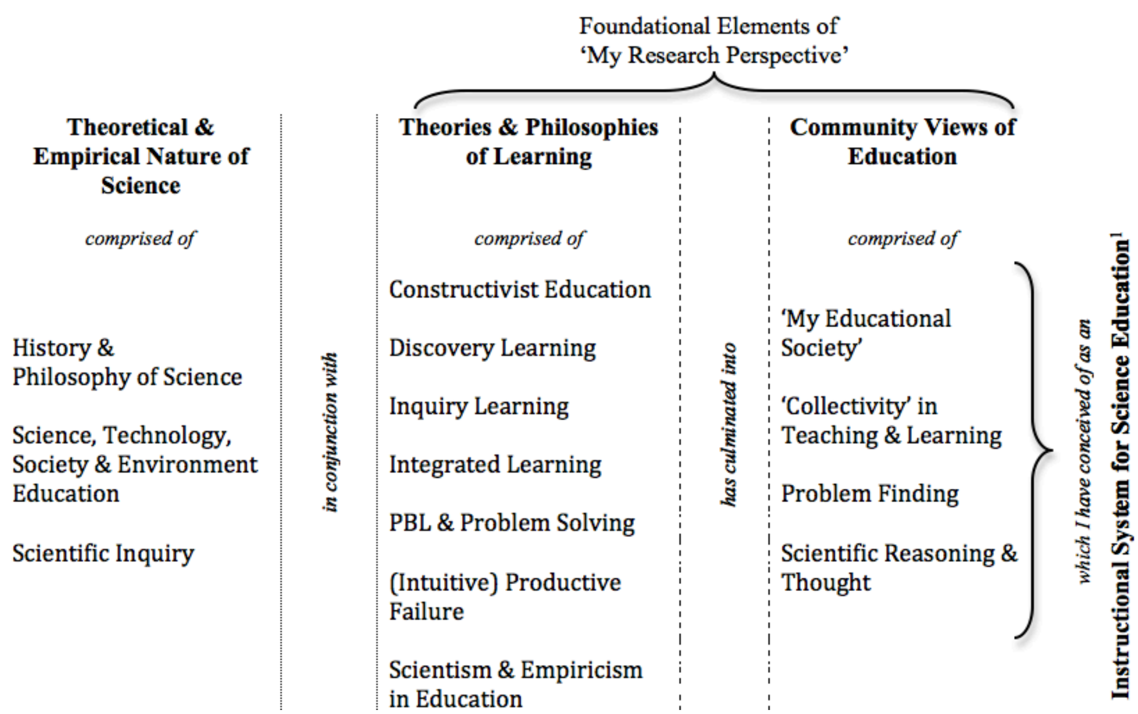


Figure 1: Abstract Detailing Framework for Research Paradigm

[1]Consists of a series of educational events and tasks which reflect a multi-faceted view of science as a function of science education; one of such activities, the 'Cooperative Concept Map' will be investigated as a culminating task for the promotion of collective criticality and reflection for the development of pre-service elementary science educators.

The purpose of this dissertation is fourfold: a) to synthesize and analyze literature defining current approaches to science education, its epistemic pedagogical systems (Nature of Science; inquiry, discovery and integrated learning) and to propose a pedagogical lens to focus their instruction; b) to situate the nature and role of science education within the greater realm of educational endeavour and to propose a structure

for the development of community views of science through guided collective reflection and introspection; c) to present and critique a system of science conception known as 'Community Views of Science' (CVOS) from a pedagogical, epistemological and empirical standpoint; and d) to empirically and theoretically dissect and interpret each interconnected constituent element of CVOS.

To expand upon 'd)', a qualitative exploration and analysis of cooperative and individual concept mapping activities with undergraduate pre-service elementary learners (N=55) from Concordia University's Department of Education will demonstrate that self-actualization of collective views of science can possibly be fostered by instructional strategies embedded in an instructional system designed for the actualization of epistemic belief systems.

This exploratory study of pre-service educators will address the following objectives. First, explore and analyze interpretations of concept maps and concept mapping, as well as the affect of concept mapping analysis on epistemic realization and self-actualization. Second, explore, analyze and test the affect of cooperative concept mapping on epistemic realization, self-actualization and the development of a 'Community View of Science'. Third, elaborate upon the use of cooperative concept mapping within pre-service elementary science educator classrooms to reflect the methods, processes, approaches, purposes, structures and systems of science as related to science education. Fourth, reflect on and discuss the nature of philosophical and empirical inquiry while 'breaking methodological boundaries' as defined by traditional qualitative research.

With tenets from the ‘Nature of Science’ as the eventual goal of ‘Community Views of Science’, results of this exploratory study pinpoint potential uses for and associated outcomes of cooperative concept mapping as a culminating task for the development of epistemic malleability within pre-service elementary science educators (the inherent ability to begin questioning personal views of science so as to develop a healthy scepticism for and criticality towards science as a solution).

Acknowledgements

This treatise was afforded through the freedom to challenge academic boundaries, a privilege imparted by my supervisory committee—Dr. Vivek Venkatesh, Dr. Robert M. Bernard and Dr. Richard F. Schmid. I hope to mirror your deft as I continue to navigate the fringes of educational thought.

My most sincere thank you (apart from my wife, Vero) is reserved for my participants and students—those poor souls who endure 'walking alongside' as we meander through my pedagogic odyssey.

For my offspring:

I made you, yet you made me who I am.
Live with it.

Dedicated to my sons
—Caxy and Ichi—
For teaching me of fatherhood and for questioning my learning.

Table of Contents

List of Figures

List of Tables

Glossary

CCM	Cooperative Concept Map (instructional strategy developed and explored)
CMA	Concept Map Analysis (instructional strategy and source of comparative data for CCM)
CVOS	Community Views of Science (instructional system developed and explored)
NOS	Nature of Science (epistemological 'goals' of science education)
QEP	Quebec Education Program (Quebec curriculum, associated resources and documents)
SCSI	Socio-Critical Science and Inquiry (elaboration and extrapolation of CVOS as an epistemological approach for science and science education)
STEM	Science, Technology, Engineering and Mathematics (contemporary approach for science education)
STSE	Science, Technology, Society and the Environment (approach for science education)
VNOS	Views of the Nature of Science (questionnaire exploring NOS beliefs)

Preface: Pedagogue All Day, Researcher At Night

My teaching over the past seven years within Quebec's three major English language post-secondary institutions—Concordia, Bishop's and McGill Universities—has afforded the frame of reference which will be described in this dissertation study. My role as a facilitator for over twelve methodology courses (26 course section in total) in pedagogy, mathematics and science is the foundation for the development of my research program.

I believe an educator's role is threefold—to initiate and encourage critical thinking through promoting and facilitating meaningful interactions within discourse communities in hopes of evolving current paradigms and understandings towards what learning is, what can be learned and how—all with the larger goal of building and fostering a community of learners. Dialogue, being at root of most forms of inquiry, centres upon the need to foster a collective understanding of the discourses and counter-discourses which currently govern the academic and scholarly interpretations of Education and its supporting frameworks.

My role as an academic pedagogue is to facilitate the development of critical perspectives surrounding pedagogical interpretations (and practical applications of them, for example, classroom uses) while recognizing their foundational role within the realm of instructional design, pre-service teacher development and education in general. Such can be achieved through a rudimentary scientific procedure—systematically analyzing primary literature and defining applicability of discussed theories and designing, developing and evaluating educational materials.

My main goal as an educator is to ensure that I am available and willing to engage in reciprocal dialogue which is personally fostered through an embedded reliance upon self-actualization as a central facet for self-criticality and therefore critical thinking—doing so has resulted in an ongoing commitment to my students and reliance upon self-reflexivity as a base for academic and scholarly growth and development.

Education in a larger sense, from a ‘Hollywood-esque’ interpretation, is in need of a ‘rally cry’, a call to arms where we divulge our expectations and biases whilst regulating ‘the classroom’ as the key environment where educators occupy dreaded front lines to advocate, promote and reinforce our inner-most altruistic educational ideals—to not only inspire our students, but to promote individuality through collective uniqueness. With such a perspective, it is no wonder that I enter each class, each course and each day with creativity, energy, youthful exuberance and a passion to teach.

Introduction: I Once was Blind, but Now I See

There are moments in the evolution of scientific paradigms which call for moving beyond what the paradigm can offer—examples include, but are not limited to the progression from dated views of planetary orbits to a greater conception of Copernican Heliocentrism, defining the limits of Galilean relativity to allow for the development of Newtonian mechanics or acknowledging the shortcomings of Newtonian physics when compared to theories of universal law rooted in relative physics. What remains distinct and similar throughout such paradigmatic shifts and what allows for the evolution of theoretical interpretations are the inadequacies of a given paradigm to provide conscientious and comprehensive solutions to problems or gaps within our understanding of nature.

Through in-depth analyses of our natural environment 'scientists' have progressed both technologically and societally in hopes of finding solutions to our existential plagues. Through extended explorations and examinations of nature, scientists (e.g. educators and researchers) have developed seemingly steadfast methods governing how they have come to interpret our environment. These methods, rooted within scientific principles, reinforce an air of verification and confirmation as the only means to determine fact and truth.

As pedagogues, our role within an educational system is to promote positive citizenship (Dewey, 1915; Gilbert, 2013; Hestenes, 2013; Zeidler, Berkowitz & Bennett, 2014)—to develop learners who are capable of furthering the greater body of developed knowledge (those who have the requisite skills and ability to do so) (Pedretti & Nazir, 2010). To achieve such a goal, educators and researchers employ a variety of pedagogical strategies and approaches which may facilitate the ingraining of our knowledge production processes and systems within our learners (Klopfer & Cooley, 1963; Abruscato, 2004; Davies, 2010; Rosenblatt, 2011).

Within science education, there exists a need to foster the development of learners who are aware of their role within educational systems and scientific processes—the development and interpretation of new scientific knowledge—this dissertation contends that the field of education is currently wrestling with a moment of paradigmatic disequilibrium. This has methodically led to a need for a refined lens for the interpretation of science and science education.

From such epistemological (culminating theoretical and philosophical) roots the purpose of this dissertation is fourfold:

a) To synthesize and analyze literature defining current approaches to science education, its epistemic pedagogical systems (Nature of Science (NOS); inquiry, discovery and integrated learning) and to propose a pedagogical lens to focus their instruction (see figure 1, 'Theoretical & Empirical Nature of Science' & 'Theories & Philosophies of Learning')
b) To situate the nature and role of science education within the greater realm of educational endeavour and to propose a structure for the development of community views of science through guided collective reflection and introspection (see figure 1, 'Community Views of Education')
c) To present and critique a developed system of science conception known as 'Community Views of Science' (CVOS) from a pedagogical,

epistemological and empirical standpoint (see figure 1, ‘Instructional System for Science Education’)

d) To empirically and theoretically interpret each interconnected constituent element of CVOS (see figure 1, footnote 1)

Theoretical Framework: Situating within an Educational Paradigm

Collectivity in Teaching & Learning: Promoting a Critical Community

Science is as we know it?: Traditional & contemporary approaches to science education. Traditional conceptions of science education are structured through and rooted within three overarching educational principles. Behaviourism characterizes the learner as a black box, seeks to analyze and interpret contextual and environmental factors promoting or inhibiting learning in response to direct or indirect stimuli; cognitivism, which sees the learner as interpretable and analyzable—essentially a white box or mind to be understood from both psychological and scientific perspectives; and constructivism, which delves into and seeks to interpret interactions between these three frameworks while paying particular attention to the roles of major stakeholders—learners, teachers, institutions and communities (see Table 1: ‘My Educational Society’) (Ertmer & Newby, 1993; Jonassen, 1991; Phillips, 1995; Skinner, 1968). An epistemological view of constructivism reflects, in most part, an overarching goal to analyze and interpret the need for and role of collective thought in knowledge building—to inform educational thought and practice regarding the creation of communities of learning (Hyslop-Margison & Strobel, 2008; Phillips, 1995).

Contemporary pedagogical design for science education extracts methods and processes from the above, in hopes of developing practically relevant, informed approaches for the design of science instruction. Approaches, which include the inquiry, integrated, discovery and problem-based have been employed as a means to ensure the integration of the scientific method, multiple content-specific areas and pragmatic learner involvement for the development of educational programs, materials and environments (Abruscato, 2004; Davies, 2010; Tobin, Tippins & Gallard, 1994; Herman, Clough & Olson, 2013). Examining such learners within their pedagogic communities and the dissection of interactions at various structural levels highlights the need for a learner-centred framework exploring collective individuality within our educational structures; a shift regarding how prominent stakeholders of this structure personify and envision the learner—not solely as an element of an environment, but as a member of an educational community and society (Phillips, 1995; Hyslop-Margison & Strobel, 2008; Wegerif, Postlethwaite, Skinner, Mansour, Morgan & Hetherington, 2013).

Though widely promoted in science classrooms, each of these science education approaches inculcates within learners a varying perspective of science, rooted in the scientific method without placing conscientious importance on their role as critics of 'proven', proceduralized scientific thought (Klopfer & Cooley, 1963; Phillips, 1971; Clark, 1990; Bauer, 1992; McComas, 1996; Abdelkhalick, 2006; Ledermann, 1992, 2007; Gilbert, 2013).

Inquiry-based approaches to science education focus on developing inquiry process skills, specifically defining a problem, hypothesizing, observing, interpreting and analyzing observations and implementing outcomes of observational analyses. The integrated approach or cross-curricular perspective to science details its inherent overlap with other major educational fields (e.g. Mathematics, Social Studies, Technology, Language Arts and Fine Arts). The discovery approach reflects hands-on, practical, pragmatic science—learning through individual engagement with nature and building knowledge through active participation with the environment (Tobin, Tippins & Gallard, 1994; Colburn & Clough, 1997; Abruscato, 2004; Davies, 2010).

Theoretically informed pedagogical practice which provides learners with scenarios and situations for problem solving, affords young minds the opportunity to actively engage in scientific inquiry whilst developing a cursory understanding of scientific modes of inquiry and thought (Davies, 2010; Rosenblatt, 2011; Gilbert, 2013). Research in science education has long promoted that a combination of integrated, inquiry and discovery approaches can foster the development of learners who harness the knowledge and ability to 'understand science' (Klopfer & Cooley, 1963; McComas, 1996; Abdelkhalick, 2006; Ledermann, 1992, 2007).

To elaborate how research has come to interpret the inner workings of science as a socio-collective process, there is a need to develop pedagogical practices fostering the development of critically aware science educators who embody the nature and role of critical citizen scientists (Gabel, 1994; Irwin, 1995; Roth, 1997; Shaikh & Zuberi, 2012). These theoretically derived approaches extracted from and rooted within interpretations of educational psychology and misinformed pedagogy are not in any way comprehensive reflections of the greater social implications of science.

Through a collective view of science, this research seeks to reconcile the practical, pedagogical and socio-collective understatements of these approaches through a system exploring the nature of scientific inquiries and endeavours in the creation and development of an educational society.

Nature of science, scientific transparency & pedagogy. Science, as defined by research in science education is perceived by the masses as true science, rooted in positivistic principles (Abdelkhalick, 2006; Ledermann, 1992, 2007). Traditional true science and the scientific method, which is the structural foundation and applied mechanism for exploratory scientism, depicts a generalized approach for describing or examining concepts, constructs, contexts and so on (Phillips, 1971; Popper, 1985; Bauer, 1992; Abruscato, 2004; Rosenblatt, 2011). Through the research proposed in this dissertation, it is hoped that guiding learners to become aware of their epistemic belief systems, specifically those related to the inner workings of science and the post-structural discourses which articulate it (Foucault, 1980), will better prepare them to analyze scientific knowledge production and therefore assume prominent roles as members and creators within it—allowing science to evolve from 'true' to 'communal' (Wegerif et al., 2013; Zeidler, Berkowitz & Bennett, 2014).

Scientific transparency further elaborates a post-positivistic perspective of science education and rectifies inherent Popperian (1985a; 1985b; 1985c) problems with the scientific method (Bauer, 1992; Gabel, 1994; Phillips, 1971). If true science can be conceived of as positivistic application, then communal thought and knowledge building through community-based approaches can be seen as post-positivistic science education (Phillips & Burbules, 2000; Aduriz-Bravo, 2013; Wegerif et al., 2013). This dissertation calls for the refining of science education—for a pedagogical approach which reinforces a post-positivistic approach to scientific knowledge building within educational curricula.

Moving from passively interpreting scientific information to actively engaging in the development and construction of such knowledge—fostering and instilling a 'community view of science'

A post-positivistic, community view of science can promote the development of aware citizens who are able to realize their role within greater societal structures (i.e. 'a cog in the machine') and interpret as well as divulge discursivity amongst the masses (i.e. 'to rage against the machine') (Foucault, 1977a). Our current epistemic system in science classrooms is the over-used and under-interpreted 'Nature of Science' (Klopfer & Cooley, 1963; McComas,1996; Alters, 1997; Abdelkhalick, 2006; Ledermann, 1992, 2007; Davies, 2010; Gabel, 1994; Irez, 2006; Rosenblatt, 2011; Roscoe & Mrazek, 2005). Of particular concern within NOS-based systems, is the lack of a thorough post-structural, socio-collective framework which governs how science affects the greater goals of society, as well as its impact on the environment or technological and social evolution.

Through community perspectives, as a lens for the interpretation of NOS, individuals are afforded the necessary dialogue to expose universal discourses governing how individuals are made to think, act and be (Foucault, 1977a; Cohn, 1987; Alters, 1997). Such dialogue can empower individuals to interpret scientific discourse, pinpoint and exploit flaws in structural integrity to initiate a shift in thought—once again moving within the spectrum from true science to community science (Hestenes, 2013; Wegerif et al., 2013).

Community views of science, as a lens for the interpretation of the nature of science. Promoting a collective view of science also involves the use of science objectives rooted in the Science, Technology, Society and the Environment framework. These objectives include promoting: a) social responsibility; b) critical thinking and decision making skills; c) an ability to formulate sound ethical and moral decisions about issues arising from the impact of science on our daily lives; and d) knowledge, skills and confidence to express opinions and take responsible action to address real world issues in science (Aikenhead, 1994; Roscoe & Mrazek, 2005; Pedretti, 2010; Hestenes, 2013; Zeidler, Berkowitz & Bennett, 2014).

Theoretical and practical divergences inhibit progression to an epistemological approach for science education. Through a combination of extensive practical experience guiding pre-service elementary educators and current research on approaches to science education (e.g. Roth, 1997; Martinet, Raymond & Gauthier, 2001; Irez, 2006; Nesbit & Adesope, 2006; Novak & Canas, 2006; Neumann, Neumann & Nehm, 2011; Herman, Clough & Olson, 2013), this research contends that there is a need for a renewed epistemic system or collective view which reflects the structure of the scientific community, the intricacies associated with teaching NOS and the potential negative outcomes of science as detailed through STSE (Klopfer & Cooley, 1963; Aikenhead, 1994; McComas, 1996; Abdelkhalick, 2006; Ledermann, 1992, 2007; Roscoe & Mrazek, 2005; Pedretti, 2010; Gilbert, 2013).

A thorough understanding of major principles in NOS—which include assertions regarding scientific knowledge being tentative; the confounding nature of facts, theories and hypotheses; scientific methods; inextricability of observations and inferences; and nature of human error—is key when considering the overall development of socio-critical science educators (Martinet & Gauthier, 2001). It describes how the system of science works and how individuals can be critical members within this system (e.g. Klopfer & Cooley, 1963; Canguilhem, 1968; Latour & Woolgar, 1986; Irwin, 1995; Kuhn, 1996; McComas, 1996; McDermott, 1996; Phillips, 1971; Popper, 1985a; 1985b; 1985c; Roscoe & Mrazek, 2005; Abdelkhalick, 2006; Ledermann, 1992, 2007).

To further the conceptual development of post-structural, constructivist science education, it is proposed that epistemological reflection reinforces our understanding of how NOS, though in need of a lens to focus science educators interpretation, can be expanded to include or elaborate the goals of science education as extracted from STSE (Aikenhead, 1994; Pedretti, 2010).

The following 'beginnings' of an instructional system representing the teaching of science in elementary (and pre-service elementary educator) classrooms has been developed to further foster and expound the promotion of a collective view of science. This becomes essential when considering the goals of our science education community, to develop citizens who are able to understand and use science.

As a system, 'Community Views of Science' (CVOS) distinguishes epistemology rooted in theories and principles extracted from traditional and contemporary science education. A sound pedagogical approach would include promoting, maintaining, evaluating and criticizing the collective view. It can be described as follows:

- Social nature of facts, hypotheses and theories: This can be interpreted as a reflection of the assumptions which frame scientific communities—each assumed theory is rooted within paradigmatic assumptions and approaches which govern interpretation and implementation. Facts, hypotheses and theories should be questioned, as should their inculcation in society.

- Social nature and inextricability of observations and inferences: Seeing how scientists are not independent go-getters toiling away in laboratories, reflecting on the nature of paradigmatic thought, collective observations and inferences is of importance. Working within a particular paradigm would involve belief in paradigmatic assumptions and theories which limit objectivity and impartiality in observation (Canguillhelm, 1988; Kuhn, 1962; Latour, 1986). Through collective observations or working with a paradigm, science will be better suited to deal with paradigmatic flux and eventual gestalt shift.
- Empiricism and objectivity through methods and processes: Such a perspective would have learners reflect on whether objectivity can be achieved or whether it is an integrated facet of the methods and processes individuals employ to reach scientific conclusions. This element allows for open discourse regarding the 'lens of objectivity' created through set generic processes of examination and exploration.
- Pervasiveness and dilution of human error: Error is omnipresent in our frame of scientific thinking and nothing less than a paradigmatic shift will result in the acceptance of human error and scientific misunderstanding (consider the move to Copernican Heliocentrism; Galilean to Newtonian mechanics; Newtonian to Relative physics). Human error within science shatters paradigms and results in a reframing of what has been conceived of as science. Of concern is how human error is diluted through collective scientific discourse—scientists solving similar problems are more willing to

accept error and dilute its effect on the paradigm when the foundation of the paradigm becomes challenged—a paradigmatic shift involves questioning a set of beliefs which structures how a given paradigm has been conceived.

- Socio-collective nature and impact of knowledge as being a tentative entity: The above elements cast doubt on the overall nature of what science can offer for societal evolution—conceiving of and promoting knowledge as tentative reinforces the perception of error in science. If our knowledge is tentative then are outcomes and implications tentative as well?
- Unforeseen impact of scientific knowledge and endeavours: New science, be it evolution in methods of natural resource extraction and manipulation, integration and adoption of technology within communities and society or physiological and psychological interpretations of the human mind can have a widespread direct negative impact. For example, misconstrued perspectives of human intelligence and ability resulted in the squandering of considerable effort and resources to solve problems which were misguidedly conceived.
- Need for scientific transparency and a shift to science as community science: Through transparent science, users are critical of scientific knowledge, are aware of its source and the processes through which it is developed and governed. Evolving scientific thought so its foundation is rooted within community science will reflect the true socio-collective nature of science.

Current epistemological thought regarding the nature of scientific inquiry does not allow for an epistemological shift to occur. In reality, the scientific community fails to acknowledge that our current epistemic systems and structures of scientific exploration are rooted in assumptions—assumptions which at times are contradictory themselves.

For example, when reflecting on how our universe came to be, Einstein contended that our "…quantum system was philosophically and mathematically unequipped to exist in the same universe with general relativity"; that two seemingly irreconcilable areas of physics need to co-exist before we can begin conceiving of how the universe came to be and functions (Boslough, 1989, p. 47).

Problem finding. Problem-finding re-examines the notion of 'mop-up artists' from the Kuhnian (1996) perspective—scientists as 'artists', solving defined problems within their working paradigms. To delineate the boundaries of and work within a paradigm, scientists seek to solve minute, distinct problems which appear through the evolution and interpretation of the existing framework. As an increasing number of scientists work within a particular paradigm, problems or moments of exploration emerge. How they emerge, how they are deemed to be problems in need of a solution is the central facet of problem finding—a misunderstood and under-explored phenomenon. Problem finding and the nature of the problem found is rooted within adopted epistemologies and can be conceived of as a reflection of how we, as scientists, interpret our role in a given situation.

Problem solving in science education has generally focused on the use of discrepant events as a means to highlight discrete connections between seemingly divergent science topics and ideas (Tobin, Tippins & Gallard, 1994; Abruscato, 2004; Roscoe & Mrazek, 2005). Doing so encourages learners to search for and describe the context to be explored and the content knowledge required to interpret that particular context. Discrepancy, in most cases, is meant to reflect a single mode of thinking and reasoning—learners are expected to prescribe to similar processes in an attempt to derive similar explanations and solutions (Hadzigeorgiou, 2013; Gilbert, 2013)

This research contends to, within CVOS, enforce and encourage the use of 'discrepant scenarios'—where learners must not only search for and describe contextual elements and content knowledge, but where they must also begin to consider the limits and boundaries of the problem situation they are being asked to solve—to 'find' as well as 'solve' problems. Such scenarios would allow learners to develop and maintain their own reasoning process to define problems in need of focus. Within some pedagogical contexts, learners can also be encouraged to participate as members of collectives aiming to solve similar problems within divergent or convergent contexts—the class as a whole can target 'gaps' paradigmatically and learners can target 'solutions' contextually.

(Intuitive) Productive failure. Learning sciences literature is divided as to how much and what kind of scaffolding or support should be provided to learners engaged in ill-structured problem solving (Kapur, 2008). Current instructional methods implemented in our universities do not provide post-secondary learners with the appropriate tools and approaches to engage in ill-structured problem solving and therefore fail to instil the ability to dissect and interpret the nature of the task. Ill-structured tasks refer to academic activities which have multiple solutions and where the instructor provides little to no initial scaffolding or guidance—learners are left to independently derive tasks to determine individualized processes for completion.

As an added theoretical element in the proposed research, productive failure (Kapur, 2008), a pedagogical concept intuitively applied throughout undergraduate and graduate courses during my tenure in academic instruction, focuses its efforts on facilitating learning amongst learners by forcibly having them tackle ill-structured problems well-beyond their academic ability to derive a solution for. Through empirical research rooted in cognitive science, Kapur has identified learner abilities requisite to overcome individual dissonance as well as learned processes employed for the interpretation of problems where little or no guidance or scaffolding is provided. Such moments of dissonance, similar to those created by discrepant events, are pivotal in how learners begin to conceive of ill-structured tasks and are in need of exploration through a perspective structured through CVOS (Hestenes, 2013; Gilbert, 2013).

This dissertation contends that an instructional system which makes effective use of the tenets prescribed by productive failure, in conjunction with varying elements extracted from my community views can further explore and explain the distinct element of 'hidden efficacy' (Kapur, 2008), especially with regard to tasks embedded in science education.

An Epistemological Autobiography: Situating My Research Program in Educational Theory

Defining Practitionership: 'My Educational Society'

From Dewey (1900; 1897), Friere (2000), Tagore (1998) and Foucault (1977; 1980), to Rosenblatt (2011), Hyslop-Margison & Strobel (2008), Gilbert (2013) and Zeidler, Berkowitz & Bennett, (2014) it can be argued that the role of education is to promote the development of critically-aware and informed citizens who understand their underlying role within the structures that exist and to enact and embody knowledge so they may be proponents of social harmonization.

Acknowledging roles of and interactions between the four members of ‘My Educational Society’ (e.g. instructors and learners—used to represent the inherent power relationship with regards to the transmission of knowledge; institutions—extended relationship between theory and practice, curricula-driven procedures, guidelines, missions, role and nature of the ‘school’; communities, micro-to-macro learning communities—classroom community, school community and research community) can facilitate: a) the recognition of foundational and constituent elements of pedagogical practice; b) the acknowledgement of the greater social implications of education; c) fostering perceptions regarding the role of structures in teaching and learning; and d) interpretations and importance of membership within such a distinct and dynamic context.

	Foundations of Education	Pedagogical Practice	Societal Implications
Instructors[1], Learners[2] & Pedagogical Practice	Comparing and adapting varying pedagogical approaches Holisticism in teaching practices Integrating "Teachnologies"	Planning, developing and managing instruction Teaching across the school and state curriculum Methods and plans of evaluation in education Integrating "Teachnologies"	Diversity and inclusion in education Learning with 'special needs' Integrating Technology
Institutions[3] & Communities[4]	Philosophies and epistemologies of education Creating, promoting and maintaining communities of learning/practice	Classic versus modern learning theories and educational psychology Creating, promoting and maintaining communities of learning/practice	Importance of ministerial/state curricula Creating, promoting and maintaining Communities of learning/practice

Table 1. 'My Educational Society'
[1]Instructors & [2]Learners: Used to represent the inherent power relationship with regards to the transmission of knowledge
[3]Institutions: Extended relationship between theory and practice; curricula-driven procedures, guidelines, general objectives; role and nature of the 'school'
[4]Communities: Micro-to-macro learning communities—classroom community, school community and research community

It is proposed that critical citizenship and social harmonization are promoted through informed pedagogy which is comprised through interactions between the described four central members of an educational society—instructors, learners, institutions and communities (see Table 1. ‘My Educational Society’). Extracting their key elements (ideals, approaches, roles and structures) can aid in promoting and establishing theoretically-informed, practically-sound, societally-relevant pedagogical practice. Of particular importance, is the development of critically aware, informed citizens or agents of change who can ‘find’ as well as solve problems—‘problem finding’ being central to evolution in thought.

From Theoretical Framework to Pedagogical Approach: Derivation of a Science Education System of Instruction

Scientific Reasoning and Thought: Collective Introspection through Cooperative Creation and Reflection

Practically, the proposed exploration offers: a) significant insight into the use of a potentially beneficial cognitive tool to examine the complexities of collaborative and cooperative interactions; b) effects of pre-conceptions on engagement with science content; and c) hindrances towards and resistance to epistemologies and frameworks which contradict personal beliefs.

From a curricular standpoint, within the current framework of science education, further developing and refining pedagogy which reflects the teaching of NOS can help in creating, defining and delineating criteria or guidelines for the integration of NOS and STSE curricular objectives within pre-service science educator development (Klopfer & Cooley, 1963; McComas, 1996; Abdelkhalick, 2006; Ledermann, 1992, 2007; Gilbert, 2013; Zeidler, Berkowitz & Bennett, 2014).

Revealing the processes through which students learn intricate and interrelated concepts, such as NOS (through student-generated artefacts or specifically concept maps) can enlighten educators and provide a detailed conceptualization of how students process, comprehend and synthesize principles. Exploring such student processes can help in the development of pedagogical practices which encourage the teaching of science in an interconnected and overarching STSE and community-driven framework. Overall, it is the goal of every science educator to foster the ideals of scientific communities—how science works at a systematic level. Through such an approach, educators nurture the creation of citizen scientists—those who will endeavour to be agents of change within the current structural system.

Developing and Implementing an Instructional System for Science Education

The focus for this exploration was “EDUC 382: Teaching Science Concepts in the Elementary Classroom”, a course for which the primary researcher has been involved with as of 2006—from design and development to facilitation and delivery. Over the past seven years, the discussed research program has attempted to establish a system of instruction reinforcing and reaffirming my belief that inherent epistemic systems are in need of self-actualization rooted in moments of critical individual and collective reflexivity. Through an amalgamation of the presented theoretical constructs (‘My Educational Society’, ‘Discovery Learning’, ‘Problem Finding’, ‘Intuitive Productive Failure’, ‘Nature of Science and Science Education’), this research attempts to derive a science-education system, referred to as ‘Community Views of Science’ (CVOS).

As interpreted from Maslow’s (1943) hierarchy of needs which defines the apotheosis of basic needs (for example, physiological, safety, belonging and esteem) as the basis for self-actualization (the development of citizens—be they ethical, moral or ideological—whose focus remains on the greater good), the working interpretation for this study roots self-actualization within the embodiment of constructs reflecting a malleable interpretation of science as being a socio-critical endeavour and therefore a basis for creating ‘citizens of science’. Though not rooted in a linear or hierarchical progression as illustrated by Maslow (1943), CVOS-based self-actualization seeks to sequentially promote learners to reconstruct their interpretation of the inner-workings and overall outcomes of science on society and therefore their fundamental roles as scientifically-minded citizens.

Each theoretical construct in CVOS is represented through a series of pedagogical strategies which are meant to highlight an inherent learning objective and goal. For example, an activity known as *Goo Yuck*, engages learners in discovery learning in hopes of creating cooperative dissonance with regards to the decision making processes relative to scientific inquiry. Another activity, *Weather Stations*, focuses on problem finding and has learners tackle the task of creating, unbeknownst to them, flawed weather monitoring instruments which they must pilot and then redesign and recreate—all of which is completed as a requirement for a group-based endeavour tracking and monitoring weather patterns in the Greater Montreal area. Other activities follow suit and represent varying theoretical constructs, as described. The research herein explores a strategy of worth—in both impact on learner populations and as a variable to explore and measure within the developed instructional science-education system—cooperative concept mapping (CCM).

The connection between concept mapping and NOS can be theoretically extracted from the vast and exhaustive literature surrounding the pedagogical use of semantic networks (e.g. Ruiz-Primo & Shavelson, 1996; Roth, 1997; Nesbit & Adesope, 2006; Novak & Canas, 2006; Aduriz-Bravo, 2013). Such cognitive tools have been proven to adequately describe complex knowledge systems and in most cases result in positive learning gains when used appropriately. In science education, a root problem has been the teaching (more so attainment) of NOS, which can be described as an interconnected system of ideas that reflect how science works and its overall collective impact (societally, environmentally, economically, globally and so on). Therefore, it seems fitting that concept maps can, both from a theoretical and structural sense, be an effective tool in teaching and fostering aspects of NOS within science education classrooms.

In addition to exploring the constituents of CVOS, for the empirical purpose of this dissertation, CCM will be the main element analyzed and interpreted, ad nauseam.

Research Methodology: Developing an Exploratory Framework

Research Intentions: Defining Purpose and Objectives

My research interests and associated production spans three distinct fields—through a perspective rooted in critical pedagogy, critical transparency, reasoned difference/thought and theoretical self-regulated learning, this research program examines collectivity and reflexivity in pre-service teacher education as well as conceptualizations and examinations of technologies and of learning through technology.

The research proposed herein lies within frames of thought rooted in the methodological, practical and philosophical derivations of teaching and learning for pre-service teacher development—knowledge of scientific research and evidence, as well as instructional design and performance are extracted from Educational Technology while pedagogical development for creative and thoughtful reasoning is based on critical curriculum analyses and interpretations within the K-12 domain—all while spanning our collectively conceived spectrum of 'theoretical learning'.

The developed community view of science is designed to create moments of awareness within members of community scientists, reinforcing post-structural criticality towards the development, interpretation and application of what society has come to determine as scientific knowledge and respective knowledge building methods and processes. Of particular importance is the need to question the foundation of inquiry, the root of our explorations into scientific thought—to locate and isolate problems in our understanding and conception of nature and our interactions with and through it (McDermott, 1996).

Pedagogical applications of the community view of science are not foreign to our current pedagogical approach within science education. The community view of science works in unison and is extracted from traditional conceptions of education and pedagogy, yet it places due focus on learner membership and empowerment within the greater social collective—as is congruent with our goal of developing and fostering social collectivity for utopian social harmonization.

Benefits to analyzing any approach to science education should be wholly criticized so that research and education may further reinforce the development of critically aware, informed citizens. As science pedagogues, we are entrusted to instil a love of science within learners, to further foster the ideal of community scientists, where citizens are responsible for the development as well as criticism of science and scientific endeavours. Collective pedagogical goals therefore remain static—to foster the creation of the scientific collective and to promote its foundational growth through open, critical dialogue surrounding the use of the community view of science as a framework for science pedagogy.

Research intentions, to add to our collective body of knowledge, are extrapolated from the above-offered synthesis of literature, as well as an analysis of the synthesized material which has culminated to a practical lens (CVOS)—not procedural but conceptual and directive.

From an empirical perspective, to analyze a tool in an arsenal of epistemic belief revelation (and to satisfy the requirements laid forth by scientism in education), this research intends to qualitatively analyze CCM as a tool for the introspective realization of epistemic beliefs as well as develop means and methods for CCM creation and analysis—spring boarding the proposed interpretations of information and association extracted from concept map dissection and accommodation by exploring individual learner/concept map interactions and explorations.

In no way does the research proposed call for large-scale course overhauls and curriculum reviews—efforts are focused on the analysis of the constituent elements which have culminated into the developed system of science education; development of tools and course structures which support guided self-actualization are main areas of focus.

The proposed instructional system aims to further contemporize and pedagogically interpret the curricular objectives as detailed through Quebec's Education Program (QEP)

(Martinet, Raymond, & Gauthier, 2001). As interpreted, the QEP reflects modern frameworks and sound theoretical underpinnings (the evolution of 21st Century Quebec as well as perspectives on discovery, inquiry, problem-based and learner-centred approaches) and was the curricular focus of the cohorts being explored. It is contended, however, that these approaches, as critiqued and presented (see 'Theoretical Framework), are perhaps far more traditional in nature and therefore in need of exploration from a renewed lens—for example transforming our perception of learner-based science from problem-based learning and problem-solving to problem finding (from solving a pre-determined problem, to determining where problems may lie). Such transformations though seemingly minute, offer the contemporized pedagogical implications sought—to review and refine instructional strategies and approaches so science education can possibly reform and evolve beyond what has been exhausted within current curricula.

In sum, the following research objectives situate the purpose of this dissertation, while elaborating and exploring the intentions of the discussed academic research program (see Introduction: Purpose):

a) Explore and analyze interpretations of concept maps and concept mapping as well as the affect of concept mapping analysis on epistemic realization and self-actualization
b) Explore, analyze and test the affect of CCM on epistemic realization, self-actualization and the development of a 'Community View of Science'
c) Elaborate upon the use of CCM within pre-service elementary science educator classrooms to reflect the methods, processes, approaches, purposes, structures and systems of science as reflected to science education

d) Reflect on and discuss the nature of philosophical and empirical inquiry while 'breaking methodological boundaries' as defined by traditional qualitative research

Research Design and Data Collection

'My Research Program'. My developed research program was fostered during my six years within the doctoral Educational Technology program at Concordia University. It is a product of collaboration and inter-university research and development exploring and reviewing constructs of teaching and learning from divergent and convergent theoretical and practical perspectives (for example, my research agenda is a culmination of collaboration with Dr. Manu Kapur (National Institute of Education, Singapore)—exploring aspects of productive failure in science and science education; Dr. Roger Azevedo (Canada Research Chair, McGill University)—using eye-tracking technology to investigate concepts of metacognition and self-regulation in conjunction with concept map development and interpretation; Dr. Rafella Negretti (University of Stockholm, Sweden)—exploring aspects of a learner interaction and feedback model developed through research conducted during my Master's thesis; and Dr. David Waddington (Concordia University)—exploring Deweyan concepts of transparency and science in technology).

The following reference collaborative grants and research studies held in conjunction with those listed above (as a means to further define and reflect my expanding research profile and 'My Research Program'):

Concordia University, Office of the Vice-President, Research & Graduate Studies - Seed Funding Program - Team Grant Award - (CDN$12,750 from Concordia with

Matching funds of SEK 18,000 from University of Stockholm, Singapore $1,300 from Nanyang Technological Institute and CDN$ 1,300 from McGill University); From April 2011 to April 2012 - Project Title: "I still haven't found what I'm looking for ... ": Exploring the role of learner metacognition and academic self-regulation in the development of indexing tools for online learning environments. Principal Investigator: Vivek Venkatesh (Concordia University). Co-Investigators: Kamran Shaikh (Concordia). Collaborators: Roger Azevedo (McGill University), Manu Kapur (Nanyang Technological University), Raffaella Negretti (University of Stockholm).

Concordia University, Office of the Vice-President, Research & Graduate Studies - Seed Funding Program - Team Grant Award - (CDN$14,999 from Concordia); From April 2010 to April 2011 - Project Title: Improving the design of social interactions in online courses: Case studies of educational and informal web-based communities. Principal Investigator: Vivek Venkatesh (Concordia University). Co-Investigators: David I. Waddington (Concordia), Kamran Shaikh (Concordia).

Fonds québecois de recherche sur la société et la culture (FQRSC) *Établissment de nouveaux professeurs-chercheurs* ($39,600); From April 2009 to April 2012; Project title: *L'utilisation d'ontologies de domaines et de tâches dans les environnements d'apprentissage en ligne: une étude mixte qui explore comment améliorer les résultats et l'autorégulation des étudiants universitaires en rédaction d'essais*. Principal Investigator: Vivek Venkatesh

Thoughts on ethics of research in the classroom. Though practitioner research—investigating one's own classroom—can be interpreted as a "grassroots" initiative of action research (Anderson, 1994), there do exist potential ethical and scientific pitfalls worthy of moderation and an attempt at control.

To quell any problematic aspect or ethical concerns brought about by classroom-based research, certain measures were adopted within this proposed research study to account for researcher objectivity and participant confidentiality. For example, current and future classroom data remained protected and stored until courses were completed and grades submitted (the primary researcher was unaware of participants' consent during course delivery; participants names and student identification numbers were revealed post-grade submission; participant rights to refuse and extrication from the research study were respected as they were constantly made aware of such rights; refusal to participate in the study or extrication from the study was only revealed to the instructor post-course completion and as such data collected from these participants was removed from analysis; participants were provided with contact information for Concordia University's ombudsman as well the primary researcher's departmental supervisor—Dr. Vivek Venkatesh); data collection instrumentation was disseminated and compiled by the course teaching assistant (therefore extricating the instructor and primary researcher from such phases of the data collection process); ethical concerns regarding the revelation of personal issues or harm to participants were dealt with through the Office of Research and Department of Education of Concordia University. In addition, all research data remained engrained in the overall course structure and participants were not asked to complete tasks outside the general realm of the course unless they were selected for and consented to a semi-structured longitudinal interview. No incentive for participation was provided to student participants during the data collection process. As per the tri-council ethics requirements, participants were not deceived or manipulated in any manner.

Research design & rigour. Using terminology derived from educational research methods, the study described falls under the guise of a mixed-methods qualitative exploration. It can also be argued, from a specific perspective, that tenets of action research and grounded theory have played a prominent role in how this research program assisted in the conception and development of the above theoretical synthesis and proposed research design.

To account for concepts of rigour—again borrowing from terminology reviewed by qualitative research methods—the research proposed was developed on the basis of standardized instruments for data collection whenever possible (e.g. Views of Nature of Science Questionnaire—VNOS) and multiple data sources, from multiple perspectives, all while assuring for some form of triangulation, external validation and member-checking. Researcher subjectivity in data collection and analysis was accounted for through the use of secondary observers as well as measures of accountability (e.g. video and audio recordings of interactions with participants). To reflect Guba's (1981) four general criteria for evaluation of qualitative research—truth value, applicability, consistency and neutrality—the following measures were adopted:

- Truth Value: Accounts and participants views were confirmed through individuals who possessed knowledge regarding the subject matter—as a measure of credibility; participants were those aware of the systems and structures which frame the proposed research study.
- Applicability: To address the need for transferability, the varying sources of data collected from multiple perspectives, would allow for consequent comparison and replicability—however the goal of the proposed research

skews slightly from this endeavour (see ‘Research Intentions’ for an elaboration).

- Consistency: Though not a normative study, the manner through which the proposed research has been designed accounts for multiple perspectives and traceable sources of information (i.e. numerous forms of data collection) therefore accounting for consistency in research findings.
- Neutrality: By investigating data presented and not interactions between instructor and student, as well as the variety of data collected over an elapsed time (i.e. longitudinally)—distance between researcher and participant is secured and neutrality of data interpretation becomes plausible.

Data collection locations & institutional approval of ethics to conduct research. To satisfy academic curiousity, data from three separate cohorts of learners—all of whom were pre-service elementary educators from prominent Anglophone universities in Quebec—were used as the representative sample.

Seeing as how data collection took place within two separate academic institutions (Concordia University and McGill University’s “Laboratory for the Study of Metacognition and Advanced Learning Technologies—SMART Lab), ethical approval was obtained from both institutions’ governing ethical boards (Concordia’s Research Ethics and Compliance Unit (Office of Research) and McGill’s Research Ethics Office (Institutional Review Board). See ‘Appendix’ for research ethics approval forms regarding the collection of data as detailed in this research study.

Approval for use of human participants, from Concordia University and McGill University, was obtained as an addendum to a pre-existing summary protocol form (SPF) developed for a Concordia seed funding initiative spearheaded by Dr. Vivek Venkatesh, for which the primary researcher is a co-investigator. The project, entitled “I still haven't found what I'm looking for ...: Exploring the role of learner metacognition and academic self-regulation in the development of indexing tools for online learning environments”, was supported by and inherently reflective of the primary researcher’s work though efforts are differentiated by a number of varying structural, theoretical and philosophical foundations (refer to section on ‘Research Intentions’ for an explanation of how this research program diverged from traditional forms of empiricism in education).

Participant cohorts & methodology. The three cohorts of learners include:

- Cohort 1 (n=32; 30 female and two male students): Pre-service teachers from a Bachelor of Education, teacher training program, enrolled in “EDU201: Orientation to Teaching” and “EDU275: Planning and Managing Classrooms and Student Behaviours”, were used for pilot investigations of CCM data collection instruments and to provide structure for the analysis of Cohort 2 data
- Cohort 2 (n=43; 38 female and five male students): Pre-service teachers from an Early Childhood and Elementary education methodology course, “EDUC 382: Teaching Science Concepts in the Elementary Classroom”
- Cohort 3 (n=12; ten female and two male students): Consists of pre-service teachers from previous semesters of an Early Childhood and Elementary education methodology course, “EDUC 382: Teaching Science Concepts in

the Elementary Classroom". Data collection with this cohort unfolded at McGill University's SMART Laboratory

'Cohort 1': Pilot sample. Two separate courses examining the nature of pedagogy in elementary education were used to pilot the CCM activity. Data collected includes, a) CCM artefacts (students, working in groups of three or four, were asked to cooperatively map out their response to "What is Science"); b) guiding reflective questions, answered by both groups as a whole and students individually, which sought to examine the procedure employed by groups of learners to cooperatively map whilst rectifying differences in group knowledge and accommodating group views; and c) a focus group reviewing materials used by 'Cohort 2' when engaging in the CCM activity (e.g. activity instructions and brief description of concept mapping) and by 'Cohort 3' when engaging in concept map analysis and dissection.

In short, the following data were available for analysis, albeit from a pilot-study perspective (as a means to determine data-driven theory and coding schemes which played a prominent role during exploratory phases of data collection):

- Cooperative concept maps
- Reflective focus group (reviewing activity as well as data collection materials; see Appendix A: Focus Group Questions)
- Individual reflections on the nature of the CCM activity (see Appendix B: Reflective Questions)
- Review of materials used for the data collection procedure of 'Cohort 2' (see Appendices A, B, F-N: Materials for Data Collection)

Detailed data collection methods & procedure for 'Cohort 1'. Participants were students in courses for which the primary researcher was the instructor and though representative of the learner population to be explored, a convenience sample.

Pilot data collection (material and activity review) was integrated into the overall course structure as an activity which can be used in elementary science classrooms. Participants were aware that their reviews of the material and activity could potentially structure documents and data collection tools employed in the data collection portion of this dissertation ('Cohort 2' and 'Cohort 3').

Review of the data collection instruments for grammatical, logical and contextual errors were followed by student assessment of concept maps and mapping—they were shown an example of an expert concept map and were given simple instructions regarding the contents of a concept map, its structure and its purpose (for example, concept maps are composed of nodes (reflecting big concepts or ideas) connected to each other through the use of lines and associations, reflecting the relationship between the big concepts or ideas).

At this point students were provided with A1 paper (594 mm x 841 mm), coloured pens (red, blue and black) and asked general questions—"What is Science" & "How Does it Work?" This was followed by a short question and answer period (15 minutes) where students were permitted to ask for elaboration of the questions or activity. They were then told that 60 minutes was allotted to cooperatively map their response.

After 60 minutes, students were asked to answer the reflective questions (see Appendix B: Individual Reflective Questions) and to participate in a 30-minute focus group exploring the activity (see Appendix A: Focus Group Questions).

'Cohort 2': Cooperative concept mapping group (CCM). In "EDUC 382: Teaching Science Concepts in the Elementary Classroom", students were asked to complete a science beliefs questionnaire prior to a short discussion on the principles of NOS. Students were then allowed to form their own cooperative groups and were provided with a general question, "What is Science". They were then given 45 minutes to develop a CCM detailing their response.

Similar to Cohort 1, data includes, a) CCM artefacts (students, working in groups of three or four asked to cooperatively map out their response to "What is Science"); b) guiding reflective questions, answered by both groups as a whole and students individually, sought to examine the procedure employed by groups of learners to cooperatively map whilst rectifying differences in group knowledge and accommodating group views; and c) a focus group reviewing the nature of the cooperative mapping activity as a whole and exploring the cohort's epistemic view of science (a focus group detailing the cohort's post-activity views of NOS was chosen in lieu of a post-questionnaire in hopes of employing differentiated data collection techniques and to reflect the community perspective being propagated through course design).

Other forms of data were found in the form of group and individual observations; primary (instructor) and secondary observers; a research journal and other classroom artefacts not directly related to the concept mapping activity but reflective of the course structure.

In short, the following data were available for analysis:

- VNOS Questionnaires (to benchmark science beliefs and interpretations)
- Cooperative concept maps created

- Classroom artefacts (e.g. classroom materials completed and collected over the course of the semester)
- Reflective focus group
- Individuals responses to reflective questions (reflecting on science)
- Reflections on the nature of the activity
- Primary and secondary observer field research notes
- Primary investigator research journal
- Email questionnaire with select sample of participants from ‘Cohort 2’ (elaborating on responses during focus group)
- Longitudinal semi-structured interviews

Detailed data collection methods & procedure for ‘Cohort 2’. Participants were students in “EDUC382: Teaching Science Concepts for the Elementary Classroom”, a course for which the primary researcher was the instructor and though representative of the learner population to be explored, a convenience sample. Select students were contacted for longitudinal semi-structured interviews.

Data collection was integrated into the overall course structure as a cooperative activity these students may use in their elementary science classrooms. At the beginning of the semester participants were made aware of dissertation research goals and intentions and provided with consent forms to complete (if they so desire) (see Appendix: Consent Form—EDUC382: Teaching Science Concepts in the Elementary Classroom). They were made aware that their participation was voluntary and that all material developed during the semester would be collected as a means to analyze their evolving understanding of science (for examples of such activities, see Appendix: Goo Yuck and Weather Instruments).

During the first week of classes, students were given a ‘Nature of Science’ questionnaire to benchmark their understanding of what science is and how it works (see Appendix: Pre-Survey).

After reviewing examples of an expert concept map (see Appendix: Sample Concept Maps) and simple instructions regarding the contents of a concept map, its structure and its purpose (for example, concept maps are composed of nodes—reflecting big concepts or ideas—connected to each other through the use of lines and associations, reflecting the relationship between the big concepts or ideas), students were provided with A1 paper (594 mm x 841 mm), coloured pens (red, blue and black) and asked the general questions, “What is Science” & “How Does it Work?. This was followed by a short question and answer period (15 minutes) where students were permitted to ask for elaboration on the questions or activity. They were then told that they would receive 45 minutes to cooperatively map their response.

After 45 minutes of map development, students were asked to answer the reflective questions (this was estimated to take 20 minutes) (see Appendix: Individual Reflective Questions) and to participate in a 45-minute focus group exploring the activity (see Appendix: Focus Group Questions).

Given responses during the focus group and individual reflective questions, select students were contacted for an email-based questionnaire and longitudinal interview (see Appendix: Post-Survey; Longitudinal Interview).

The following table details data collection instruments and methods used, their purpose as a function of this research study as well as any necessary yet extraneous details assisting in interpreting the varying elements of cooperative concept mapping as a function of CVOS (see Table 2. Summary of Data Collection for 'Cohort 2').

Instrument	Purpose	Details
VNOS Questionnaires	Pre- and post-task benchmark of science beliefs and interpretations	Use 'VNOS C' (Ten open-ended questions); Construct Validity: Novice/Expert reviews Authors: Lederman, N. G. et al. (2002)
Cooperative Concept Maps	Analyzed for: 1) Concept accuracy 2) Comprehension 3) Integration of 'Collective Beliefs'	Maps created as a classroom activity answering: "What is Science" & "How Does it Work?"
Reflective VNOS & CCM Focus Group	Used in addition to VNOS post-questionnaires to review collective interpretations of NOS and CCM	To ascertain how groups came to collective understandings with respect to the map developed
Individual 'Reflective Thoughts on Science'	Solicit participant data on science beliefs post cooperative concept mapping activity	To elaborate on effect of cooperative activity on individual beliefs
Individual 'Reflective Thoughts on CCM'	Solicit participant data on cooperative concept mapping activity	Means to elaborate on the feasibility and efficacy of CCM
Primary & Secondary Observation Notes	Support (i.e. confirm or negate) data collected during interviews, focus groups and class sessions	Secondary observer present for all phases of data collection Notes compared and cross-referenced regularly ('dialogic substantiation')
Primary Investigator Research Journal	Maintain a recorded timeline of events and to support observations and analyses	
Select-sample Email Questionnaire	Elaborate on responses during focus group	Elucidate key responses
Longitudinal semi-structured interviews	Explore durability of thoughts and beliefs with respect to activity	Select participants interviewed after engaging in activity
Classroom Artefacts	To aid in an analysis of CVOS as an Instructional System To support arguments concerning: i) participant epistemic beliefs; ii) participant science knowledge; iii) course structure	Materials completed by students compiled over the course of the semester

Table 2. Summary of Data Collection for 'Cohort 2'

'Cohort 3': Concept map analysis group (CMA). At McGill's SMART Lab, after completing an adapted version of VNOS, participants (n=12) engaged in a metacognitive exercise—through the use of semi-structured interviews, guided through think-aloud protocols, participants' explored, dissected and reflected upon four student-generated nature of science concept maps and one expert-created nature of science concept map. The VNOS beliefs questionnaire—which consists of ten open-ended questions explicating student views surrounding the main tenets of NOS—assists in characterizing students with respect to NOS principles detailed above (see 'Theoretical Framework').

Along with these interviews (Think-Aloud protocols which were used to shed light on certain metacognitive principles—what participants are doing and why), post-activity science belief questionnaires (VNOS) were collected and post-activity semi-structured interviews were conducted. It was hoped that these sources would delve further into participant decision making processes while interacting with the map and further clarify any concerns or questions regarding collective science beliefs.

In short, the following data were available for analysis:

- VNOS (to benchmark science beliefs and interpretations)
- Pre-task interviews with participants reviewing their interpretation of VNOS and other confounding elements to the study
- Think-Aloud protocols detailing concept map dissection
- Post-task interviews with participants reviewing their interpretation of the concept map dissection task and exploring any moments of reflection with respect to accommodation and adaptation of personal belief systems
- Primary and secondary observer field research notes
- Primary investigator research journal

- Longitudinal post-task interviews (select participants were interviewed after engaging in the dissection activity)

Detailed data collection methods & procedure for 'Cohort 3'. Approximately 300 prior students were contacted through a mass email detailing the nature of the study (see Appendix C: Email Soliciting Student Participation) with a response rate of 10%. Of the 30 who were willing to participate, twelve met the necessary pre-requisites of participation and have been included in the analysis for this study.

A secondary observer was present for interviews and data collection. Prior to arrival, through email, students were asked to complete the "Views of Nature of Science" questionnaire (see Appendix: Nature of Science—Pre-Survey). Upon arrival at the SMART Laboratory at McGill, participants were given five to ten minutes to accommodate and acclimatize with their surroundings. They were then provided with a consent form (see Appendix: Consent Form—McGill) and general procedures as well as any special considerations were reviewed.

Participants were then given an activity handout to reflect on the nature of a think-aloud protocol (see Appendix: Priming Think-Aloud Protocol) and its contents were reviewed as they engaged in the think aloud protocol engagement activity.

Following successful interpretation of the think-aloud and 'concept map analysis' task, participants were introduced to the study and given a handout outlining the procedure (See Appendix: Introduction to Activity; Stepwise Instructions) which would then be summarized collectively (primary investigator, secondary observer and participant) in simple terms (see Appendix: Study Procedure). At this point, they were provided with a think-aloud protocol (see Appendix: Think Aloud Protocol) and the audio-recorded interview commenced. Participants were asked to respond to a few brief demographics questions (see Appendix: Demographics) and then asked general questions related to science ("How does Science Work?" and "What is Science?").

Participants were given a total of 60 minutes to complete the analysis of five concept maps (see Appendix: Novice & Expert Concept Maps; four 'novice' maps and one 'expert' map—novice and expert delineated by complexity of associations, interconnectedness of maps and fluidity of nodes). Each map was therefore successively displayed for 12 minutes.

These twelve minutes consisted of the following:

- Three minutes of free exploration
- One minute to answer the following questions:
    - What were your main areas of interest?
    - Why were they your main areas of interest?
- Eight minutes to dissect provided concept maps while answering the following questions:
    - How does this concept map characterize and define science?
    - With regards to the map, are there rules, procedures, processes, frameworks or approaches for science?
    - What are some main scientific concepts displayed in this map?
    - Do any areas of the map stick out as being anomalous or which counter your current beliefs of science?

This ended the 'concept map analysis' portion of the study and participants were given a few minutes to compose themselves. A post-interview exploring pertinent questions which arose during the data collection, structured as a review of a 'Nature of Science' handout and reviewing the activity as well as its potential benefit, was conducted (see Appendix: Nature of Science Handout). Participants were then thanked for their participation and audio-recording at this point came to an end. As a finale, students were provided with a post-survey to complete within two weeks post-experiment (see Appendix: Nature of Science Post-Survey).

The following table details data collection instruments and methods used, their purpose as a function of the research study as well as any necessary yet extraneous details of their possible use as a means to interpret the varying elements of concept mapping and concept mapping tasks as a function of instructional systems (see Table 3. Summary of Data Collection for 'Cohort 3').

Instrument	Purpose	Details
VNOS Questionnaires	Pre- and post-task benchmark of science beliefs and interpretations	Use 'VNOS C' (Ten open-ended questions) Construct Validity: Novice/Expert reviews Authors: Lederman, N. G. et al. (2002)
Pre-task interviews	Review participant interpretation of VNOS and other confounding elements of the study	
Think-Aloud protocols	Structured interview of participant concept map dissection	Approximately 60 minutes
Post-task interviews	Review participant interpretation of the task and explore moments of reflection (with respect to accommodation and adaptation of personal belief systems)	
Primary & Secondary Observation Notes	Support (i.e. confirm or negate) data collected during interviews and think-alouds	Secondary observer present for all phases of data collection Notes compared and cross-referenced regularly ('dialogic substantiation')
Primary Investigator Research Journal	Maintain a recorded timeline of events and to support observations and potential analyses	Akin to a 'Captain's Log'— Includes observational analyses, potential codes & literature; pre-cursor to data analysis
Longitudinal semi-structured interviews	Explore durability of thoughts and beliefs with respect to activity	Select participants interviewed after engaging in activity

Table 3. Summary of Data Collection for 'Cohort 3'

Results: Summary Table of Collected Data and Initial Codes

The following table (Table 4. Summary of Results and Extrapolated Codes), describes data as collected from the two exploratory cohorts while highlighting significant participant reflections, observed outcomes and potential effects of the culminating tasks with regards to 'Views of Nature of Science', 'Views of Concept Maps', 'Effects of Concept Map Analysis' and, of particular importance, 'Views and

Effects of Cooperative Concept Mapping'. Participant quotes as well as main findings—extracted and corroborated through a process of 'dialogic substantiation' and triangulation—are included in the table and discussed in some detail throughout the coming analysis and interpretation sections (see, Results of Significance: Introspection, Insinuation and Implication).

Cohort	Construct	Data Source	Sample Participant Perspectives	Extrapolated Codes
'Cohort 2': Concept Map Analysis	Views of Nature of Science	• VNOS Questionnaire	"Science is intrinsically linked to society and culture"; "Scientific method is connected to experimentation and inquiry"; "Theory as best explanation, fact as only explanation"; "Scientific principles are universal"; "Science is about a process, a method"; "Science can tell us the best possible outcome to many situations"; "Science is only as advanced as our understanding of the natural world"; "Scientific facts and theories are about certainty"; "Culture can kill science"; "Science as exploration and discovery"; "When I do science, I don't have to be creative"; "Art and science don't mix"	Science as a solution; nature of truth; rigidity towards scientific facts, theories and knowledge; science as removed from art and creativity; outcomes of science as socio-cultural thought
	Views of Concept Maps	• Pre-task Interviews • Concept Map Analysis	"It's hard to navigate these concept maps, they need more structure, more organization"; "It makes understanding someone else's understanding a lot easier, once you get over the 'jumble'"; "I have a real hard time trying to extract step-by-step details of what science is"; "It's easier to see where the connections don't make sense or where I don't agree with them"; "There's a lot of info in these maps, I'm not sure I can understand it all"	Structurally flawed; meaningful and interpretable; reflective of 'other'/'stream of consciousness'; non-linear

	Effect of Concept Map Analysis	• Post-task Interviews • Longitudinal Interviews	"I can compare what I see with what others see"; "I need time to reflect, to question what I know and what is being presented"; "The connections make sense, but they don't really fit with what I think"; "I think science is about finding solutions to problems, not what this tries to show"; "I have to think more, cause I'm not sure I agree with all the connections"; "Other people's connections made me rethink my own"; "I wasn't certain about what I knew anymore, but I was more confident about the things I did know were right"; "The maps that were really complex…I realized I needed to make more connections"	Reconciliation of perceptions; epistemic reflection; questioning 'oneself' and accepting 'others'; epistemic realization; epistemic belief self-actualization
'Cohort 3': Cooperative Concept Mapping	Views of Nature of Science	• VNOS Questionnaire • VNOS/CCM Focus Group • Cooperative Concept Maps	"Science is intrinsically linked to society and culture"; "Scientific method is connected to experimentation and inquiry"; "Science is a solution for our problems"; "Science facts are true, but theories can be changed or evolve"; "Scientific knowledge is true"; "Scientists don't have to be creative"; "There is no art in science"; "Scientists have to be creative to find problems and cool solutions"; "If science didn't have rules, we wouldn't have basic knowledge to use to create theories"	Science as a solution; nature of truth; rigidity towards scientific facts, theories and knowledge; science as removed from art and creativity; outcomes of science as socio-cultural thought

Views of Cooperative Concept Mapping	• Cooperative Concept Maps • Reflective Thoughts on Cooperative Concept Maps • VNOS/CCM Focus Group	"We were able to see how everything is connected"; "Each term is multifaceted and has a deeper meaning"; "Hard to work on a piece of paper, but once you start brainstorming and sharing it gets easier"; "We discussed terms and meanings before including it in our map"; "Defining and debating was the best part, helped us understand"; "This was a really helpful task, showed us how far we came from the beginning of the semester—baby steps!"	Means to create community; medium for discussion and introspection; means for dialogic inquiry; forum for peer scaffolding; difficult to manipulate structurally
Effect of Cooperative Concept Mapping	• Reflective Thoughts on Cooperative Concept Maps • Cooperative Concept Maps • Longitudinal Interviews	"I found out a lot about how my classmates think"; "It's okay to make mistakes and we should tell our students it's okay to make mistakes"; "Was fun to collaborate on creating ideas and fighting for what we thought they meant"; "I was able to connect what I learned this semester"; "Wow, it's a lot more complicated and interconnected than we thought"; "There are far more associations than we had assumed"; "It's great to see how all the concepts are linked"; "This was a really helpful task, showed us how far we came from the beginning of the semester—baby steps!"	Promoting collectivity; development of inquiry and dialogue; development and refinement of 'science as a process'; peer substantiation of ideas; confirmation through divergence; 'epistemic spark'; epistemic substantiation; epistemic realization; epistemic debate;

Effect of Cooperative Concept Mapping on 'Views of Nature of Science'	• Cooperative Concept Maps • VNOS Questionnaire • VNOS/CCM Focus Group • Reflective Thoughts on Cooperative Concept Maps • Longitudinal Interviews	"Science is more than I and everyone else thought it was before doing this"; "Science is not just the scientific method, it's really about how society and culture appreciates or understands science"; "Using science depends on the society and culture that it's being used in—I only learned that today!"; "Scientists work just like us by bouncing ideas off each other"; "We can all be scientists, we are all scientists"; "It's great to see how all the concepts are linked"; "There are a lot of terms in science that say the same thing. I need to plan out more to be able to teach science"	Development and refinement of 'science as a process'; questioning of scientific processes; questioning of socio-cultural science; science as reflective of collective and individual voice

Table 4. Summary of Results and Extrapolated Codes

Analytical Framework: Defining Qualitative Interpretation

Framework for Heuristic Analysis: Phenomenologically-driven Recursive Abstraction

As a means to frame an analysis of the collected data, phenomenologically-driven recursive abstraction (Keeney & Keeney, 2012) was employed to distil significant observations, reflections and events as perceived and interpreted by the primary researcher and secondary observer (Moustakas, 1994; Denzin & Lincoln, 2000). This process, which is at the cusp of heuristic analysis, contributes to the transformation of these varying accounts, from prose to abstraction. Though accepted within qualitative circles as a worthwhile method to synthesize and present researcher-based interpretations, it is acknowledged that doing so may create distance between collected data and presented findings. As mentioned (see Research Methodology), to quell misinterpretations amongst observers and research syntheses, classical methods of triangulation are employed to ensure necessary minimums of rigour are achieved.

To evolve beyond traditional reductionist approaches, considered a requisite of empiricist qualitative exploration, a process of ‘dialogic substantiation’ (Kleining & Witt, 2000; Keeney & Keeney, 2012) afforded the necessary means to systematically discuss and interpret research findings as a reflection of each observer’s methodological and paradigmatic stance. Though time-consuming, engaging in such recurring and ongoing discourse affirmed, confirmed and/or disconfirmed findings while attempting to acknowledge the affect of researcher beliefs on points of supposed interest. For example, while observing learners analyze the contents of concept maps, the primary researcher’s attention was inherently focused upon methods and processes employed by learners to extract and evaluate presented information—the researcher's need to interpret the effect of proceduralized systems and structures of analysis were evident. In contrast, the secondary observer's grounding in problem-based learning was apparent through observations of events elaborating upon learner reactions to ill-structured problem-based scenarios and associated mechanisms of appeasement and control. Though seemingly homogenous interpretations, theories, reason and thought supporting the arguments were adequately divisive.

Analysis of data therefore sought to highlight and juxtapose learner perspectives with researcher-based observations of why and how these perspectives and perhaps 'reasoned change' (for example, in epistemic belief) were fostered, promoted and possibly confirmed through multiple data sources (for example, classroom artefacts or handouts structuring experiments/explorations, science journals completed during experiments, reflections and interpretations of science activities and of being a scientist) (see Appendix, 'Sample Analysis of Participant Perspectives', analysis of pre-task VNOS).

Interpretive Summary: Orchestrating an Elaboration

The primary goal of this research study is to analyze the system of instruction developed, as a whole, whilst exploring combinations of theory-based instructional strategies, of which particular importance is placed upon CCM as a task with the potential to serve as a culminating exercise—guiding learners to moments of collective critical reflexivity as a precursor to epistemic awareness and realization.

Stand-alone, CCM may not be epistemology changing, nor does this research program hope for it to be. It is conceived of as an indispensable member of the developed instructional system (CVOS) and this details its worth as a tool for self-actualization of science beliefs through cooperative introspection and reasoning. As such, coding and analysis, as is the case in any exploratory study, details theory-based and data-driven codes which allow for the interpretation of the tools potential benefit independently and when surrounded by elements of its current environment.

Through 'Cohort 2' and 'Cohort 3', this research study elaborates upon moments of reflection, adaptation and accommodation which reflect change in learner awareness of epistemic belief systems or moments where change was sparked. Data reveal the consistent effects of pre-conceived notions of science when analyzing and dissecting concept maps and how the analysis of concept maps through the use of the above constructs results in an understanding of the root causes for such consistencies in beliefs. Regardless, details of how participants view and subsequently analyze maps, what they fixate on and respective reasons why are indispensable for the advancement of concept mapping theories and literature—(e.g. (meta)cognitive load as well as concept-association derivation and interpretation).

From 'Cohort 2', this study mines principles and best practices for the use of CCM in a science education focused instructional system, detailing how group dynamics and individual differences are dialectically synthesized during artefact creation. For example, adaptation of personal beliefs with respect to those of others, accommodation of others' beliefs with respect to those of the group, usefulness of the activity and actual engrained change of epistemic foundations (whether CCM led to learners reflecting on their combined view or if engaging in cooperative map building resulted in a realization of epistemic belief systems or that such beliefs are malleable and reflective of overarching interpretations of how science functions and of our membership as scientists) are worthwhile avenues for dialogue.

Examples of epistemic change can be interpreted through differences in pre- and post-task VNOS questionnaires, focus groups and longitudinal semi-structured interviews (see ‘Table 4. Summary of Results and Extrapolated Codes’—comparison of participant perspectives of ‘Views of Nature of Science’ and ‘Effect of CCM on Views of Nature of Science’). These participant responses highlight changes from science being viewed traditionally as rigid and the provider of solutions fundamental for societal progress to a malleable, socio-collective process of exploration.

As a program of research, this study underlines concepts worth exploring for the emancipation of knowledge and knowledge systems with regard to the general learning public (scientific public)—such constructs being at the forefront of the proposed research agenda. It is with this intention that future research, derived from this study exploring epistemics, focuses on the propagation of the described instructional system (CVOS) and of related constructs (tools, procedures and mechanisms which aid in promoting and fostering CVOS).

Regarding knowledge vehicles, research of CVOS explores other constituent elements independently, inter-connectedly and as a composite whole (for example, to explore ‘problem finding’ as a function of ‘collective reflexivity’). Longitudinal implementations of CVOS-based systematic instruction in pre-service teacher development and an exploration of short and long term in-service teacher retention of views and beliefs surrounding science as well as collectivity and reflexivity in science may also prove worthwhile.

Results of Significance: Introspection, Insinuation and Implication

Analyzing, Extracting and Interpreting Thought through Concept Maps

The following analysis seeks to elaborate the central objectives of this exploratory study—first, to explore and analyze interpretations of concept maps and concept mapping, as well as the affect of concept mapping analysis on epistemic realization and self-actualization. Second, to explore, analyze and test the affect of cooperative concept mapping on epistemic realization, self-actualization and the development of a 'Community View of Science'. Third, to elaborate upon the use of cooperative concept mapping within pre-service elementary science classrooms and to reflect the methods, processes, approaches, purposes, structures and systems of science central to science education. Lastly, the fourth objective (overarching epistemological and underlying paradigmatic objective), to discuss the nature of philosophical and empirical inquiry while 'breaking methodological boundaries' as defined by traditional qualitative research.

These objectives have been abridged and included as headings for representative sections of the presented analyses.

Objective 1: Concept Maps, Concept Mapping, Epistemic Realization and Self-Actualization

Concept mapping as a 'stream of consciousness' Exploring learners intentions and probable applications of concept maps was necessary to better develop pedagogical methods which would assist in effectively implementing CCM into the science education instructional system.

Initial interactions with science-based concept maps were plagued by foreseen trivialities—the majority of participants commented upon the structure of the maps, pinpointing organization, layout and order as definitive factors guiding their eventual use and comprehension of the information being presented (see Table 4. Summary of Results). Upon realization that concept maps were more so a non-linear timestamp detailing connections and relationships between 'big ideas' within any given structure, system or school of thought, their use as a reflection of the creator's 'stream of dynamic thought' was highly regarded as a positive.

When properly constructed, participants were able to 'enter' and 'exit' the map, connecting ideas therein, whilst remaining aware of the larger perspective (in this case, science and reflections on what makes science), as well as the minutiae of each underlying concept (for example, the connection between socio-collective views and the 'Nature of Science'). This allowed for unique interpretations across participants—conclusions were shared and uniform however the reasoning supporting such conclusions was individualistic and varied.

Somewhat surprisingly, through the participants' initial mixed reaction of confusion and pejoratives, maps of increasing complexity (see Appendix, 'Expert Concept Map') resulted in the most meaningful extraction and an increase in frequency of comparison (increased interconnectivity was met with a desire to extract and interpret). Maps of little complexity (see Appendix, 'Concept Maps'), where participants felt slighted by the lack of depth and breadth were deemed simplistic and unfitting of the conceptual nature of the task.

The perpetual first date: 'Hello, have we met before? I am a concept map". Awareness of concept map dynamicity resulted in interpretive freedom; participants progressed beyond the need to 'see what they perceive was being presented' and to allow themselves to personalize their interpretation and to critically examine the concept map. Such critical examination provided the means for a moment, a moment where participants began engaging with the subject matter, comparing what was being presented to what they feel they 'know'—an instantaneous questioning of oneself. It is contended that this realization of their criticality was the initial spark of epistemic realization needed for the self-actualization of epistemic belief. As a result of and accompanying self-actualization was the ability to truly start 'working through the concept map'—in other words, getting to know the map (concepts which give it shape and the associations which give it meaning).

Points of contention became points of self-reasoning—if ideas presented could be digested at face value, they were accepted and assimilated whereas those which presented information contradictory to personal beliefs were reasoned. In some instances, at this point, the map began to morph, transforming from a conscious representation of 'another' to a malleable representation of 'oneself'. For example, when faced with a point of contention, participants either fought or fled—inductively or deductively reasoning and weaving their own interpretation of the contended construct or assimilating what was presented as a reflection of a 'contrary stream of consciousness'. Such comparative views were therefore a culmination of 'self' and the personal development of meaning through extraction as they represented an extension of paradigmatically grounded views—at some point through this process of reasoning and dissection, participants began to perceive their grounding within their working paradigm (their lens, that of pedagogues, became increasingly evident as they searched for personal meaning). Personal 'streams of consciousnesses' (for example, epistemic beliefs of science) reinforced why maps were interpreted through a particular lens and the necessity for irrelevance with respect to the nature of semantic representations (for example, pre-service teachers were quick to acknowledge their inherent need for clarity in structure or ‘organization’, indicating and perhaps revealing an intrinsic need to reinforce the societal perspective and image of a teacher).

Realization of a working paradigm, as a primary step, was a worthwhile outcome as it assisted in the development of an explorative and guided method for pre-service teachers to appreciate their role as scientists—they are fundamental members for the development of young scientific minds, empowering their students with the skills and processes necessary to engage in scientific endeavour. Though teaching science may not be widely accepted within science as a scientific discipline, it involves the transference of scientific processes; science becomes teaching the means to develop and interpret science versus the ability to reiterate science, as reflected through contemporary approaches to science education.

Contrary to belief of pre-service educator initial perspectives and misaligned with the innate purpose of a map, the associations and relationships between concepts were deemed ‘more’ influential when compared to the concepts or ‘big ideas’ structuring the map. Participants in this phase, generally related or associated overarching concepts through their own hierarchical nomenclature—developing their own relationships to confirm, affirm, disconfirm or negate the interconnections being presented; they began to interpret the map through their own reason and thought though mysteriously aware of the discrepancy between what they were seeing and what they were interpreting (for example, placing meaning on known concepts without directly referring to or acknowledging the terminology presented in the map, 'this is a process', 'this is a method', 'this is knowledge').

The above analysis aspired to structure the pedagogical approach employed during the CCM activity—the generalized interpretations and explorations of concept maps and mapping detailed the means and methods employed by learners to extract knowledge from the deemed useless conscious representations of another. Of particular importance was the dissonance or 'points of contention' created by concept maps as these represent moments where prudent inquiry and guided questioning could result in constructive dialogue for the development of collectivity within the created classroom community.

Objective 2: Cooperative Concept Mapping, Epistemic Realization, Self-Actualization and Community Views of Science

Cooperative concept mapping as a culminating vehicle for discourse and dialogue in science education. Data used to determine the feasibility and veracity of employing CCM as a culminating task for the development of discourse and dialogue includes: a) the "Views of Nature of Science" pre-questionnaire to benchmark student conceptions of science; b) a post-task focus group as a means to further engage students in a collective discussion with regards to scientific interpretation; c) a reflective handout highlighting perspectives of collective artefact development; d) observational notes to further confirm or disconfirm participant claims and responses to reflective handouts; e) developed CCMs to determine accuracy of thoughts and representation of dialogue as related to science; and f) individual longitudinal interviews to further elucidate reflective responses collected though other means (for example, questionnaires, focus group, handouts, notes and concept maps).

Defining pseudo-scientist. Pedagogical intentions were far from the lofty goal of epistemic change, as doing so would require a great deal more than a simple one-shot task (a more fitting approach, for example, would be an instructional system intended to call attention to the overarching goals of the Nature of Science). The inherent goal of the CCM task was to underline the nature of malleability and rigidity within epistemic belief systems as represented through science from the perspective of the pseudo-scientist.

Interpreted from a socio-collective perspective, a pseudo-scientist as defined by the greater scientific community, represents the hierarchically stratified perspective of science as a solution and of scientists as providers of them—scientists being those who are engrossed in discipline-specific development of scientific knowledge. Those who work outside disciplines, who practice scientific exploration through secondary or tertiary endeavours (for example, citizen scientists) are relegated to the sidelines of scientific development and thinking, considered outside the realm of science and more so working within the fringes; not adding to the greater body of scientific knowledge but extracting from it. Such un-emancipated scientific knowledge reinforces interpretations of science as a form of disciplinary thought—inextricably linked to a discipline versus rooting within and dependence upon a process or method. It is therefore a purpose of this exploration and of the CCM task to aid in the development of a singular, practical ideal—that science or ‘doing science’ involves the adoption and application of its root process, the scientific method—nothing more, nothing less.

For example, considering the pre-service teacher population being explored, there was a need to see oneself as a chemist, biologist, physicist and so on to effectively teach science. Hypothetically, if such limits were extended to the arts, abstraction and manipulation of form and function, interpretation of the natural world through a creative lens, would not define 'artist'. Art would be reserved for those working within a particular paradigm, discipline or medium—only those whose work remains within societally-defined and accepted boundaries, who limit themselves to the medium, form and function dictated by their paradigm would be considered artists (for example, painters, sculptors and citizens of a similar ilk). Through such a conceptual definition, inter-disciplinarity and tangential schools of thought (science as art form) become a moot concept.

As a culminating task, CCM achieved its intended purpose; collective interpretations became evident and participants defined science as they have come to interpret it—from practical, experiential and pedagogical perspectives. The CCM task managed to provide a forum to engage in discussions with peers, to collectively determine that their conceptions of science are similar. It was seen as a cathartic process, allowing for an open conversation, vetting concepts and their associations as they cumulatively determined the structure of their individualized interpretations as a reflection of a collective ideal. This process lent itself to worthwhile, meaningful moments of negotiation, where learners felt it necessary to 'come to terms with' what they had each learned over the course of the semester—engaging, to a certain degree, in their own version of dialogic substantiation—discussing, vetting and refining interpretations so as to pinpoint and define those constructs which led to cognitive dissonance. For example, one particular collective concentrated negotiative efforts on defining 'central variables and missing links' of science education. Such efforts were hindered by attempts to define 'the role of students', which was eventually deemed improbable as their function continuously fluctuated from scientist to learner to teacher. The learner, when considered a member of the scientific process, was far more central than they had initially conceived.

Other outcomes worth noting include the notions of science as being intrinsically connected to society, its role in developing, promoting and maintaining a community, embedded-ness within our daily lives both as a method/process and as foundational knowledge composed of 'overwhelming depth' and 'layers'. On a number of occasions the scientific method as a means to elaborate and structure experimentation and inquiry was highlighted and science was seen as guided process not solution.

Discussion centred upon the 'brainstorming process', the strategic development of a shared pool of concepts, associations and relationships to be included in the cooperative concept maps. Noteworthy secondary outcomes to this process include the realization of numerous 'overlapping ideas' amongst peers, that these ideas of science were 'extremely' linked on a number of different 'multi-faceted' levels and that associations were far greater than initially conceived.

While defining terms within the collective pool of thought, uniqueness in interpretation and definition ultimately dictated terms and ideas considered 'workable' or 'in need of elaboration'. This very uniqueness, disparity between word-meanings and their uses, drove dialogue and facilitated the development of collective conceptions. Participants felt 'overwhelmed' though 'comfortable' knowing that they could support their views as easily as their peers could challenge them and vice versa. Reciprocity in learning, from such perspective of collective dialogic inquiry, was evident through the final inclusions made within most maps—overarching concepts or 'big ideas' were defined not through reconciliation of group thought or reason, but through representation of group thought and reason. The concept map was therefore applied as it was intended and its structure allowed for each participant's 'voice' to be clearly apparent, without stratification—each definition was included yet no one interpretation took precedence or was included at a structurally 'higher' level.

In comparison, structure was also considered a major roadblock as students associated their inability to present reconciled definitions to an overarching lack of knowledge as well as an inefficacy towards 'boiling down thoughts' or 'focusing on needing too many links' which 'watered down' arguments. Refinement of linkages was particularly problematic, as manipulation seemed 'easy' and 'ineffective'—possibly pinpointing the need for CCM creation guidelines to stress elaborated and descriptive linking terms. It can be assumed and affirmed, however, that troubles negotiating links and connections were more so a factor of time-on-task versus understanding. Longitudinal interviews pinpointed learner dependency upon ongoing discussions, without time or structural limitations, as they were necessary to wholly determine the extent of existing relationships between 'big ideas' and/or concepts discussed/included by working groups.

As a function of self-actualization, CCM facilitated the realization of epistemic belief systems—learners became aware and prideful; they successfully evolved in comparison to their initial conceptions of science as reflected through their benchmarked responses to the VNOS questionnaire as well as their evolution in interpreting structures and systems which govern scientific thought. 'How far they came', 'baby steps' and ‘being on their way’ were comment sentiments shared amongst the cohort as a reflection of achieving epistemic change, or sparking the process of epistemic change.

On the other hand, for some, epistemic rigidity and the paradigmatic notion of ‘a teacher’ overpowered the purpose of the CCM activity—teaching and its fervent methodological underpinnings of planning and structure were seen as far more fundamental than engaging in scientific discourse with learners. Science, for a small minority, is not a product of human inquisitiveness, rather a discipline or domain like any other—rigid and in need of extensive pedagogical planning for effective transmission of knowledge. From such a perspective, science is minimized to transferable ideas, facts and theories—methods of yore are relied upon (for example, memorization and regurgitation) instead of personalized reason and thought.

Objective 3: Cooperative Concept Mapping, Pre-Service Teacher Education and Systems of Science Education

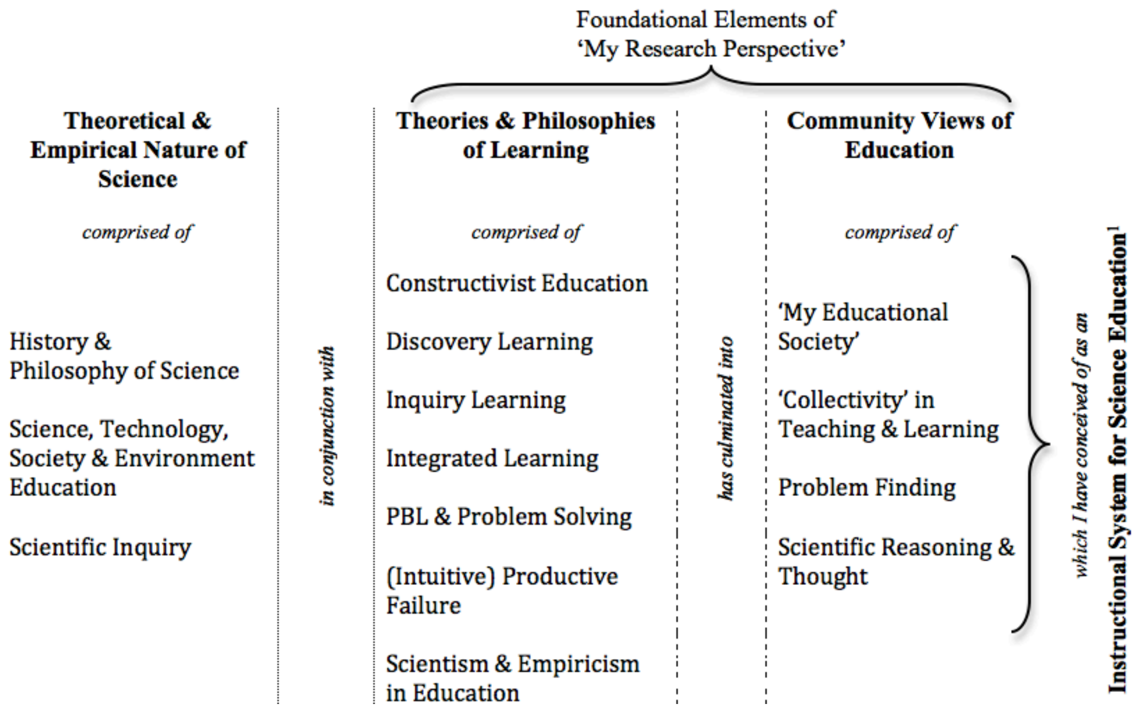


Figure 2. Re-visiting cooperative concept mapping as a function of CVOS
[1]'Cooperative Concept Mapping' was explored as a culminating task for the promotion of collective criticality and reflection for the development of pre-service elementary science educators.

Cooperative concept mapping as function of the developed system of instruction. As represented through the figure above (Figure 2. Cooperative concept mapping as a function of CVOS) and as elaborated through the table below (see Table 5. CCM as a Function of CVOS), the goal for this exploratory study was to present an instructional system which affords pre-service science educators an opportunity to realize their inherent perspectives of science, to challenge the rigidity of such epistemic beliefs, to further the existence of epistemic systems and to present reasoning which attempts to illustrate their malleability. Though the instructional system was not dissected and explored in its entirety, elements were extracted and explored in some detail—namely, cooperative concept mapping as a culminating task allowing for the creation of a ‘space’ for collective ‘sharing of voice’.

Element of CVOS	CCM Data Exploring Development of CVOS	Instructional System Supporting Development of CVOS
Social nature of facts, hypotheses and theories	Participant statements and reflections detailing: peer-based affirmations of scientific thoughts; science as a process of social inquiry; scientific method as a collective process	Problem finding as a means to encourage dialogue and discourse surrounding interpretation of fact, theory and hypothesis
Social nature and inextricability of observations and inferences	Reaffirmation of scientific knowledge as a combination of multiple perspectives; scientific knowledge as an outcome of observation and inference as an outcome of observation	Assumed roles in scientific discovery and development
Empiricism and objectivity through methods and processes	Statements elaborating scientific method as a socio-collective process	Problem finding; draw a Scientist; draw a teacher
Pervasiveness and dilution of human error	Human error considered a factor of socio-cultural interpretations and implementations of science	Discrepant scenarios; problem finding as depicting science as flawed
Socio-collective nature and impact of knowledge as being a tentative entity	Scientific knowledge vetted and confirmed, impact	Pedagogical endeavours (e.g. science fair) aimed to provide voice for student and citizen science

Unforeseen impact of scientific knowledge and endeavours	Unforeseen impact of scientific knowledge deemed an outcome of 'science as a solution' and a 'lack of criticality' towards scientific knowledge	(Intuitive) productive failure and associated tasks reflective of 'negatives' associated to science; problem-finding as a determinant of discrepancies/errors in science/scientific knowledge
Need for scientific transparency and a shift to science as community science	Transparency as means for the involvement of citizens (e.g. 'general population')	Collectivity in the classroom; development of community through combined scientific efforts and assumed roles within observation, inference and analysis

Table 5. CCM as a Function of CVOS

Objectives 1, 2 and 3: Transforming Epistemic Beliefs ('Sparking Change' and 'Fanning Embers')

Structures and systems: Science, no longer a solution. In opposition to their initial epistemic views of science as a deliverer of solutions—detailed through collected 'Views of the Nature of Science'—CCM participants were quick to acknowledge that science can be conceived of as a means to determine a possible explanation, a process used to illuminate versus conclude. This outcome was of importance as it initiated the questioning of previously engrained beliefs of science and allowed for participants to perceive of science as contingent upon hypotheses and assumptions, not fact and truth—therefore actively questioning the very roots of societally accepted science and asymptotically reflecting a major tenet of the "Nature of Science". This very distinction between solution and explanation, confirmed through longitudinal interviews, was the precursor to creating the very spark which allowed for malleability in epistemic belief systems.

Rigidity versus Malleability. The greatest epistemic affront experienced by the pre-service science educators explored and analyzed was created by the battle between acknowledging and accepting roles and responsibilities as defined by the societal definition of ‘teacher’ versus that of ‘scientist’. To further this point of epistemic rigidity, a separate reflective activity, coined ‘Draw a Teacher’ (see Appendix, ‘Draw a Teacher’), was put into practice throughout the semester. Akin to the widely used ‘Draw a Scientist’ activity, ‘Draw a Teacher’ illustrated the existence of societally pre-determined traits and characteristics of ‘teachers’ which, over time, become engrained within our greater teacher population (a discourse, if viewed from the Foucauldian camp). Through ‘Draw a Teacher’ it became abundantly clear that most participants’ personal beliefs about teaching were dictated through misconstrued conceptions of teaching and learning as being a highly structured and planned process. Surprisingly, opposing perspectives were dismissed, deemed ineligible for further discussion. I believe a similar mindset exists when pedagogues are confronted with the notion of being scientists—of engaging in, exploring and learning from scientific pursuits. Their inability to relinquish the title of teacher, rigidity in how they perceive themselves and their inclusion within the working paradigm, creates unnecessary limits to how they interact with knowledge outside their realm of thought. For this to be an exhibited trait of teachers is, in my opinion, a formidable flaw as it highlights an innate rigidity towards idea and reasoning outside a perceived spectrum of expertise.

A glimmer of hope, however, does exist. As was expounded through the CCM task, these very pre-conceived notions of teacher and scientist are not as rigid as assumed—they are, in reality, malleable. Those who are willing to engage in collective thought (there are some who refuse to renounce what they have understood as teaching) are also willing to have their belief systems challenged by outsiders, as well as themselves. Such malleability, in my opinion, lays the foundation for altering, modifying, adapting or influencing epistemological thought—essential if we are to consider the development of reasoned, scientifically minded, pedagogues.

Streams of consciousness as substantiation. As was seen through comparisons of CMA and CCM groups' perspectives on the nature of their respective tasks, CCM participants were able to underline and pinpoint the creator's 'stream of consciousness' as it was represented through the developed concept maps.

This outcome can possibly be explained through participants' need to substantiate their pre-conceived notions of science. CCM, as stated by participants, provided a first hand account from their peers—similar to an eye-witness testimony—elaborating upon their differing views of what makes science, science (for example, details surrounding conception of connections, the existence of links between/through terms and supporting practical/experiential accounts). Through CMA, participants' awareness of concept mapping as a representation of non-linear streams of thought was evident though not as clear—most of the participants were left contemplating why or how the presented thoughts about science significantly differed from or elaborated upon their own. They questioned themselves, but failed to progress to the second step of investigating the roots of such questioning—perhaps the lacking associated discourse, the space created between creator and interpreter was noteworthy and capable of minimizing the resultant epistemic spark. The challenge (in other words, the fire created within the interpreter) was small enough to quell—incapable of razing thoughts in their entirety, but capable of singeing them.

Though, it can also be said that the interpretation of these roles, of 'creator' and 'interpreter' were invariably changed for those involved in the CCM task—seeing as how all involved were considered creators and interpreters, the knowledge being shared may have been considered a collective product of their community—substantiated by, embedded within and reliant upon the divergent yet complementary members of the collective. Such shifts, once again, challenge the nature of pre-service educators' rigidity of epistemic beliefs, that knowledge, though contradictory can be supportive.

Science as Collectivity: Resolving Discourse and Debate through Cooperative Creation

The art and act of developing an artefact, of culminating dialogue and debate through visual representation was seen as a contributory factor in promoting participants to engage with and explore thoughts and views surrounding science. This was achieved through their envisioning a common goal—to represent one's ideas through the perspective of a collective.

Efforts to guide inquiry, through pedagogical scaffolds (e.g. appropriate guiding questions, representative classroom tasks and so on) furthered the inherent process of 'dialogic substantiation', regardless of the logistics and semantics associated to the CCM task—defining linking terms, uniqueness in interpretations and creating a pool of concepts. As employed by the participants, dialogic substantiation and the ensuing divisive dialogue elaborating innermost beliefs was believed to have multiplied the benefits associated to cooperative development of concept maps. In the end, what meant more to participants was having their views adequately challenged as they interpreted such opposition as being rooted in the task and therefore representative of how they had grown within a new perspective of science and science education.

Conclusions and Educational Significance:
CVOS, NOS, Science Education and Teacher Preparation

Contemporary approaches to teacher preparation emphasize the development of inter-disciplinary practitioners, capable of holistic reflection and abstraction—aware of conceptual, practical, structural and systematic roadblocks to teaching and learning while remaining tacit in institutional agendas and focused on developing socio-critical citizens with worldviews rooted in agency for change. The “Nature of Science” aims to inculcate, within citizens, a healthy yet malleable scepticism of scientific methods, processes and outcomes. From these roots—the intersection of critical, reasoned pedagogy and science—the developed ‘Community Views of Science’ aims to reinforce the “Nature of Science” as a worthwhile objective for science education of the 21st Century. Though it underlines and elaborates a need to focus science education efforts upon social inquiry as the vehicle for criticality towards the interpretation of scientific information and knowledge, its goal remains clear—to have learners, young and old, realize their role as a necessary and functional cog in the scientific machine.

To achieve its purpose in pre-service teacher education, to create ‘socio-critical’ inheritors and conveyors of knowledge, CVOS was conceived of as an instructional system—comprised of and subsumed by a series of pedagogically-grounded, interconnected, community-driven, inquiry based educational events and tasks which allowed for the creation, promotion and maintenance of ‘space’; ‘space’ where argumentation and discourse—‘dialogic substantiation’—could and did allow for the realization of existent epistemic belief systems.

As a sequential and atomistic progression through scaffolded discovery, CVOS and its associated instructional system wholeheartedly embrace current evolutions in science education and relevant greying of paradigmatic boundaries—the move away from a critical perspective of science as a solution towards science as an outcome (for example current interpretations of Science, Technology, Engineering and Mathematics—STEM—education, whose focus remains on promoting the benefits to ‘careers’, ‘institutions’ and ‘organizations’ engaged within scientific practice). Though implicitly at odds with the pillars of CVOS (STEM, as an example of an approach at odds with CVOS), CVOS’ inherent reflectivity of science as socio-cultural endeavour, allows for the quelling of these very differences; learners are encouraged to see the development of such new paradigms as systems affording criticality. What remains absolute is the need to question and debate the intentions of such ‘new school’ approaches—to determine whether their influence will afford for the creation of pre-service educators capable of instilling within learners a need to question and interpret, not indoctrinate.

Therefore, to promote the use of dialogically grounded culminating tasks within science education, the following recommendations for the use of the cooperative concept mapping as a proponent within a developed system of instruction (as described herein) incorporate both logistic and pedago-cognitive guidelines. These include, a) allowing for and scaffolding the collective development and elaboration of terminology representative of concept mapping (includes both concepts and associations); b) allowing for the self-creation and management of groups as roles tend to result haphazardly, somewhat self-assumed/enforced; c) to guide inquiry through tasks and events promoting dialogue and to provide resources foreshadowing major tenets of the developed instructional system; d) to create 'space' for the development of non-stratified knowledge—equal voice, equal opportunity and therefore validity in a proven argument and thought—the roots of divergency and curiousity; e) to limit instructor 'preachy-ness', as this is simply bad pedagogical form and creates/affirms perspectives of stratified knowledge; and f) to consistently and continuously question reason, thought and ideology (as this is profound pedagogical practice, in its 'truest' form).

As a result of the cooperative concept mapping culminating task and the instructional system presented above, it became apparent that collectivity in science—afforded and developed through the reinforcing of community—can seem a lofty goal, though it is possible to causally develop. As such, seeing as community and collectivity remain within our pedagogical grasp, it can be contended that social harmonization, perhaps through a form of 'dialogic substantiation' can also be achieved. Then again, who knew communication was at the root of 'getting along'.

Defining Practitionership: Revamping 'My Educational Society'

The research described herein, exploring cooperative concept mapping and its potential effects on creating community views of science, also intended to refine and present an elaborated account of practitionership as assimilated and presented by the primary researcher. As described (see, 'My Educational Society'), the notion of an educational society was brought forth as a means to define a framework for a 'community'—members as well as their roles, confounding and moderating variables and constituent elements—which affords the development of 'societal views' through a focus on informed pedagogical practice.

Refined below, 'My Educational Society' (see Table 6. Revamped 'My Educational Society') presents the primary researcher's evolved view of an educational society—defining roles of and variables impacting the development of informed and reasoned pedagogical practice as a function of a community view of science and the development of scientific knowledge. Though it remains tentative and in need of clarification (perhaps even exploration), it presents, to an adequate degree, the primary researcher's notion of evolved or progressive practitionership—to directly extract from and to inculcate outcomes of one's research in hopes of redefining the very structure employed as a lens interpreting the microscopic and macroscopic relationships which exist within a working paradigm—recursively and iteratively, from theory to research to practice.

In comparison to table 1 ('My Educational Society') the following revamped 'My Educational Society', focuses on the use of scientific processes and methods of exploration to further an ideal of communal criticality within teaching and learning.

	Foundations of Education	Pedagogical Practice	Societal Implications
Instructors[1], Learners[2] & Pedagogical Practice	‘Systematically’ comparing varying pedagogical approaches Holisticism in teaching practices Integrating “Teachnologies”	Communally planning and developing instruction Teaching across the school and state curriculum Processes, methods and plans in education Integrating and promoting “Scientific Inquiry” Integrating “Teachnologies”	Knowledge as tentative and development as a collective process Diversity and inclusion in education Integrating collective interpretations of science and technology
Institutions[3] & Communities[4]	Philosophies and epistemologies of education and the history and nature of science in education Creating, promoting and maintaining communities/collectives of learning/practice Differentiating institutional and communal perspectives	Science in education Educational research as a product of scientific inquiry Collective questioning of information and knowledge Creating, promoting and maintaining communities of learning/practice	Importance of ministerial/state curricula Creating, promoting and maintaining communities

Table 6. Revamped ‘My Educational Society’

[1]Instructors & [2]Learners: Used to represent the inherent power relationship with regards to the transmission of knowledge

[3]Institutions: Extended relationship between theory and practice; curricula-driven procedures, guidelines, general objectives; role and nature of the ‘school’

[4]Communities: Micro-to-macro learning communities—classroom community, school community and research community

Future Research: From Doctoral Dissertation to Academic Profile

As an aspiring academic, developing a program of research affording concepts worth exploring for the emancipation of knowledge and knowledge systems with regard to the general learning public, is at the forefront of my discussed research agenda. It is with this intention that future research, derived from this dissertation exploring epistemics, focuses on the propagation of the described instructional system (CVOS) and of related constructs (tools, procedures and mechanisms which aid in the promotion and fostering of CVOS).

To further the development of knowledge vehicles, research of CVOS will possibly explore its other constituent elements independently, inter-connectedly and as a composite whole (for example, to explore problem finding as a function of collective reflexivity). Longitudinal implementations of CVOS-based systematic instruction in pre-service teacher development and an exploration of short and long term in-service teacher retention of views and beliefs surrounding science and collectivity and reflexivity in science may also prove time-consuming (in a good way/for years to come) and worthwhile.

To further the primary researcher's scientific profile, to be an empiricist cog in the research machine, future research seeks to further delve into the ecological and cognitive variables which can deepen our understanding of CCM creation. Perhaps, in hopes of reflecting scholarly development as an educational technologist, technologies affording CCM creation in real time may be explored (e.g. research-driven user interfaces).

Though worthwhile as a culminating task to initiate and reinforce epistemic change within pre-service elementary educators, the CCM activity was limited due to its inclusion as a classroom activity—learners and therefore participants were obligated to analyze and interpret the CCM task as well as develop the CCM artefact within a single classroom session. Such limited time for reflection (on the task and content of the map) was perhaps responsible for the simplicity of the concept maps developed—though it should be noted that associated reflections were given ample regard and were completed diligently. Future explorations replicating CCM development will assuredly include multiple moments for and resources supporting the reflective process. For example, if completed over an extended period where classroom constraints could be mitigated, the CCM task would include time for general concept map interpretation, development of a collective pool of concepts, associations and relationships, development of a 'big idea' map (conceptualization of what the collective map will hope to explore) and development of a collective map. As a means to foster reflection within and amongst groups, reflection sessions (instigating dialogue upon the various stages) would be interspersed throughout.

In addition to the interview-based CMA, 'Cohort 3' was also subject to eye-tracking which aimed to shed light upon the nature of gaze behaviour as well as the systematic nature of semantic network interpretation. Group-dynamics analysis with respect to concept map dissection may prove engaging and beneficial to eye-tracking literature surrounding variables embedded within theoretical self-regulated learning. The eye tracking portion of the research plan, albeit it in a pilot phase, hopes to further define key variables from a cognitive science and education perspective.

In any case, analysis and primary coding of individual and group eye-tracking data will serve as an adequate stepping-stone into academic research (e.g. commence mining, compiling and analyzing traditional eye-tracking variables such as fixation, duration and transition—these traditional variables can be interpreted vis-à-vis a personal construct, as a function of problem finding).

Concluding Remarks: Defining Educational Thought and Reason

Community views of science were examined through analyses of learner reflections and dissections of semantic networks and maps. The goal of this dissertation was to develop pedagogically-forward methods of instruction and evaluation to better 'interpret scientific reasoning' as impacted by epistemic systems of scientific indoctrination—by painting a picture of how pseudo-scientists (e.g. pre-service teachers) go about deciphering, analyzing and interpreting curriculum-based resources and subsequently developing a model of community science propagated as a means to achieve the long sought ideals envisioned by the "Nature of Science". 'Socio-critical Science and Inquiry' (SCSI), as has been extrapolated from this exploration CVOS, aims to paradigmatically refine current conceptual definitions of science education (perhaps, within current science education trends, SCSI can assist in the development of a framework for Science in STEM education).

Confounding the Debate: Empiricism, Philosophies and Epistemologies

Though a cursory review of educational thought would highlight certain inconsistencies between empirical and philosophical orientations towards educational research, it is believed that foundationally interpreting and dissecting the two as separate entities of a linear spectrum is a fundamental flaw regarding how inquiry in education is conceived, perceived, interpreted and enacted.

To wholly interpret the progression of inquiry within Education, we must acknowledge the natural progression and evolution of inquisitiveness as well as how distinct systems of society (Bijker et. al, 1989; Boyd, 2006) engage in a complex dance—how each system, be it a reflection of technological structures or social structures, affects one another. For example, Dewey (1900; 1956; 1971) and Waddington (2010) depict social evolution as being a proponent for and direct result of technological integration and scientific evolution. As science and technology advances, as they permeate daily life, we as a collective seek to integrate their prowess into our general functioning (an interpretation of McLuhan's "Media is the message", 1964)—usually in hopes of manipulating our natural resources and modes of production (Heidegger, 1977).

It can be argued that philosophical interpretations of the human mind, the ongoing debate between idealism and realism, resulted in a greater conception of empiricism within education—when reality and the mind are assumed to exist, the eventual result will be the development of theories which aim to interpret interactions between individuals and their environments. Therefore, it cannot be said without a doubt, that empiricism and philosophies of knowing are 'at odds'—they are rooted within each other and are essentially a reflection of one another.

To contend that many perceive empiricism and philosophical orientations as being divergent, forgoes their inextricable roots within a greater epistemological frame of thinking—when combined they act as a framework for "knowing". Given the nature of such an epistemology, we as pedagogues (teachers and researchers) within this distinct field, are left to determine the paradigmatic boundaries of our 'workplace' (Kuhn, 1962; Canguillhelm, 1988). It is our choice whether we choose to remain stagnant within the spectrum, either accepting: a) the false quantitative and qualitative duality; b) a philosophical reflection of the mind; or c) interactions within and amongst both. If we choose to remain dynamic within the spectrum/system, we become willing to understand the need for a perspective rooted in interactions between methodologies and interpretations of individuality.

With that said, structural or procedural standpoints result in a need to support our endeavours through generalized processes (e.g. scientific method) allowing us to purport a lens of objectivity. These processes, rooted within the scientific method, allow for the systematic exploration of minutiae—of distinct operationalized variables we intuitively control regardless of our efforts to ensure generalizability while remaining valid and reliable (Creswell, 2011).

An exploration of educational thought, from 'grandmasters' to 'neophytes', asserts the goals of education as reinforcement for the attainment of social collectivity. From such empowered voices (e.g. Dewey, 1900, 1971; Friere, 2000; Tagore, 1952; Boal, 2000; Foucault, 1977, 1980; Hyslop-Margison & Strobel, 2008; Waddington, 2010; Martinet, Raymond & Gauthier, 2001; Rosenblatt, 2011), it can be perceived that the fundamental role of education is to ensure the development of critically-aware informed citizens who are able to understand their underlying role within the structures that do exist and most importantly to enact and embody knowledge so they may be proponents of greater social harmonization.

References

Abd-El-Khalick, F., Lederman, N. G. (2000). Improving science teachers' conceptions of the nature of science: a critical review of the literature. *International Journal of Science Education, 22*(7), 665–701.

Abd-El-Khalick, F. (2006). Over and over again: college students' views of nature of science. In: Scientific Inquiry and Nature of Science: Implications for Teaching, Learning, and Teacher Education, ed. L. B. Flick and N. G. Lederman, Dordrecht, The Netherlands: Kluwer Academic Publishers, 389–426.

Abruscato, J. (2004). *Teaching children science* (6th ed.). New York, NY: Allyn & Bacon.

Agustin, A. B. (2013). A 'semantic view' of scientific models for science education. *Science & Education, 22*(7), 1593-1611.

Alters, B.J. (1997). Who's nature of science? *Journal of Research in Science Teaching*, *34*(1), 39-55.

Anderson, G. L. (1994). *Studying Your Own School. An Educator's Guide to Qualitative Practitioner Research.* Thousand Oaks, CA: Corwin Press, Inc.

Bauer, H. (1992). *Scientific literacy and the myth of the scientific method.* Urbana, Ill: University of Illinois Press.

Boslough, J. (1985). *Stephen Hawking's universe: An introduction to the most remarkable scientist of our time*. New York, NY: Avon Books.

Canguilhem, G. (1968). *Etudes d'histoire et de philosophie des sciences*. Paris: Librairie Philosophique.

Clark, C. (1990). What you can learn from applesauce: A case of qualitative inquiry in use. *Qualitative Inquiry in Education: The Continuing Debate*, 327-338. New York, NY: Teacher's College Press.

Cohn, C. (1987). Sex and death in the rational world of defence intellectuals. *Signs, 12*(4), 687-718.

Colburn, A. & Clough, M.P. (1997). Implementing the learning cycle: A gradual transition to a new teaching approach. *The Science Teacher,* May, 30-33.

Creswell, J. W. (2008). *Educational research: Planning, conducting and evaluating quantitative and qualitative research* (3rd ed.). Columbus, OH: Merrill Prentice-Hall.

Davies, D. (2010). *Teaching science creatively*. New York, NY: Routledge.

Dewey, J. (1897). My pedagogic creed. *School Journal, 54*, 77-80.

Dewey, J. (1915). *School and society*. Chicago, Ill: University of Chicago Press.

Ertmer, P. & Newby, T. (1993). Behaviourism, cognitivism, constructivism: Comparing critical features from an instructional design perspective. *Performance Improvement Quarterly, 6*(4), 50-72.

Foucault, M. (1977). *Discipline and punish: The birth of the prison*. Toronto, ON: Random House.

Foucault, M. (1977). *The archaeology of knowledge.* London, UK: Tavistock Publications.

Foucault, M. (1979). On governmentality. *Ideology and Consciousness*, 6, Autumn.

Foucault, M. (1980). *Power/knowledge: Selected interviews and other writings 1972-1977*. C. Gordon (Ed.). New York, NY: Pantheon.

Freire, P. (2000). *Pedagogy of the oppressed*. London, UK: Continuum.

Gabel, D. L. (1994). *Handbook of research on science teaching and learning*. New York, NY: Macmillan Publishing Company.

Gilbert, J. K. (2013). Constructing Worlds through Science Education. New York, NY: Routledge.

Guba, E. G. (1981). Criteria for assessing the trustworthiness of naturalistic inquiries. *Educational Resources Information Center Annual Review Paper, 29*, 75-91.

Hadzigeorgiou, Y. (2013). Reclaiming the value of wonder in science education. In K. Egan, A. I. Cant & G. Judson, *Wonder-Full Education: The Centrality of Wonder in Teaching and Learning Across the Curriculum* (40-63). New York, NY: Routledge.

Herman, B. C., Clough, M. P. & Olson, J. K. (2013). Teachers' nature of science implementation practices 2–5 years after having completed an intensive science education program. *Science Education, 97*(2), 271-309.

Hestenes, D. (2013). Remodeling science education. *European Journal of Science and Mathematics Education*, *1*(1), 13-22.

Hyslop-Margison & Naseem, M. A. (2007). *Scientism and education: Empirical research as neo-liberal ideology*. New York, NY: Springer.

Hyslop-Margison, E.J. & Strobel, J. (2008) Constructivism and education: Misunderstandings and pedagogical implications. *The Teacher Educator, 43*(1), 72-86.

Irez, S. (2006). Are we prepared? An assessment of preservice science teacher educators' beliefs about nature of science. *International Journal of Science Education*, *90*, 1113–1143.

Irwin, A. (1995). Citizen science: A study of people, expertise and sustainable development. New York, NY: Routledge.

Jonassen, D. (1991). Objectivism vs. constructivism. *Educational Technology Research and Development, 39*, 5-14.

Keeney, H., & Keeney, B. (2012). Recursive frame analysis: Reflections on the development of a qualitative research model. *The Qualitative Report*, *17*(2), 514-524. Retrieved from http://www.nova.edu/ssss/QR/QR17-2/keeney.pdf

Krefting, L. (1991). Rigor in qualitative research: The assessment of trustworthiness. *The American Journal of Occupational Therapy*, *45*(3), 214-222.

Kleining, G. & Witt, H. (2000). The qualitative heuristic approach: A methodology for discovery in psychology and the social sciences. Rediscovering the method of introspection as an example. *Forum Qualitative Sozialforschung/Forum: Qualitative Social Research*, *1*(1), Article 13.

Klopfer, L.E., & Cooley, W.W. (1963). The history of science cases for high schools in the development of student understanding of science and scientists. *Journal of Research in Science Teaching*, *1*, 33-47.

Kuhn, T. (1996). *The structure of scientific revolutions.* Chicago, Ill: University of Chicago Press.

Latour, B. & Woolgar, S. (1986). *Laboratory life.* Princeton, NJ: Princeton University Press.

Lave, J. & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation*. Cambridge, UK: Cambridge University Press.

Leach, J. & Scott, P. (2013). Designing and evaluating science teaching sequences: An approach drawing upon the concept of learning demand and a social constructivist perspective on learning. In R. Holliman & E. Scanlon, *Mediating Science Learning Through Information and Communications Technology* (81-102). New York, NY: Routledge.\

Lederman, N. G., Abd-El-Khalick, F., Bell, R. L., & Schwartz, R. (2002). Views of nature of science questionnaire: Toward valid and meaningful assessment of learner's conceptions of nature of science. *Journal of Research in Science Teaching*, *39*(6), 497-521.

Lederman, N. G. (1999). Teachers' understanding of the nature of science and classroom practice: Factors that facilitate or impede the relationship. *Journal of Research in Science Teaching*, *36*, 916–929.

Lederman, N. G., & Zeidler, D. L. (1987). Science teachers' conceptions of the nature of science: Do they really influence teacher behavior? *Science Education*, *71*, 721–734.

Martinet, M.A., Raymond, D. & Gauthier, C. (2001). Teacher Training: Orientations and Professional Competencies. Quebec Education Program, *Ministère de l'Éducation, du Sport et Loisirs*.

Maslow, A. H. (1943). A theory of human motivation. *Psychological Review*, *50*(4), 370.

Maslow, A. H. (1943). *Motivation and personality*. New York: Harper.

McDermott, R. (1996). The acquisition of a child by a learning disability. In S. Chaiklin & J. Lave (Eds.), *Understanding Practice: Perspectives on Activity and Context* (269-305). Cambridge, UK: Cambridge University Press.

McInnerney, J. & Robert, T. S. (2004). Collaborative or cooperative learning? In T. S.

Roberts (Ed.), *Online collaborative learning: Theory and practice* (203-214). Hershey, PA: Information Science Publishing.

Moustakas, C. (1994). Phenomenological research methods. London: Sage.

Nesbit, J. C. & Adesope, O. O. (2006). Learning with concept and knowledge maps: A meta-analysis. *Review of Educational Research*, *76*(3), 413-448.

Neumann, I., Neumann, K. & Nehm, R. H. (2011). Evaluating instrument quality in science education: Rasch based analyses of a nature of science test. *International Journal of Science Education, 33*, 1373–1405.

Novak, J. D. & Cañas, A. J. (2006). The theory underlying concept maps and how to construct them. Pensacola, FL: Florida Institute for Human and Machine Cognition. Retrieved from http://cmap.ihmc.us/publications/researchpapers/theorycmaps/theoryunderlyingcocceptmaps.htm

Novak, J.D. & Gowin, D.B. (1984). *Learning how to learn.* Cambridge, UK: Cambridge University Press.

Pedretti, E. & Nazir, J. (2010). Currents in STSE education: Mapping a complex field, 40 years on. *Science Education, 95*(4), 601-626.

Phillips, D. C. (1971). *Theories, values and education*. Victoria, Australia: Melbourne University Press.

Phillips, D. C. (1995). The good, the bad, and the ugly: The many faces of constructivism. *Educational Researcher, 24*(7)*,* 5-12.

Phillips, D. C. & Burbules, N.C. (2000). *Postpositivism and educational research*. Maryland: Rowman and Littlefield.

Popper, K. (1985a). The problem of induction. In D. Miller (Ed.), *Popper Selections* (*101-117).* Princeton, NJ: Princeton University Press.

Popper, K. (1985b). The problem of demarcation. In D. Miller (Ed.), *Popper Selections* (118-132). Princeton, NJ: Princeton University Press.

Popper, K. (1985c). Scientific method. In D. Miller (Ed.), *Popper Selections* (133-142). Princeton, NJ: Princeton University Press.

Roscoe, K. & Mrazek, R. (2005). *Scientific literacy for Canadian students: Curriculum, instruction and assessment*. Calgary, AB: Detselig Enterprises.

Rosenblatt, L. B. (2011). *Rethinking the way we teach science: The interplay of content, pedagogy, and the nature of science*. New York, NY: Routledge.

Roth, W.M. (1997). From everyday science to science education: How science and technology studies inspired curriculum design and classroom research. *Science and Education, 6*, 373-396.

Shaikh, K. & Zuberi, A. (2012, May). An analysis of STSE pedagogical practices at an annual pre-service teacher science fair. Paper accepted for presentation at the Canadian Society for the Study of Education (CSSE) Annual Conference. Waterloo, Ontario, Canada.

Shaikh, K., Zuberi, A., Waddington, D. I., Thomas, T. & Venkatesh, V. (2011). A manifesto for technological transparency in the age of web 2.0. *Canadian Issues*, Spring, 87-90.

Skinner, B. F. (1968). Technology of teaching. NY: Appleton Century Crofts.

Tagore, R. (1998). *Rabindaranth Tagore: An anthology.* K. Dutta & A. Robinson (Eds.). London, UK: St. Martin's Griffin.

Tobin, K., Tippins, D. J., & Gallard, A. J. (1994). Research on instructional strategies for teaching science. In W.M Roth & J. Désautels (Eds.), *Science Education as/for Sociopolitical Action.* New York, NY: Peter Lang.

Waddington, D.I. (2010). Scientific self-defense: Transforming Dewey's idea of technological transparency. *Educational Theory, 60*(5), 621-638.

Wegerif, R., Postlethwaite, K., Skinner, N. Mansour, N., Morgan, A. & Hetherington, L. (2013). Dialogic Science Education for Diversity. In N. Mansour, & R. Wegerif, *Science Education for Diversity* (3-22). Netherlands: Springer Science and Business Media Dordrecht.

Zeidler, D. L., Berkowitz, M. W. & Bennett, K. (2014). Thinking (Scientifically) Responsibly: The Cultivation of Character in a Global Science Education Community. In M. P. Mueller, D. J. Tippins & A. J. Stewart (Eds.), *Assessing Schools for Generation R (Responsibility)* (83-99). Netherlands: Springer Science and Business Media Dordrecht.

Appendices

Compiled Tables and Figures

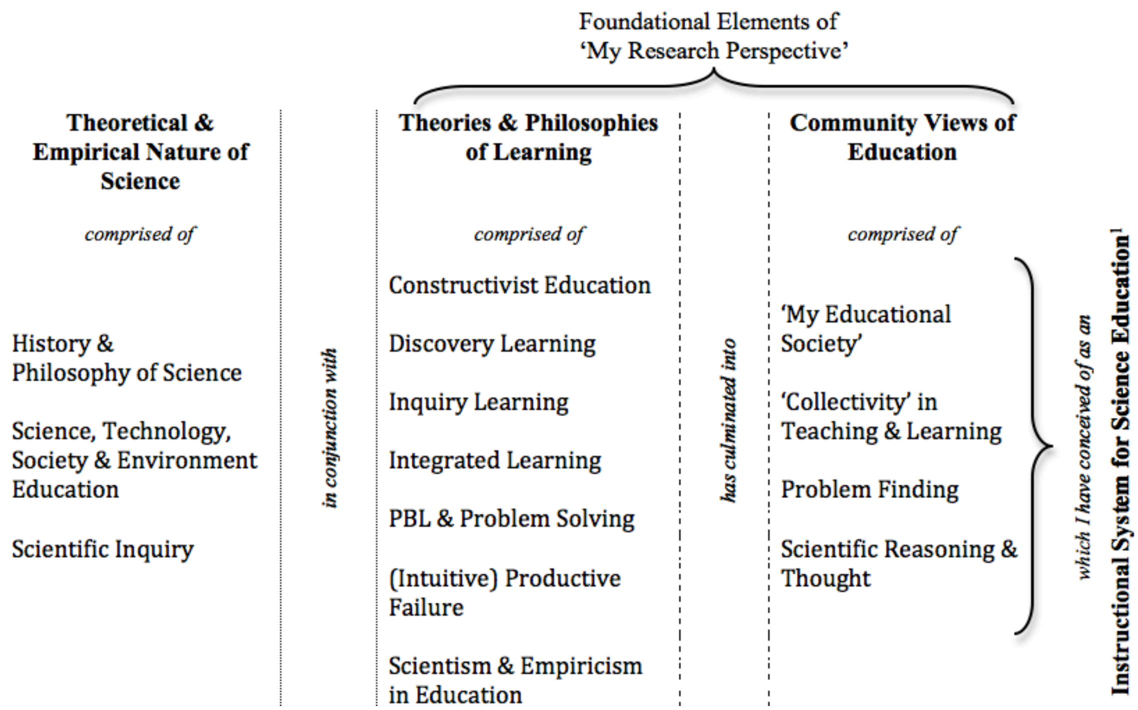


Figure 1: Abstract Detailing Framework for Research Paradigm

[1]Consists of a series of educational events and tasks which reflect a multi-faceted view of science as a function of science education; one of such activities, the 'Cooperative Concept Map' will be investigated as a culminating task for the promotion of collective criticality and reflection for the development of pre-service elementary science educators.

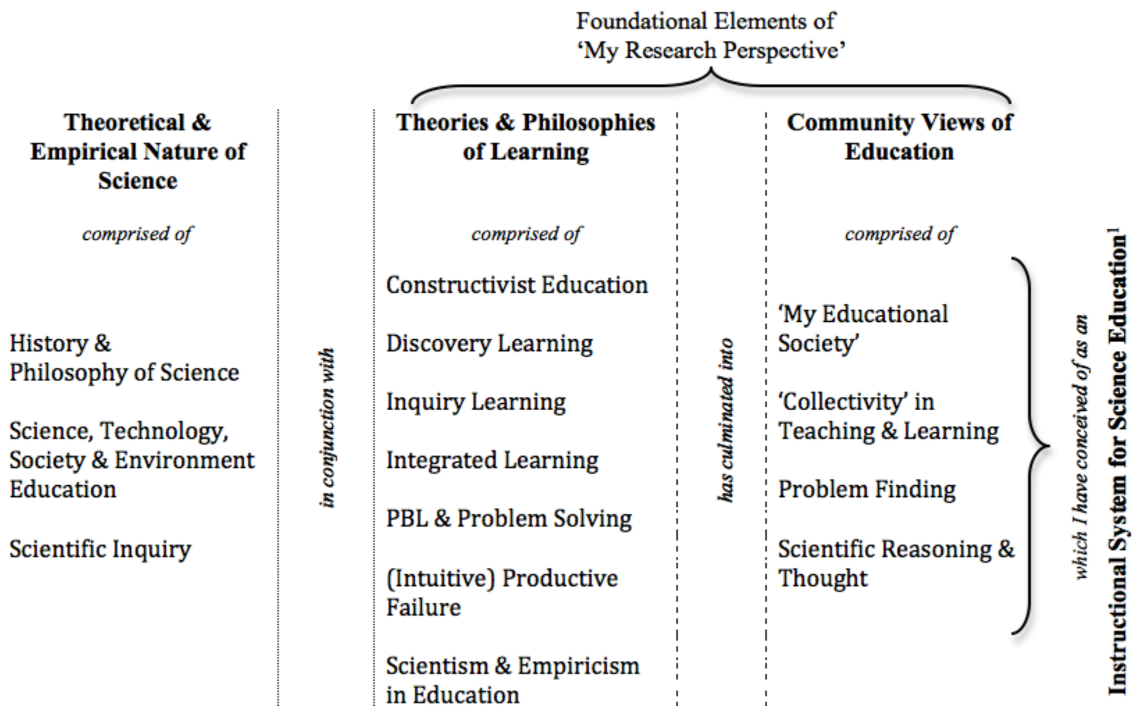


Figure 2. Re-visiting cooperative concept mapping as a function of CVOS

[1]'Cooperative Concept Mapping' was explored as a culminating task for the promotion of collective criticality and reflection for the development of pre-service elementary science educators.

	Foundations of Education	Pedagogical Practice	Societal Implications
Instructors[1], Learners[2] & Pedagogical Practice	Comparing and adapting varying pedagogical approaches Holisticism in teaching practices Integrating "Teachnologies"	Planning, developing and managing instruction Teaching across the school and state curriculum Methods and plans of evaluation in education Integrating "Teachnologies"	Diversity and inclusion in education Learning with 'special needs' Integrating Technology
Institutions[3] & Communities[4]	Philosophies and epistemologies of education Creating, promoting and maintaining communities of learning/practice	Classic versus modern learning theories and educational psychology Creating, promoting and maintaining communities of learning/practice	Importance of ministerial/state curricula Creating, promoting and maintaining Communities of learning/practice

Table 1. 'My Educational Society'

[1]Instructors & [2]Learners: Used to represent the inherent power relationship with regards to the transmission of knowledge

[3]Institutions: Extended relationship between theory and practice; curricula-driven procedures, guidelines, general objectives; role and nature of the 'school'

[4]Communities: Micro-to-macro learning communities—classroom community, school community and research community

Instrument	Purpose	Details
VNOS Questionnaires	Pre- and post-task benchmark of science beliefs and interpretations	Use 'VNOS C' (Ten open-ended questions); Construct Validity: Novice/Expert reviews Authors: Lederman, N. G. et al. (2002)
Cooperative Concept Maps	Analyzed for: 1) Concept accuracy 2) Comprehension 3) Integration of 'Collective Beliefs'	Maps created as a classroom activity answering: "What is Science" & "How Does it Work?"
Reflective VNOS & CCM Focus Group	Used in addition to VNOS post-questionnaires to review collective interpretations of NOS and CCM	To ascertain how groups came to collective understandings with respect to the map developed
Individual 'Reflective Thoughts on Science'	Solicit participant data on science beliefs post cooperative concept mapping activity	To elaborate on effect of cooperative activity on individual beliefs
Individual 'Reflective Thoughts on CCM'	Solicit participant data on cooperative concept mapping activity	Means to elaborate on the feasibility and efficacy of CCM
Primary & Secondary Observation Notes	Support (i.e. confirm or negate) data collected during interviews, focus groups and class sessions	Secondary observer present for all phases of data collection Notes compared and cross-referenced regularly ('dialogic substantiation')
Primary Investigator Research Journal	Maintain a recorded timeline of events and to support observations and analyses	
Select-sample Email Questionnaire	Elaborate on responses during focus group	Elucidate key responses
Longitudinal semi-structured interviews	Explore durability of thoughts and beliefs with respect to activity	Select participants interviewed after engaging in activity
Classroom Artefacts	To aid in an analysis of CVOS as an Instructional System To support arguments concerning: i) participant epistemic beliefs; ii) participant science knowledge; iii) course structure	Materials completed by students compiled over the course of the semester

Table 2. Summary of data collection for 'Cohort 2'

Instrument	Purpose	Details
VNOS Questionnaires	Pre- and post-task benchmark of science beliefs and interpretations	Use 'VNOS C' (Ten open-ended questions) Construct Validity: Novice/Expert reviews Authors: Lederman, N. G. et al. (2002)
Pre-task interviews	Review participant interpretation of VNOS and other confounding elements of the study	
Think-Aloud protocols	Structured interview of participant concept map dissection	Approximately 60 minutes
Post-task interviews	Review participant interpretation of the task and explore moments of reflection (with respect to accommodation and adaptation of personal belief systems)	
Primary & Secondary Observation Notes	Support (i.e. confirm or negate) data collected during interviews and think-alouds	Secondary observer present for all phases of data collection Notes compared and cross-referenced regularly ('dialogic substantiation')
Primary Investigator Research Journal	Maintain a recorded timeline of events and to support observations and potential analyses	Akin to a 'Captain's Log'— Includes observational analyses, potential codes & literature; pre-cursor to data analysis
Longitudinal semi-structured interviews	Explore durability of thoughts and beliefs with respect to activity	Select participants interviewed after engaging in activity

Table 3. Summary of data collection for 'Cohort 3'

Cohort	Construct	Data Source	Sample Participant Perspectives	Extrapolated Codes
'Cohort 2': Concept Map Analysis	Views of Nature of Science	• VNOS Questionnaire	"Science is intrinsically linked to society and culture"; "Scientific method is connected to experimentation and inquiry"; "Theory as best explanation, fact as only explanation"; "Scientific principles are universal"; "Science is about a process, a method"; "Science can tell us the best possible outcome to many situations"; "Science is only as advanced as our understanding of the natural world"; "Scientific facts and theories are about certainty"; "Culture can kill science"; "Science as exploration and discovery"; "When I do science, I don't have to be creative"; "Art and science don't mix"	Science as a solution; nature of truth; rigidity towards scientific facts, theories and knowledge; science as removed from art and creativity; outcomes of science as socio-cultural thought
	Views of Concept Maps	• Pre-task Interviews • Concept Map Analysis	"It's hard to navigate these concept maps, they need more structure, more organization"; "It makes understanding someone else's understanding a lot easier, once you get over the 'jumble'"; "I have a real hard time trying to extract step-by-step details of what science is"; "It's easier to see where the connections don't make sense or where I don't agree with them"; "There's a lot of info in these maps, I'm not sure I can understand it all"	Structurally flawed; meaningful and interpretable; reflective of 'other'/'stream of consciousness'; non-linear

	Effect of Concept Map Analysis	• Post-task Interviews • Longitudinal Interviews	"I can compare what I see with what others see"; "I need time to reflect, to question what I know and what is being presented"; "The connections make sense, but they don't really fit with what I think"; "I think science is about finding solutions to problems, not what this tries to show"; "I have to think more, cause I'm not sure I agree with all the connections"; "Other people's connections made me rethink my own"; "I wasn't certain about what I new anymore, but I was more confident about the things I did know were right"; "The maps that were really complex…I realized I needed to make more connections"	Reconciliation of perceptions; epistemic reflection; questioning 'oneself' and accepting 'others'; epistemic realization; epistemic belief self-actualization
'Cohort 3': Cooperative Concept Mapping	Views of Nature of Science	• VNOS Questionnaire • VNOS/CCM Focus Group • Cooperative Concept Maps	"Science is intrinsically linked to society and culture"; "Scientific method is connected to experimentation and inquiry"; "Science is a solution for our problems"; "Science facts are true, but theories can be changed or evolve"; "Scientific knowledge is true"; "Scientists don't have to be creative"; "There is no art in science"; "Scientists have to be creative to find problems and cool solutions"; "If science didn't have rules, we wouldn't have basic knowledge to use to create theories"	Science as a solution; nature of truth; rigidity towards scientific facts, theories and knowledge; science as removed from art and creativity; outcomes of science as socio-cultural thought

Views of Cooperative Concept Mapping	• Cooperative Concept Maps • Reflective Thoughts on Cooperative Concept Maps • VNOS/CCM Focus Group	"We were able to see how everything is connected"; "Each term is multifaceted and has a deeper meaning"; "Hard to work on a piece of paper, but once you start brainstorming and sharing it gets easier"; "We discussed terms and meanings before including it in our map"; "Defining and debating was the best part, helped us understand"; "This was a really helpful tasks, showed us how far we came from the beginning of the semester—baby steps!"	Means to create community; medium for discussion and introspection; means for dialogic inquiry; forum for peer scaffolding; difficult to manipulate structurally
Effect of Cooperative Concept Mapping	• Reflective Thoughts on Cooperative Concept Maps • Cooperative Concept Maps • Longitudinal Interviews	"I found out a lot about how my classmates think"; "It's okay to make mistakes and we should tell our students it's okay to make mistakes"; "Was fun to collaborate on creating ideas and fighting for what we thought they meant"; "I was able to connect what I learned this semester"; "Wow, it's a lot more complicated and interconnected than we thought"; "There are far more associations than we had assumed"; "It's great to see how all the concepts are linked"; "This was a really helpful tasks, showed us how far we came from the beginning of the semester—baby steps!"	Promoting collectivity; development of inquiry and dialogue; development and refinement of 'science as a process'; peer substantiation of ideas; confirmation through divergence; 'epistemic spark'; epistemic substantiation; epistemic realization; epistemic debate;

Effect of Cooperative Concept Mapping on 'Views of Nature of Science'	• Cooperative Concept Maps • VNOS Questionnaire • VNOS/CCM Focus Group • Reflective Thoughts on Cooperative Concept Maps • Longitudinal Interviews	"Science is more than I and everyone else thought it was before doing this"; "Science is not just the scientific method, its really about how society and culture appreciates or understands science"; "Using science depends on the society and culture that it's being used in—I only learned that today!"; "Scientists work just like us by bouncing ideas off each other"; "We can all be scientists, we are all scientists"; "It's great to see how all the concepts are linked"; "There are a lot of terms in science that say the same thing. I need to plan out more to be able to teach science"	Development and refinement of 'science as a process'; questioning of scientific processes; questioning of socio-cultural science; science as reflective of collective and individual voice

Table 4. Summary of Results and Extrapolated Codes

Element of CVOS	CCM Data Exploring Development of CVOS	Instructional System Supporting Development of CVOS
Social nature of facts, hypotheses and theories	Participant statements and reflections detailing: peer-based affirmations of scientific thoughts; science as a process of social inquiry; scientific method as a collective process	Problem finding as a means to encourage dialogue and discourse surrounding interpretation of fact, theory and hypothesis
Social nature and inextricability of observations and inferences	Reaffirmation of scientific knowledge as a combination of multiple perspectives; scientific knowledge as an outcome of observation and inference as an outcome of observation	Assumed roles in scientific discovery and development
Empiricism and objectivity through methods and processes	Statements elaborating scientific method as a socio-collective process	Problem finding; draw a Scientist; draw a teacher
Pervasiveness and dilution of human error	Human error considered a factor of socio-cultural interpretations and implementations of science	Discrepant scenarios; problem finding as depicting science as flawed
Socio-collective nature and impact of knowledge as being a tentative entity	Scientific knowledge vetted and confirmed, impact	Pedagogical endeavours (e.g. science fair) aimed to provide voice for student and citizen science
Unforeseen impact of scientific knowledge and endeavours	Unforeseen impact of scientific knowledge deemed an outcome of ‘science as a solution’ and a ‘lack of criticality’ towards scientific knowledge	(Intuitive) productive failure and associated tasks reflective of ‘negatives’ associated to science; problem-finding as a determinant of discrepancies/errors in science/scientific knowledge

Need for scientific transparency and a shift to science as community science	Transparency as means for the involvement of citizens (e.g. 'general population')	Collectivity in the classroom; development of community through combined scientific efforts and assumed roles within observation, inference and analysis

Table 5. CCM as a Function of CVOS

	Foundations of Education	Pedagogical Practice	Societal Implications
Instructors[1], Learners[2] & Pedagogical Practice	'Systematically' comparing varying pedagogical approaches Holisticism in teaching practices Integrating "Teachnologies"	Communally planning and developing instruction Teaching across the school and state curriculum Processes, methods and plans in education Integrating and promoting "Scientific Inquiry" Integrating "Teachnologies"	Knowledge as tentative and development as a collective process Diversity and inclusion in education Integrating collective interpretations of science and technology
Institutions[3] & Communities[4]	Philosophies and epistemologies of education and the history and nature of science in education Creating, promoting and maintaining communities/collectives of learning/practice Differentiating institutional and communal perspectives	Science in education Educational research as a product of scientific inquiry Collective questioning of information and knowledge Creating, promoting and maintaining communities of learning/practice	Importance of ministerial/state curricula Creating, promoting and maintaining communities

Table 6. Revamped 'My Educational Society'

[1]Instructors & [2]Learners: Used to represent the inherent power relationship with regards to the transmission of knowledge

[3]Institutions: Extended relationship between theory and practice; curricula-driven procedures, guidelines, general objectives; role and nature of the 'school'

[4]Communities: Micro-to-macro learning communities—classroom community, school community and research community

Data Collection Instruments

Focus Group Questions

Collaborative Creation of Concept Maps Focus Group Questions:

- What does your final product look like?
- How did you go about creating it?
    - How did you assign roles?
    - How did you come to agreements about what to include in your map?
    - How did you solve differences of opinions about what to include in your map?
    - How did you deal with changes to map contents?
- What did you learn about working in groups?
- What did you learn about science?
    - Who did you learn 'this' from?
    - What did you not know about science?
    - Do you think you taught your group about science?
- Did you share your opinion?
    - Why did you share your opinion?
    - Why did you not share your opinion?
- Did you like the activity?
    - How would you change the activity?

Concept Map Interpretation Focus Group Questions:

- What are your main areas of interest?
- Why were they your main areas of interest?
- How does your concept map characterize and define science?
- With regards to your map, are there rules, procedures, processes, frameworks or approaches for science?
- What are some main scientific concepts displayed in your map?
- Do any areas of your peers' maps stick out as being anomalous or which counter your current beliefs of science?

Reflective Questions

Concept Map Creation Questions:

- How did you go about creating it?
    - How did you assign roles?
    - How did you come to agreements about what to include in your map?
    - How did you solve differences of opinions about what to include in your map?
    - How did you deal with changes to map contents?
- What did you learn about working in groups?
- What did you learn about science?
    - Who did you learn 'this' from?
    - What did you not know about science?
    - Do you think you taught your group about science?
- Did you share your opinion?
    - Why did you share your opinion?
    - Why did you not share your opinion?
- Did you like the activity?
    - How would you change the activity?

Longitudinal Reflective Questions

- How has your understanding of science evolved over the past few months?
- What is your current conception of science?
- Are there rules, procedures, processes, frameworks or approaches for science?
- Can you reflect on when you started to think about science? What has been influential to how you see science?

Email Soliciting Student Participation

Good Morning,

I hope you are well.

Over the course of the past few years, I have dedicated my pedagogical analyses to the development of critical, well-rounded educators who are able to interpret, analyze and dissect educational systems and curricula for overall societal betterment.

I am currently conducting research for my doctoral dissertation and am in need of participants to engage in a 1.5 hour experiment analyzing and interpreting concept maps.

I see no better sample population than those who have had the opportunity to first-hand inculcate themselves in the art of teaching and learning--therefore in my opinion, you are the clearest lens available to me to further understand what academics and pedagogy need to acknowledge in hopes of possibly progressing in how we design instruction, institutions and curricula. It is through such research that I hope we can become agents of change.

If you are available on any day for 1.5 hours between your participation would be greatly appreciated.

The experiment is taking place at McGill University's SMART Laboratory. I can arrange for transport from Concordia to McGill and though minimal, some compensation can also be provided.

If you are interested and willing to help me out, please contact me as soon as possible and we can schedule a session. I can be reached at (514) 944-4564 or slap.mtl@gmail.com.

I look forward to hearing from you!

Thanks
Kamran

Consent Form—Eyetracking

CONSENT TO PARTICIPATE IN:
Re-thinking and Re-structuring science pedagogy: Promoting a community view of science

I agree to participate in a program of research being conducted by Kamran Shaikh of the Department of Education at Concordia University (*514-944-4564; kamran.shaikh@education.concordia.ca).*

A. PURPOSE

The overall goals of the proposed program of research are to: a) develop and promote epistemic community views of science in pre-service elementary science educators through the analysis of collaborative concept mapping strategies related to the Nature of Science and students' science pre-conceptions/beliefs and b) to potentially define the durability of epistemic beliefs when analyzing and interpreting concepts maps as well as identifying relative processes, patterns and approaches.

B. PROCEDURES

For Kamran's research study, I will be asked to: a) complete a questionnaire investigating concepts related to the "Nature of Science"; b) participate in "eye-tracked" concept map analysis (the duration and focus of my gaze will be recorded in order to analyze 'gaze behaviour'), c) participate in a short audio-recorded interview; and d) complete a questionnaire investigating concepts related to the "Nature of Science" after having completed the eye-tracking concept map analysis.

Depending on the future needs of the research team, I may be asked to volunteer for a short interview to collect reflections on the nature of the task. This 20-minute semi-structured interview will take place at my discretion and I can be provided with a copy of any audio recordings of the interview.

Data for the eye-tracking portion of this research will be collected at McGill's SMART Laboratory.

C. RISKS AND BENEFITS

Kamran has clearly outlined and I understand that the rationale for conducting his research. Potential risks associated with my participation in this study are minimal (if any).

Minimal compensation has been offered.

D. CONDITIONS OF PARTICIPATION

- I understand that I am free to withdraw my consent and discontinue my participation at anytime without negative consequences. If I am uncomfortable contacting Kamran, I have been given the coordinates of the appropriate personnel at Concordia's Office of Research to inform them of my decision to not participate, so that they may contact him on my behalf.

- I understand that the data from this study may be published, but that my identity will remain confidential in any official reports of these results.

I HAVE CAREFULLY STUDIED THE ABOVE AND UNDERSTAND THIS AGREEMENT. I FREELY CONSENT AND VOLUNTARILY AGREE TO PARTICIPATE IN THIS STUDY.

NAME (please print) ____

SIGNATURE ____

If at any time you have questions about the proposed research, please contact the study's Principal Investigators:

Kamran Shaikh
Department of Education, Concordia Univeristy
514-944-4564
kamran.shaikh@education.concordia.ca

Vivek Venkatesh
Associate Dean, School of Graduate Studies
Department of Education, Concordia University
514-848-2424 ext. 8936
vivek@education.concordia.ca

If at any time you have questions about your rights as a research participant, please contact the Research Ethics and Compliance Advisor, Concordia University, 514.848.2424 ex. 7481 ethics@alcor.concordia.ca.

Consent Form—"EDUC382: Teaching Science Concepts in the Elementary Classroom"

CONSENT TO PARTICIPATE IN:
Re-thinking and Re-structuring science pedagogy: Promoting a community view of science

I agree to participate in a program of research being conducted by Kamran Shaikh of the Department of Education at Concordia University (*514-944-4564; kamran.shaikh@education.concordia.ca).*

A. PURPOSE

The overall goals of the proposed program of research are to develop and promote epistemic community views of science in pre-service elementary science educators through the analysis of collaborative concept mapping strategies related to the Nature of Science and students' science pre-conceptions/beliefs.

B. PROCEDURES

For Kamran research study, in my capacity as a learner in **EDUC382/2: Teaching Science Concepts in the Elementary Classroom**, I will be required to complete the requirements for the course as detailed by the instructor. All pre-tests, assignments or projects required for the course have been included as part of the curriculum for the course – I will not be asked to complete any assignments or projects solely for the purpose of Kamran's study. My learning is not dependent on my participation in this study. Depending on the future needs of the research team, I may be asked to volunteer for a short interview reviewing my interactions, participation and learning in this course. The 20-minute semi-structured interview will take place at my discretion and I will be given a copy of any audio recordings of the interview.

C. RISKS AND BENEFITS

Kamran has clearly outlined the rationale for conducting his research. Potential risks associated with my participation in this study are minimal (if any). All of the assignments and projects I will be completing are part of the curriculum designed for the course.

Being the instructor for the course, Kamran has made it clear that my willingness to participate will have no effect on my participation, learning and overall assessment for this course. He will only be notified of my participation once final grades are submitted.

D. CONDITIONS OF PARTICIPATION

- I understand that I am free to withdraw my consent and discontinue my participation at anytime without negative consequences. If I am uncomfortable contacting Kamran, I have been given the coordinates of the appropriate personnel at Concordia's Office of Research to inform them of my decision to not participate, so that they may contact him on my behalf. Kamran, being the instructor of the course has also assured me that he will not know of my decision to volunteer my participation for the study, until after final grades have been submitted.

- I understand that the data from this study may be published, but that my identity will remain confidential in any official reports of these results.

I HAVE CAREFULLY STUDIED THE ABOVE AND UNDERSTAND THIS AGREEMENT. I FREELY CONSENT AND VOLUNTARILY AGREE TO PARTICIPATE IN THIS STUDY.

NAME (please print) ____

SIGNATURE ____

If at any time you have questions about the proposed research, please contact the study's Principal Investigators:

Kamran Shaikh
Department of Education, Concordia Univeristy
514-944-4564
kamran.shaikh@education.concordia.ca

Vivek Venkatesh
Associate Dean, School of Graduate Studies
Department of Education, Concordia University
514-848-2424 ext. 8936
vivek@education.concordia.ca

If at any time you have questions about your rights as a research participant, please contact the Research Ethics and Compliance Advisor, Concordia University, 514.848.2424 ex. 7481 ethics@alcor.concordia.ca.

Introduction to Activity—SMART Laboratory

Thank you very much for agreeing to participate in my dissertation research study. I am currently conducting research analyzing and interpreting concept maps.

Before we get to the nitty gritty of our activity, which should not last more than 1.5 hours, I have the means to offer you $10 compensating you for your participation (*insert timely quip here*).

If at any point you would like to discontinue your participation, please feel free to leave. I appreciate your support regardless—just coming out and trying is enough.

Ok, let's get started (provide students with Appendix ?: Procedure for eyetracking "Re-thinking and Re-structuring science pedagogy: Promoting a community view of science").

Let us take 5 minutes to review the document together and then we will get started.

Procedure for Eyetracking

Re-thinking and Re-structuring science pedagogy: Promoting a community view of science

Proposed Study Features and Procedure

The overall goals of the proposed program of research are to: a) develop and promote epistemic community views of science in pre-service elementary science educators through the analysis of collaborative concept mapping strategies related to the "Nature of Science" and students' science pre-conceptions/beliefs and b) to potentially define the durability of epistemic beliefs when analyzing and interpreting concepts maps as well as identifying relative processes, patterns and approaches to concept map analysis.

Participants will be asked to complete the following tasks:

1. Respond to a few brief demographics questions and complete a questionnaire investigating concepts related to the "Nature of Science" and
2. Consent to and participate in "eye-tracked" and audio-recorded concept map analysis (the duration and focus of my gaze will be recorded in order to analyze 'gaze behaviour') structured through the 'Community Views of Science' think-aloud protocol
3. Participate in a short audio-recorded interview
4. Collectively review and discuss a "Nature of Science" Handout
5. Complete a questionnaire investigating concepts related to the "Nature of Science" after having completed the eye-tracking concept map analysis

Procedure for Eye-tracking:

Participants will be primed on the technical details surrounding eye-tracking (e.g. initial 'gearing up', calibration and testing for technical problems will be guided by the standard protocol employed by the McGill SMART Laboratory).

Participants will be given a total of **60 minutes** to complete the analysis of **FIVE** concept maps. Each map will therefore be successively displayed on screen for **12 minutes**.

These twelve 12 minutes will consist of the following:

- **Three minutes** of free exploration
- **One minute** to answer the following questions:
  - *What were your main areas of interest?*
  - *Why were they your main areas of interest?*
- **Eight minutes** to dissect the concept maps while answering the following questions:
  - *How does this concept map characterize and define science?*
  - *With regards to the map, are there rules, procedures, processes, frameworks or approaches for science?*
  - *What are some main scientific concepts displayed in this map?*

- *Do any areas of the map stick out as being anomalous or which counter your current beliefs of science?*

Participant Demographics

Re-thinking and Re-structuring science pedagogy:
Promoting a community view of science

Participant Demographics

Name: ____

Completed Levels of Education/Discipline: ________________________

Occupation: ____

Years in Current Occupation: ______________________

Previous Experience Creating Concept Maps:

Beginner Intermediate Expert

Previous Experience Interpreting Concept Maps:

Beginner Intermediate Expert

Previous Experience <u>DOING</u> Science:

Little Moderate Extensive

Previous Experience <u>INTERPRETING</u> Science (e.g. reading/writing about)

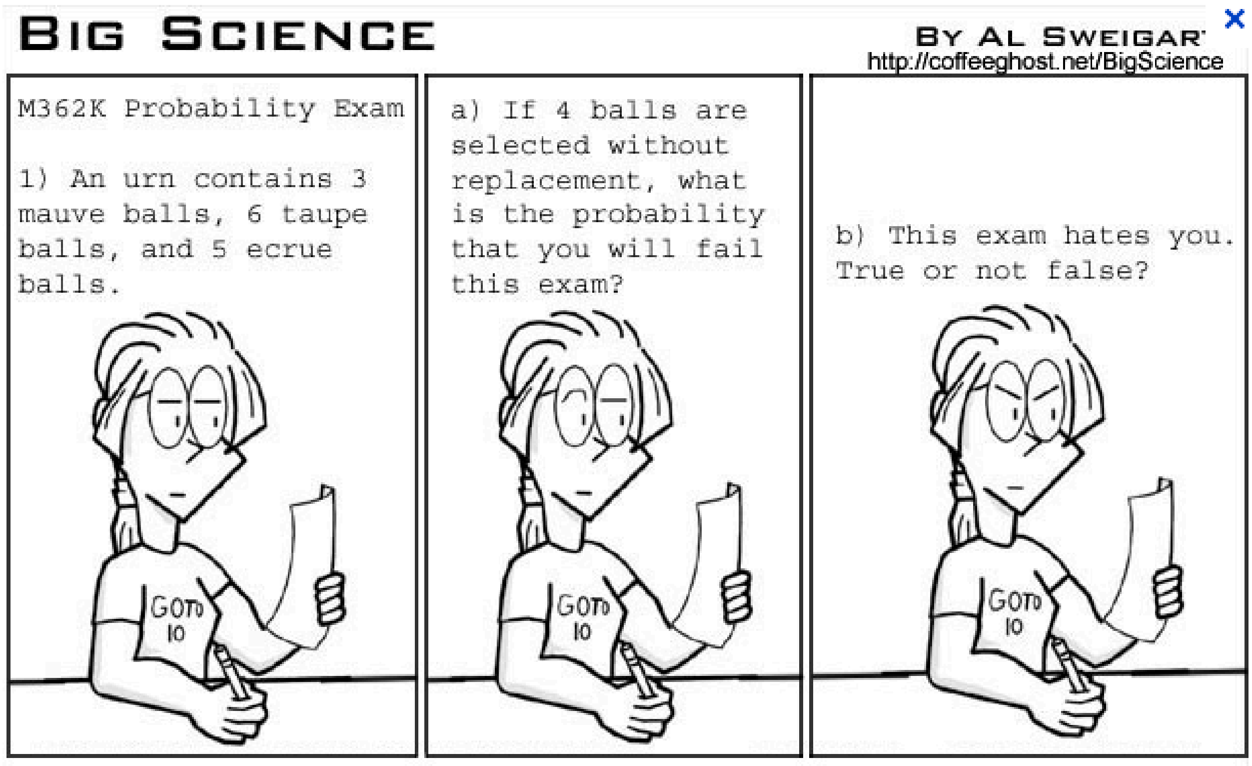
Little Moderate Extensive

Comfort With Science as a Subject Matter:

Uncomfortable Comfortable Very Comfortable

Priming Think Aloud Protocol

They Blinded me with Science!:
Promoting a Community View of Science in Science Education



What is the nature of the question she is being asked?

While answering this question, tell me how you came to your conclusion.

Think Aloud Protocol

Re-thinking and Re-structuring science pedagogy:
Promoting a community view of science

Task: Analyze the five concept maps provided and please reflect upon and answer the questions below. When necessary, I may prompt you for a particular response.

You will be given a total of **60 minutes** to complete the analysis of **FIVE** concept maps. Each map will therefore be successively displayed on screen for **12 minutes**.

For these twelve 12 minutes you will be asked to complete the following:

- **Three minutes** of free exploration

- **One minute** to answer the following questions:
  - *What were your main areas of interest and/or focus?*
  - *Why were they your main areas of interest and/or focus?*

- **Eight minutes** to dissect the concept maps while answering the following questions:
  - *How does this concept map characterize and define science?*
  - *With regards to the map, are there rules, procedures, processes, frameworks or approaches for science?*
  - *What are some main scientific concepts displayed in this map?*
  - *Do any areas of the map stick out as being anomalous or which counter your current beliefs of science?*

- Can you comment on the structure of the map?
- Discuss patterns and influences

Stepwise Instructions Eyetracking

Key instructions for EACH participant

Study's Procedure:

- Consent forms: 2 COPIES! (one for me, one for you)
- Surveys (to be done online)----PLEASE FORWARD ALL SURVEYS TO ME BEFORE SESSION START.
- Eye Track set up (aka REZA)
- Eye Tracking; for **each map**:
    - You have **3 minutes** free exploration, if less time is needed, then so be it
    - After 3 minutes, you will have **1 minute** to answer Q1 (T/A Protocol)
    - After this 1 minute of reflection, you will have **8 minutes** to analyze the map and answer the other questions (T/A Protocol)
- After all five maps are done, we will sit for a short post interview
- After the in-house portion of the study is complete, I will ask you to complete a short **SURVEY by email.**

Thank you for your participation.

Nature of Science Handout

The Who, What, When, Why and Where of Science: Revisiting a Classic Framework for Science Education

The **Nature of Science** can be summarized as a framework for science education which questions the nature of:

a) **Facts, theories and hypotheses:** A reflection on the nature of assumptions in the scientific community. An idea that each assumed theory is rooted within paradigmatic assumptions and approaches which govern overall interpretation and implementation. Facts, hypotheses and theories should be questioned, as should their inculcation in society.

b) **Observations and inferences:** Reflections on the nature of collective observation as well as paradigmatic thought and inferences. Work within a paradigm involves beliefs in certain assumptions and facts which limits objectivity and impartiality in observation.

c) **Methods and processes:** Can objectivity be achieved or is it an integrated facet of the methods and processes we employ to reach scientific conclusions?

d) **Human error:** Error is omnipresent in our frame of scientific thinking and nothing less than a paradigmatic shift will result in the acceptance of human error and scientific misunderstanding (consider the move to Copernican Heliocentrism; Galilean to Newtonian mechanics; Newtonian to Relative physics).

e) **Tentativeness of scientific knowledge:** Collectively or independently, the above elements cast doubt on what science can offer as support for societal evolution—conceiving of and promoting knowledge as tentative reinforces the perception of 'negatives' in science education. If our knowledge is tentative then are our outcomes and implications tentative as well?

This intricate system of ideas which can be interpreted as a representation of widespread epistemic beliefs, reflects an interconnected system detailing how science works and its collective impact (societally, environmentally, economically, globally and so on).

Pedagogical approaches in the science education classroom should be rooted within promoting, maintaining, evaluating and criticizing the above system of ideas. However, above all else, the scientific classroom's science curriculum should question it—as good scientists (and pedagogues) always do.

Are your epistemic science beliefs rooted in the above or have you conceived of a varied framework?

Nature of Science Pre-Survey

Benchmarking Scientific Perspectives:
Views of Nature of Science Questionnaire

Instructions:

- Please attempt to answer all questions.
- Do not hesitate to contact me for clarification.
- Save your work!
- Have fun while answering the questions, this is not a test—there is no right or wrong answer.

Questions:

1) What, in your view, is science? What makes science (or a scientific discipline such as physics, biology, etc.) different from other disciplines of inquiry (e.g., religion, philosophy)?

2) What is an experiment?

3) Does the development of scientific knowledge require experiments?
   a) If yes, explain why. Give an example to defend your position.
   b) If no, explain why. Give an example to defend your position.

4) After scientists have developed a scientific theory (e.g., atomic theory, evolution theory), does the theory ever change?
   a) If you believe that scientific theories do not change, explain why. Defend your answer with examples.
   b) If you believe that scientific theories do change: (i) Explain why theories change; (ii) Explain why we bother to learn scientific theories. Defend your answer with examples.

5) Is there a difference between a scientific theory and a scientific law? Illustrate your answer with an example.

6) Science textbooks often represent the atom as a central nucleus composed of protons (positively charged particles) and neutrons (neutral particles) with electrons (negatively charged particles) orbiting the nucleus. How certain are scientists about the structure of the atom? What specific evidence do you think scientists used to determine what an atom looks like?

7) Science textbooks often define a species as a group of organisms that share similar characteristics and can interbreed with one another to produce fertile offspring. How certain are scientists about their characterization of what a species is? What specific evidence do you think scientists used to determine what a species is?

8) It is believed that about 65 million years ago the dinosaurs became extinct. Of the hypothesis formulated by scientists to explain the extinction, two enjoy wide support. The first, formulated by one group of scientists, suggests that a huge meteorite hit the earth 65 million years ago and led to a series of events that caused the extinction. The second hypothesis, formulated by another group of scientists, suggests that massive and violent volcanic eruptions were responsible for the extinction. How are these different conclusions possible if scientists in both groups have access to and use the same set of data to derive their conclusions?

9) Some claim that science is infused with social and cultural values. That is, science reflects the social and political values, philosophical assumptions, and intellectual norms of the culture in which it is practiced. Others claim that science is universal. That is, science transcends national and cultural boundaries and is not affected by social, political, and philosophical values, and intellectual norms of the culture in which it is practiced.
   a) If you believe that science reflects social and cultural values, explain why. Defend your answer with examples.
   b) If you believe that science is universal, explain why. Defend your answer with examples.

10) Scientists perform experiments/investigations when trying to find answers to the questions they put forth. Do scientists use their creativity and imagination during their investigations?
   a) If yes, then at which stages of the investigations do you believe scientists use their imagination and creativity: planning and design, data collection, after data collection? Please explain why scientists use imagination and creativity. Provide examples if appropriate.
   b) If you believe that scientists do not use imagination and creativity, please explain why. Provide examples if appropriate.

Nature of Science Post-Survey

Elaborating Scientific Perspectives:
Views of Nature of Science Questionnaire

Instructions:

- Please attempt to answer all questions.
- Do not hesitate to contact me for clarification.
- Save your work!
- Have fun while answering the questions, this is not a test—there is no right or wrong answer.

Questions:

1. After scientists have developed a theory (e.g. atomic theory), does the theory ever change? If you believe that theories do change, explain why we bother to teach scientific theories. Defend your answer with examples.

2. What does an atom look like? How certain are scientists about the nature of the atom? What specific evidence do you think scientists use to determine what an atom looks like?

3. Is there a difference between a scientific theory and a scientific law? Give an example to illustrate your answer.

4. How are science and art similar? How are they different?

5. Scientists perform experiments/investigations when trying to solve problems. Other than the planning and design of these experiments/investigations, do scientists use their creativity and imagination during and after data collection? Please explain you answer and provide examples if appropriate.

6. Is there a difference between scientific knowledge and opinion? Give an example to illustrate your answer.

7. Some astronomers believe that the universe is expanding while others believe that it is shrinking; still others believe that the universe is in a static state without any expansion or shrinkage. How are these different conclusions possible if all of these scientists are looking at the same experiments and data.

Sample Classroom Activities (EDUC382: Teaching Science Concepts in the Elementary Classroom)

Group Name: ________________________

Building a Weather Monitoring Station

List of Materials:

- Weather Vane
  - Wooden dowel
  - Nail
  - Washer
  - Small stick
  - Cardboard triangle (5cm base and 5cm height) and cardboard square (7cm x 7cm)
  - Tape
  - Hammer

- Anemometer
  - 4 paper cups
  - Small nail
  - Bamboo skewers
  - Small dowel
  - Yogurt container lid
  - Marker
  - Tape

- Rain Gauge
  - Large container
  - Marker

- Barometer
  - Empty container
  - Rubber band
  - Balloon
  - Popsicle stick
  - Tape

- Hygrometer
  - Milk carton
  - Long nail
  - Long hair
  - Penny/other currency
  - Paper
  - Pipe cleaner
  - Paper clip

- Thermometer
  - Clear plastic bottle
  - Modeling clay
  - Water
  - Rubbing alcohol
  - Marker
  - Food coloring
  - Straw

Weather Vane

A weather vane is used to determine wind direction.

Take the wooden dowel, nail, washer and short stick. Hammer a nail through the stick and washer into the dowel, but before doing so place the short stick perpendicular to the wooden dowel with the washer on top of the dowel. Mark each side of the dowel with North, South, East and West (when you place your wind vane outside, ensure that North faces North). Widen the hole so the stick turns easily on the washer. On either end of the small stick you will place cardboard markers. On one end you will place a triangle and on the other, a square. Mount your weather vane outside, preferably in a high area to catch the wind. Record, at regular intervals, which direction the wind is coming from.

Anemometer

An anemometer is used to record wind speed.

- Take four paper cups and poke the bamboo skewers through the sides, near the top (create a bamboo diameter in each of the cups).
- Take a yogurt lid and mark off the 3, 6, 9 and 12 o'clock positions.
- You will place the other ends of the skewer from your first four cups in each of these positions.
- If you need to, fasten with tape so that they stay in place.
- Ensure that your initial four cups are all facing in the same direction to catch the wind.
- Put the middle of the lid on top of a small stick and hammer in place using a small nail.
- Ensure that the lid spins easily.
- Mark a thick line on one of the cups and on the stick so you can use it as a reference to count the number of rotations.
- Take your anemometer outside in an open place to catch the wind and mount on any surface.
- Count the number of rotations your marked cup makes in 1 minute.
- Record your results in a table.

Rain Gauge

A rain gauge is used to measure the amount of precipitation over a given period of time.

To make your rain gauge, mark off ½ cm graduations on the inside of a large container. Place your rain gauge in an area that is open and unsheltered. Check your gauge each day and record how much rain has been collected. You can also keep a log and average the amount of rain you collect over a specified period.

Barometer

Barometers are used to measure air pressure.

Pull a balloon tight over the top of an empty, large-mouth receptacle. You may have to cut the balloon's opening to make it fit properly. Secure it tightly around the receptacle with a rubber band. Tape a popsicle stick or straw to the middle of the balloon, making sure it sticks out over the edge of the receptacle to make a pointer (at least 1 or 2 cm). When ready to collect data, tape a piece of paper to a wall. Place your barometer next to the paper so that the stick or straw can move up and down next to the paper. Draw a line on the paper where the stick or straw stops. Note the weather for that day (was it sunny? Rainy?) Record your measurements each day in your weather journal. **Your barometer must be calibrated before it can be used**.

Thermometer

Thermometers are used to measure temperature.

1. Pour cold water into a clear plastic bottle until it is ¼ full.
2. Pour rubbing alcohol into the bottle until it is ½ full.
3. Add a few drops of food coloring to resemble mercury.
4. Position a straw so that it does not touch the bottom of the bottle and affix clay to the top of the bottle to hold the straw in place.
5. Allow the liquid to adjust to room temperature for at least 1 hour. Observe how far up the straw the liquid has risen.
6. Using a marker, draw a line on the bottle to indicate the current temperature.
7. The exact temperature can be determined with a traditional thermometer or thermostat, then written on the bottle.

Hygrometer

Hygrometers are used to measure humidity. **Your hygrometer will need to be calibrated before use.**

Keep a weather journal—every good scientist keeps records.

Sample Analysis of Participant Perspectives
(Annotated & Compiled VNOS Questionnaire)

— = KS
— = VA

[redacted] Views of Nature of Science.

① Scientific method

① Inquiry as ...

1) Other disciplines of inquiry, such as religion and philosophy, are based on ideas, thoughts, or concepts. Science is a discipline of inquiry that is based on the material world, on the matter that makes up our reality, our universe.

② C3 VIKS method + expt. + Inquiry

2) An experiment is an activity where the experimentor creates an hypothesis based on what he or she thinks will happen, ~~and~~ then, he or she sets up an experiment which is as unbiased as possible, ~~and~~ where the perameters + method allow for unbiased and unaffected results.

② Science as a solution

③ Nature of science; Science as a solution

Ex. ③ 'Science' as Solution

3) Yes, the development of scientific knowledge does require experiments. ~~For example~~ I believe this because scientific experiments lead to further discoveries, which results in more and more scientific knowledge. For example, if scientists had not conducted research on how to develop spaceships and how to allow humans to one day go into outer space, humans would never have been able to go to outer space, and we would now have a very different level of knowledge about our universe, solar system, galaxy, etc.

(4) Rigidity #1.

A1/

[redacted]

(4) Science fact v. theory.

4. b). I believe that scientific theories do change. They change because scientific Knowlege changes and develops as scientists discover new things. Theories must sometimes be adapted as our understanding of the concept increases. Know as The

We learn scientific theories because they are the most accurate ideas that we have abaut the ways things are at present. We use scientific theories to create an understanding abaut our reality. As we learn more, and as scientists adapt the theories, the understanding of the concept is increased.

(5) Absence of Negatives

For example, people used to believe that the Earth was flat based on scientific theories of the time. This theory had to be adapted as we gained a better understanding of ar reality, and understanding that the Earth is raund has changed ~~meaning~~ humans in very impatant ways.

[redacted]

(5) Nature of science ftl.

(6) Fact & truth vs Scientific Knowledge + Accuracy

5. I think that there is a difference between scientific theory and scientific law because they are called two different things. But if we can never be 100% sure that our scientific knowledge is completely accurate, ~~aoke if~~ how can there be laws in science? I suppose that something like the law of gravity is a scientific law because it is our reality. It is proven just because we don't ever fall off the Earth. A scientific theory would be the concept that we have of how gravity works.

(6) Science as a solution

6. I don't know. I learned about atoms in Grade 10 Biology but I don't know about how certain scientists are about the structure of an atom or about specific evidence that they have. It would have been interesting if that had been part of our Grade 10 Biology curriculum.

Hahaha :)

(7)

(8) Nature of ftl?

7. I don't know.

8. I think that scientists agree about certain aspects of the extinction. The volcanic eruptions are probably part of the series of events that are in the first group's hypothesis.

[redacted]

⑦ *C3VIKS

Intrinsic link Science + Society

9. a) I think that science does reflect social and cultural values. Doctors practice medicine differently based on where they are practising. Countries fund scientific research differently.

⑨ Science as "creative" *

⑧ Scientists as creative for solutions

10. a) Scientists use creativity and imagination during planning + design. Scientists must be creative to find new ways of looking at problems and hypothetical solutions.

① His of Science → VNFG + CCM + SO
② Nature of FTL + SM + Nos → CCM + SO + VNFG
③ CCM + VNFG + SO
④ SFTL → CCM +
⑤ STSE → Negatives (new code?) → ~~CCM~~
⑥ Nature of Knowledge + SO → NFTL + nos → CCM
⑦ S+SC or Impact
⑧ Nos FG + SO

[redacted]

= KS
= VA

1) Nature of science?

① Misconceptions of Science

1. Science is knowledge through study and lots of practice

② misconception of Scientific Method.

2. It is a procedure that you try out with a method and verifying constantly and eventually having a valid hypothesis.

3.) Yes.
Are all planets near the earth. We needed to experiment in order to get some knowledge.

② Malleab. of science

③ Theory v. fact. v. knowledge

4.) Theories change all the time as science evolves just like everything does. Especially with technology, it allows us to go even further in experimenting and therefore adjustments and changes need to be made.

③ Malleab. of science

④ Theory v. Law

5.) Yes there is a difference.

④ Nature of scientific th - Nature of truth

Scientific law is something that has been proven to be correct and always true.
Scientific theory is something that is perhaps true but not necessarily correct. It's a belief.

⑤ Nature of science

⑤ Science as false? Science as theory.

6.) I don't know, I never thought of that. I guess I always figured they determined what an atom is through experiments. Has anyone seen an atom, really?

⑥ Rigidity?

7) From DNA

⑥ Science as Rigid in SC.

8.) They probably have different beliefs even if their data is the same. Their research has probably led them to different conclusions.

[redacted]

(7) Science & sociocultural

(7)
Non-Socio-Cultural

9.) b.) Scientific discoveries are universal in the sense that scientific discoveries are true no matter what culture you present these discoveries to.

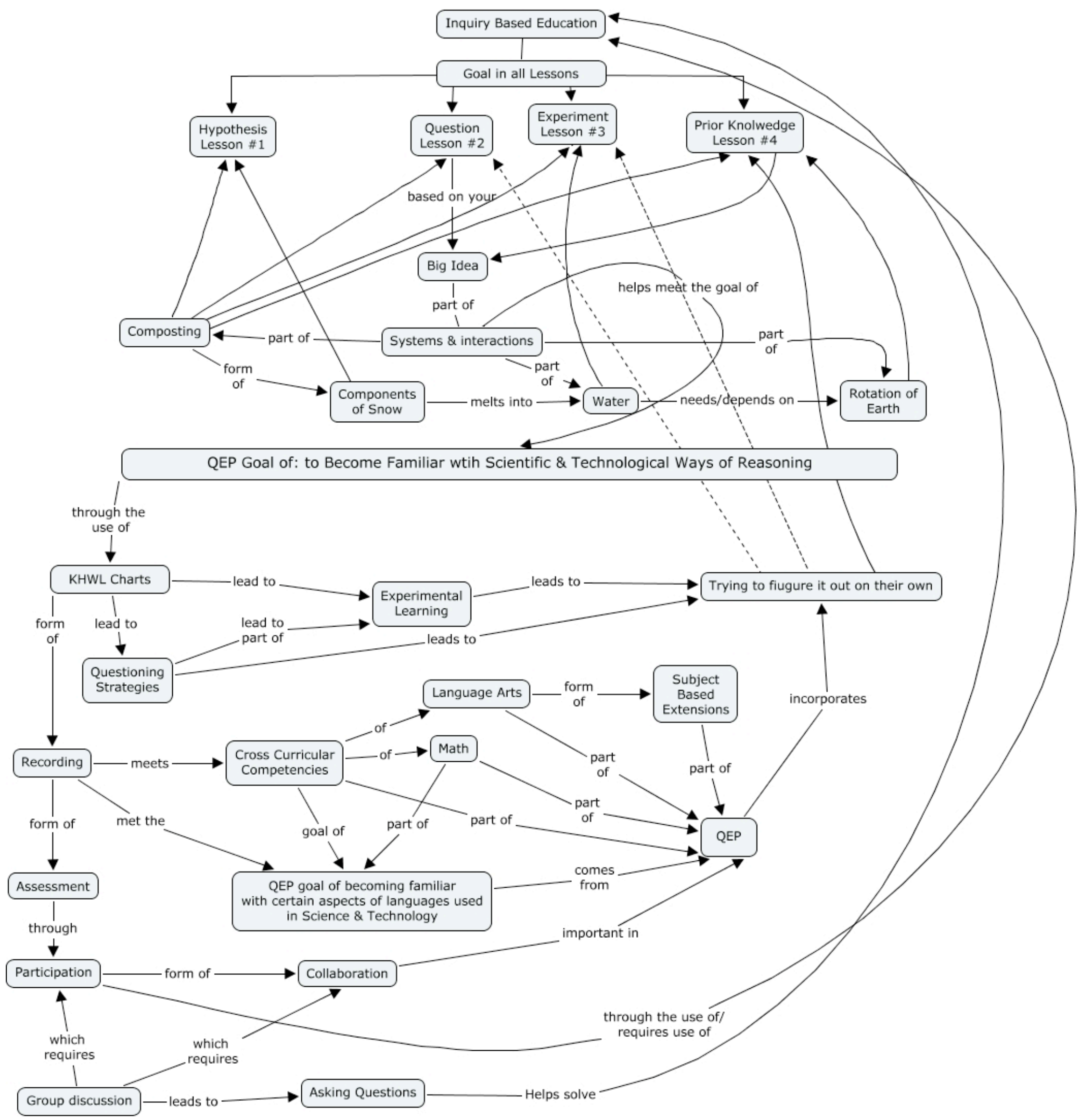
(8) Science, art & creativity

(8)
Science as lack of creativity its method.

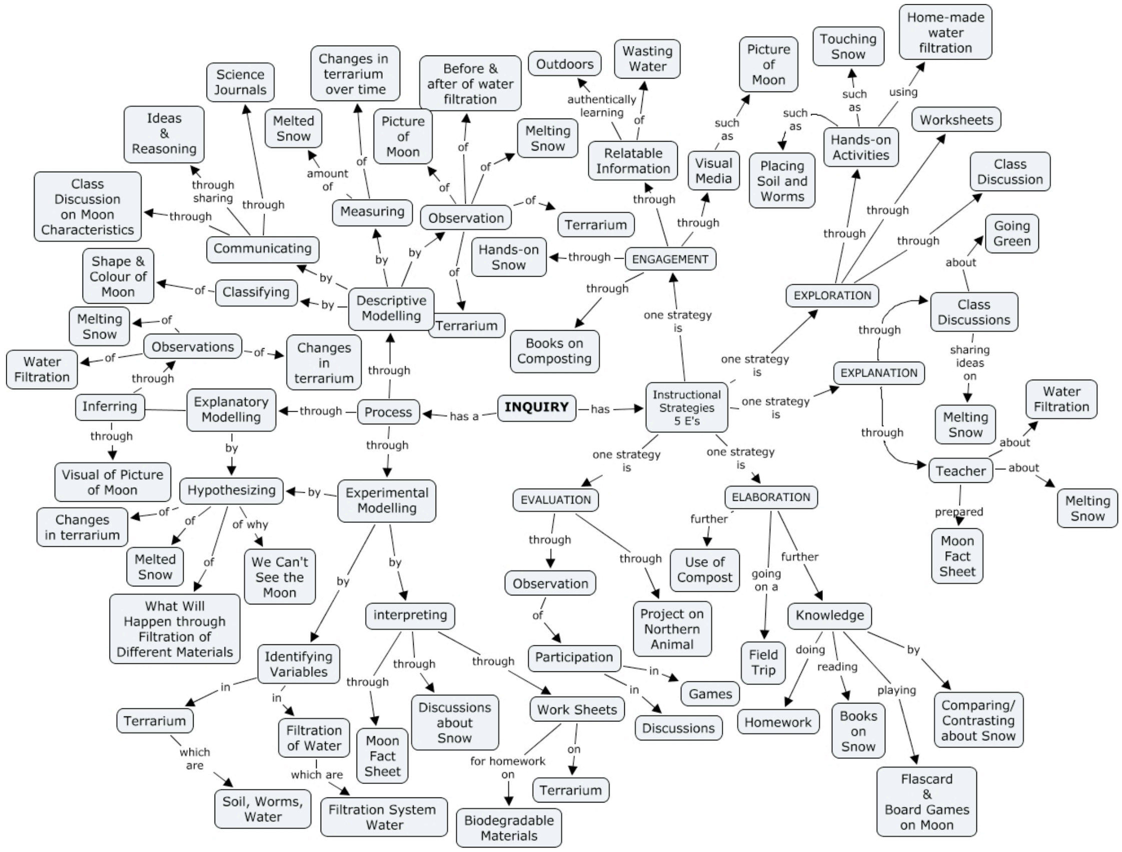
10.) b.) Scientist have no imagination or creativity. They base everything on numbers, data, research, Theories. Nothing is creative about that in my opinion

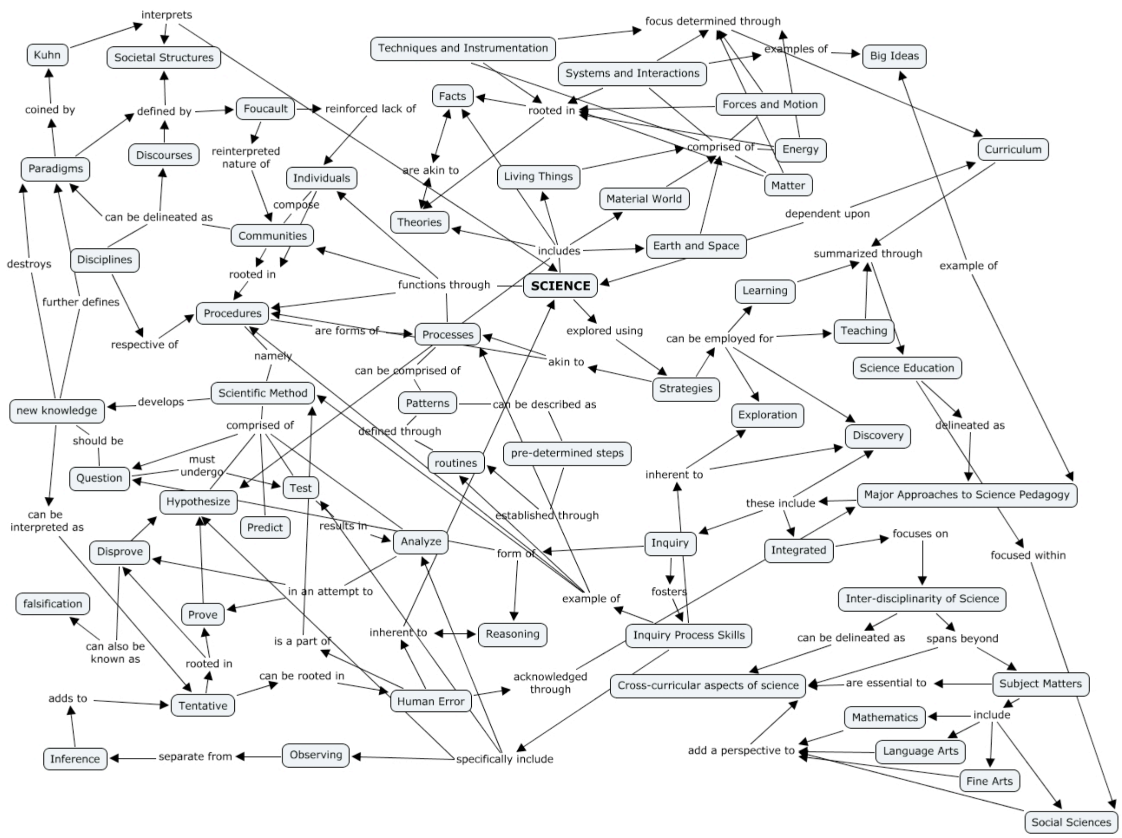
(1) verify through VNFG; CCM Reflections; WI; + SO
(2) " " " " "
(3) Reflections/Journals; GY. + SO
(4) VNFG; Reflections/Journals.
(5) CCM + VNFG + SO
(6) CCM + VNFG.
(7) CCM + VNFG + SO
(8) Outcomes of Science ⇒ CCM + SO.

Novice & Expert Concept Maps
(third map is the 'Expert' map)

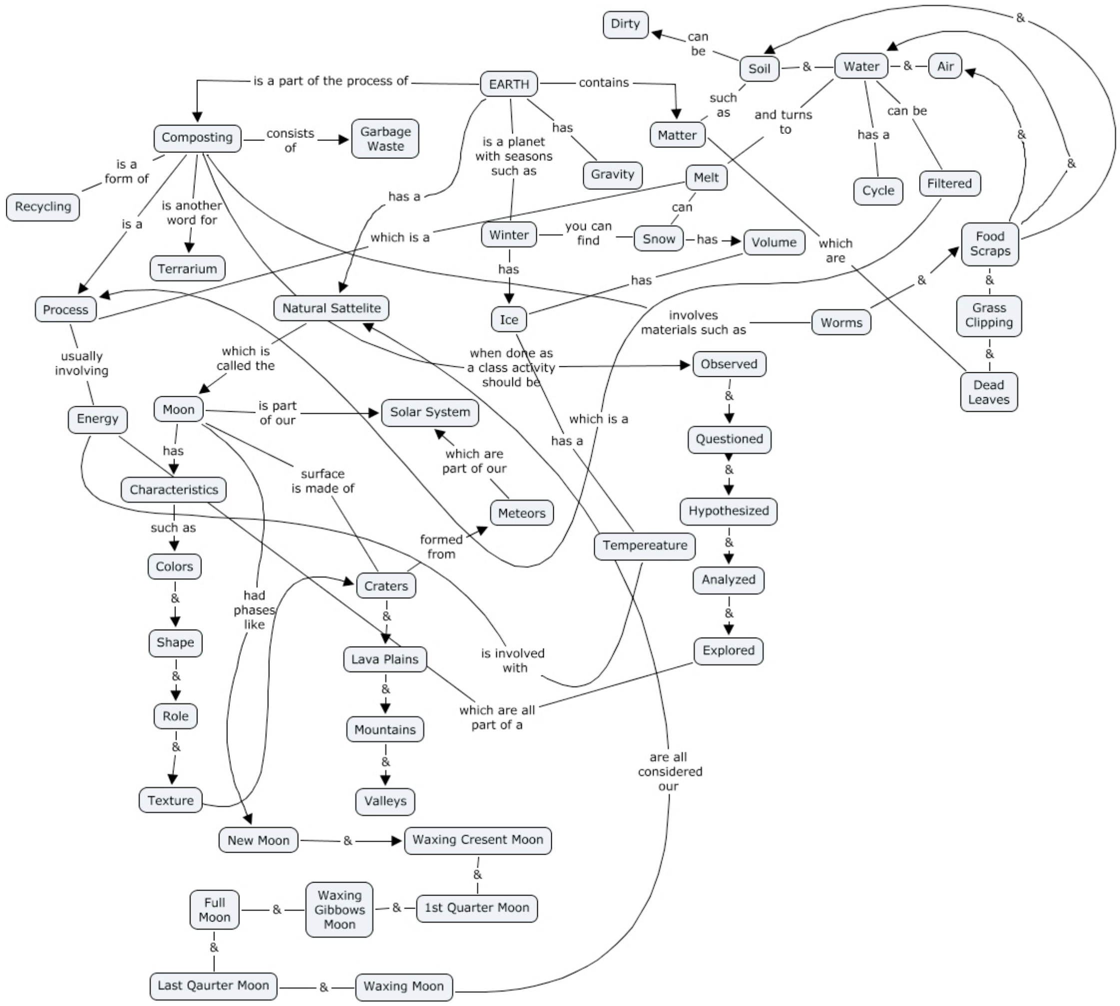


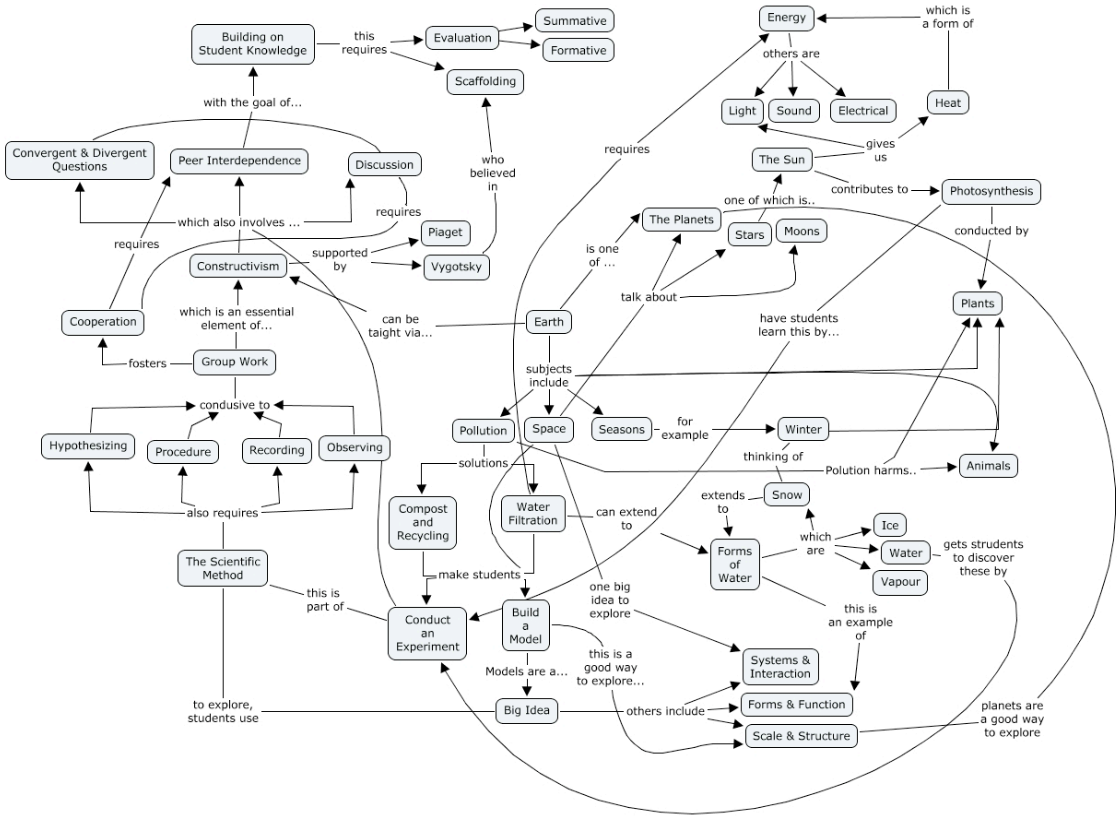
Inquiry Based Education
Goal in all Lessons
Hypothesis Lesson #1
Question Lesson #2
Experiment Lesson #3
Prior Knolwedge Lesson #4
based on your
Big Idea
part of
helps meet the goal of
Composting
part of
Systems & interactions
part of
form of
Components of Snow
part of
melts into
Water
needs/depends on
Rotation of Earth
QEP Goal of: to Become Familiar wtih Scientific & Technological Ways of Reasoning
through the use of
KHWL Charts
lead to
Experimental Learning
leads to
Trying to fiugure it out on their own
form of
lead to
lead to part of
leads to
Questioning Strategies
Language Arts
form of
Subject Based Extensions
incorporates
of
Recording
meets
Cross Curricular Competencies
of
Math
part of
part of
part of
part of
QEP
form of
met the
goal of
part of
Assessment
QEP goal of becoming familiar with certain aspects of languages used in Science & Technology
comes from
through
important in
Participation
form of
Collaboration
through the use of/ requires use of
which requires
which requires
Group discussion
leads to
Asking Questions
Helps solve


INQUIRY
has a
Process
has
Instructional Strategies 5 E's
one strategy is
ENGAGEMENT
EXPLORATION
EXPLANATION
ELABORATION
EVALUATION
through
Descriptive Modelling
Explanatory Modelling
Experimental Modelling
by
Communicating
Classifying
Measuring
Observation
Terrarium
Science Journals
Ideas & Reasoning
through sharing
Class Discussion on Moon Characteristics
Shape & Colour of Moon
Melted Snow
amount of
Changes in terrarium over time
Picture of Moon
Before & after of water filtration
Melting Snow
of
Observations
Melting Snow
Water Filtration
Changes in terrarium
Inferring
Visual of Picture of Moon
Hypothesizing
Changes in terrarium
Melted Snow
of why
We Can't See the Moon
What Will Happen through Filtration of Different Materials
Identifying Variables
in
Terrarium
which are
Soil, Worms, Water
Filtration of Water
which are
Filtration System Water
interpreting
Moon Fact Sheet
Discussions about Snow
Work Sheets
for homework on
Biodegradable Materials
on
Terrarium
Outdoors
authentically learning
Wasting Water
Relatable Information
Hands-on Snow
Books on Composting
Visual Media
such as
Picture of Moon
Placing Soil and Worms
Hands-on Activities
Touching Snow
using
Home-made water filtration
Worksheets
Class Discussion
Going Green
about
Class Discussions
sharing ideas on
Melting Snow
Teacher
Water Filtration
prepared
Moon Fact Sheet
further
Use of Compost
Project on Northern Animal
going on a
Field Trip
Knowledge
doing
Homework
reading
Books on Snow
playing
Flascard & Board Games on Moon
Comparing/ Contrasting about Snow
Participation
in
Games
Discussions

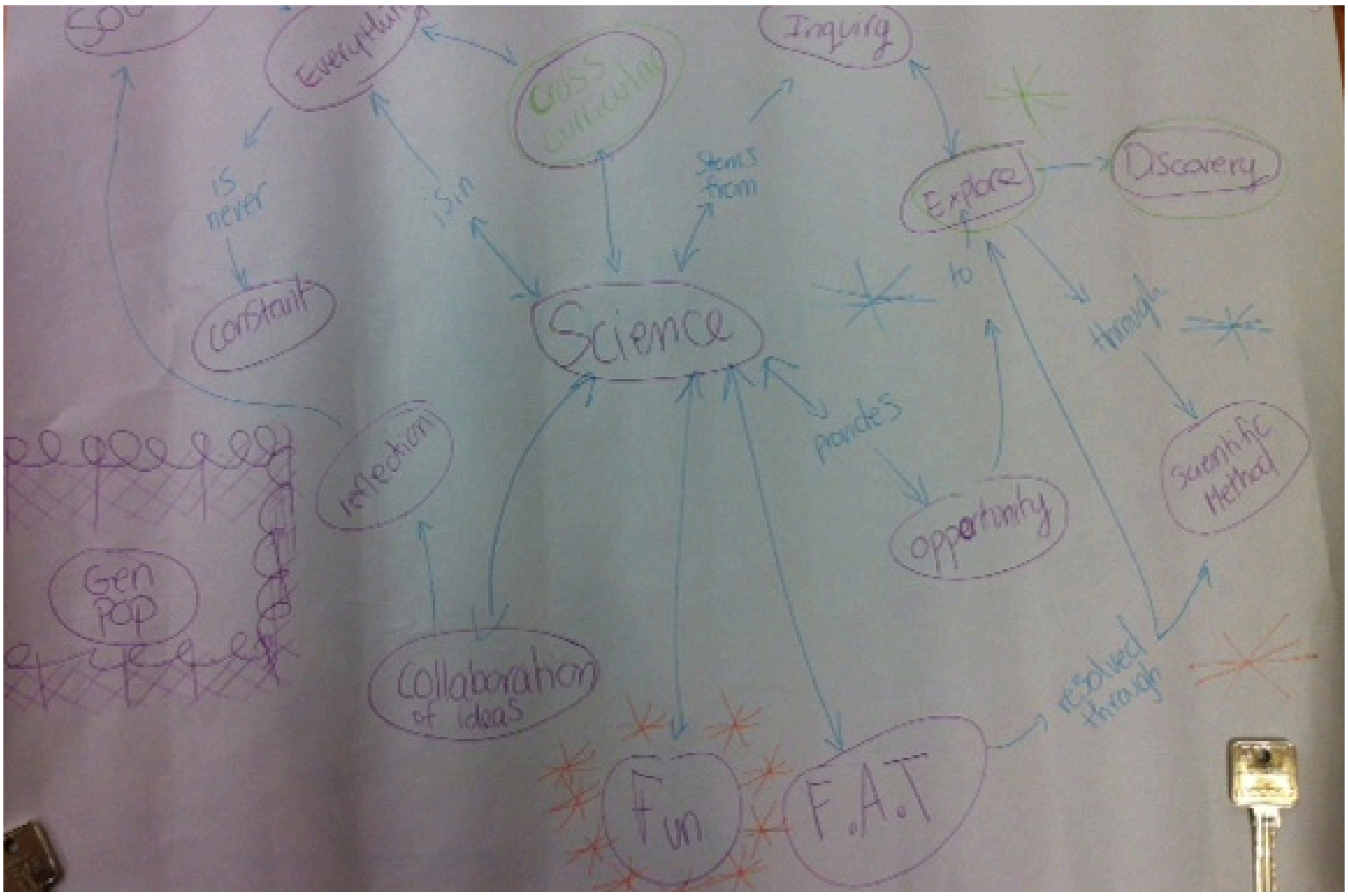


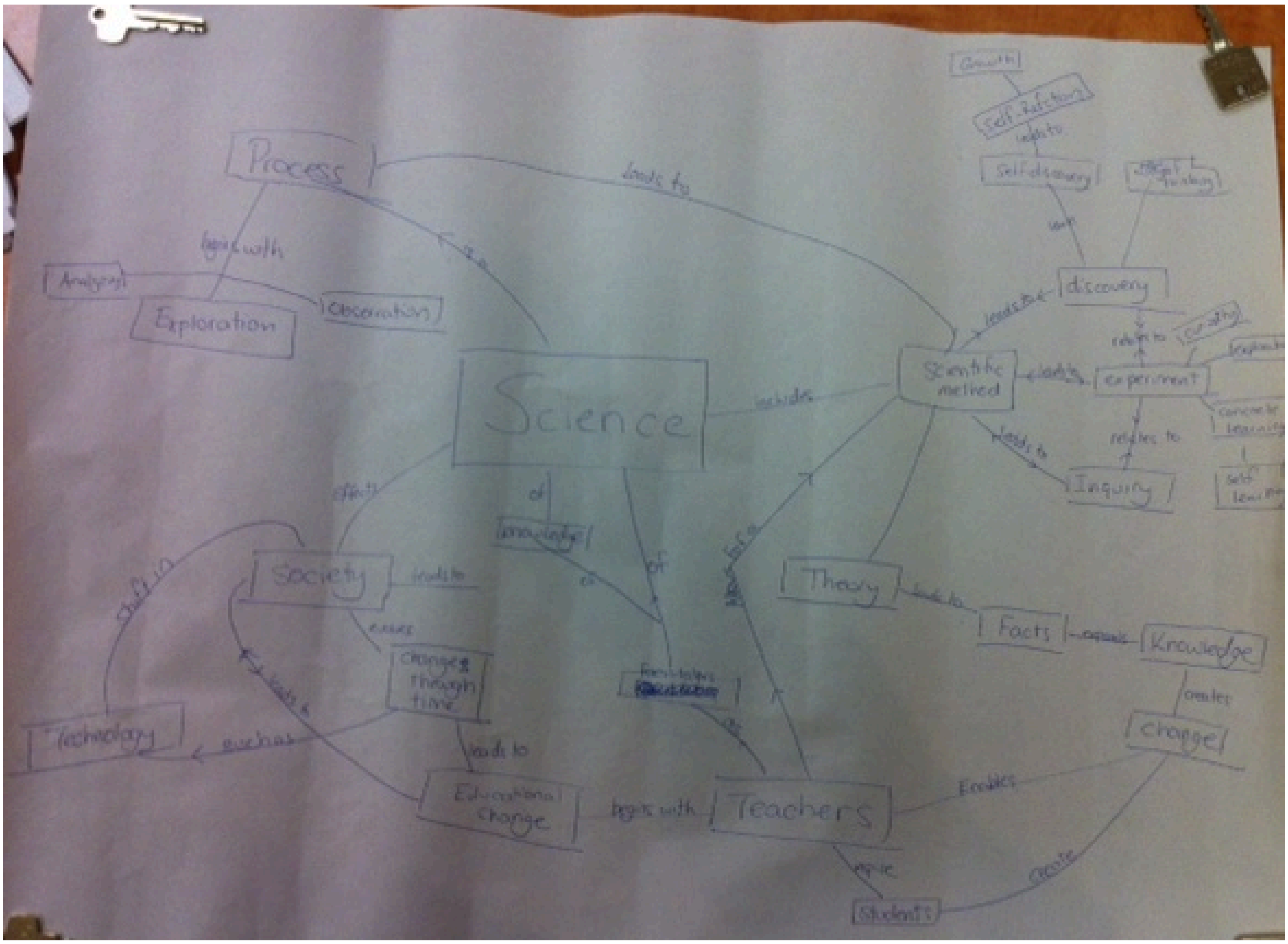
interprets
Kuhn
Societal Structures
Techniques and Instrumentation
focus determined through
examples of
Big Ideas
Systems and Interactions
Facts
rooted in
Forces and Motion
coined by
defined by
Foucault
reinforced lack of
Paradigms
Discourses
reinterpreted nature of
Individuals
are akin to
Living Things
comprised of
Energy
Curriculum
Matter
compose
Material World
can be delineated as
Communities
Theories
dependent upon
destroys
Disciplines
includes
Earth and Space
summarized through
example of
rooted in
functions through
SCIENCE
Learning
further defines
Procedures
are forms of
Processes
explored using
can be employed for
Teaching
respective of
namely
akin to
Science Education
can be comprised of
Strategies
new knowledge
develops
Scientific Method
Patterns
can be described as
Exploration
comprised of
defined through
delineated as
should be
must undergo
routines
pre-determined steps
Discovery
Question
Test
inherent to
Hypothesize
established through
these include
Major Approaches to Science Pedagogy
can be interpreted as
Predict
results in
Analyze
Inquiry
Integrated
focuses on
Disprove
form of
focused within
in an attempt to
fosters
falsification
example of
Inter-disciplinary of Science
Prove
is a part of
inherent to
Reasoning
Inquiry Process Skills
can be delineated as
spans beyond
can also be known as
rooted in
can be rooted in
acknowledged through
Cross-curricular aspects of science
are essential to
Subject Matters
adds to
Tentative
Human Error
Mathematics
include
add a perspective to
Language Arts
Inference
separate from
Observing
specifically include
Fine Arts
Social Sciences


Dirty
can be
Soil
&
Water
&
Air
EARTH
is a part of the process of
contains
Composting
consists of
Garbage Waste
Matter
such as
and turns to
has a
can be
has
is a planet with seasons such as
Gravity
Melt
Cycle
Filtered
is a form of
Recycling
is a
is another word for
Terrarium
has a
which is a
Winter
you can find
can
Snow
has
Volume
which are
Food Scraps
has
has
Process
Natural Sattelite
Ice
involves materials such as
Worms
Grass Clipping
Dead Leaves
usually involving
which is called the
when done as a class activity should be
Observed
Energy
Moon
is part of our
Solar System
which is a
has a
Questioned
has
which are part of our
surface is made of
Characteristics
Meteors
Hypothesized
such as
formed from
Tempereature
Colors
Craters
Analyzed
had phases like
Shape
Lava Plains
is involved with
Explored
Role
Mountains
which are all part of a
are all considered our
Texture
Valleys
New Moon
Waxing Cresent Moon
Full Moon
Waxing Gibbows Moon
1st Quarter Moon
Last Qaurter Moon
Waxing Moon

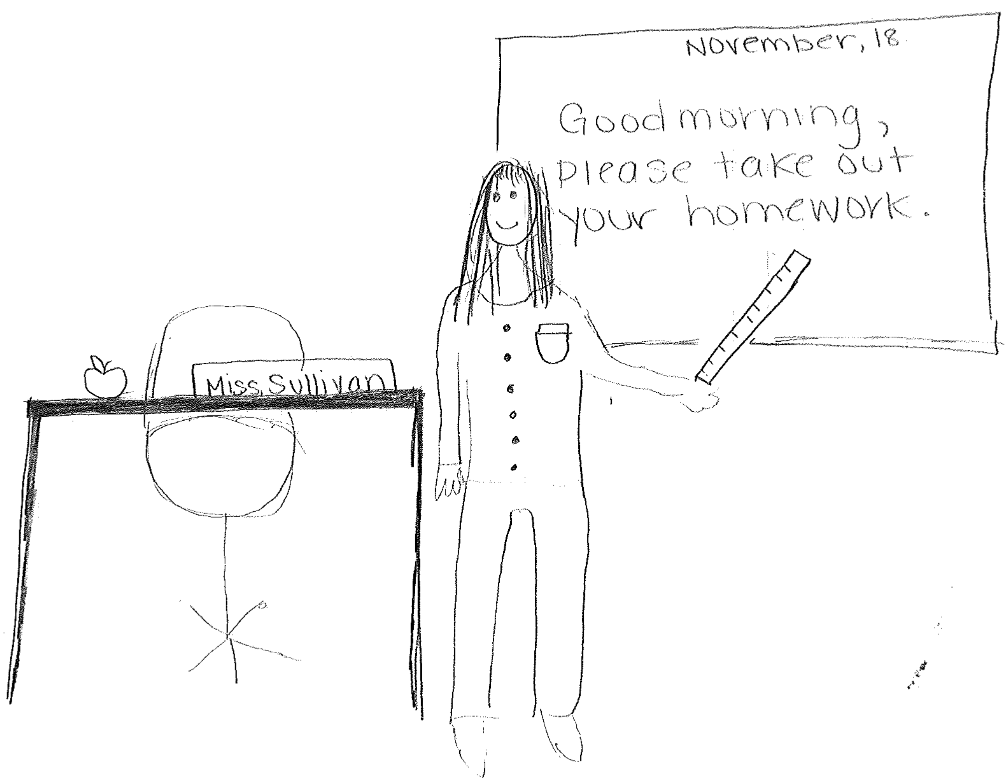

Building on Student Knowledge
this requires
Evaluation
Summative
Formative
Scaffolding
with the goal of...
Convergent & Divergent Questions
Peer Interdependence
Discussion
who believed in
which also involves ...
requires
requires
Piaget
supported by
Vygotsky
Constructivism
Cooperation
which is an essential element of...
can be taight via...
Group Work
fosters
condusive to
Hypothesizing
Procedure
Recording
Observing
also requires
The Scientific Method
this is part of
to explore, students use
Energy
which is a form of
others are
Light
Sound
Electrical
Heat
requires
gives us
The Sun
contributes to
Photosynthesis
one of which is..
The Planets
Stars
Moons
conducted by
is one of ...
talk about
Plants
Earth
have students learn this by...
subjects include
Pollution
Space
Seasons
for example
Winter
thinking of
solutions
Polution harms..
Animals
Compost and Recycling
Water Filtration
can extend to
extends to
Snow
Forms of Water
which are
Ice
Water
Vapour
gets strudents to discover these by
make students
Conduct an Experiment
Build a Model
one big idea to explore
this is a good way to explore...
this is an example of
Systems & Interaction
Models are a...
Big Idea
others include
Forms & Function
Scale & Structure
planets are a good way to explore


Experimenting
Everything
TEACHING
WORLD
Questioning
???
Children
Learning
Everything is science
Science is learning
Novel + New
Scary?!
discover
Connections
improve, grow + develop


Everything
Cross Curricular
Inquiring
Explore
Discovery
is never
is in
stems from
constant
Science
to
through
reflection
provides
Scientific Method
opportunity
Gen Pop
Collaboration of ideas
resolved through
Fun
F.A.T


Process
leads to
begins with
Analysis
Exploration
Observation
Science
includes
Scientific method
discovery
leads to
Growth
Self-Reflection
Self-discovery
experiment
relates to
concrete learning
Inquiry
affects
Society
knowledge
of
Theory
leads to
Facts
equals
Knowledge
creates
change
changes through time
such as
Technology
leads to
Educational change
begins with
Teachers
Enables
Students
create

[redacted]

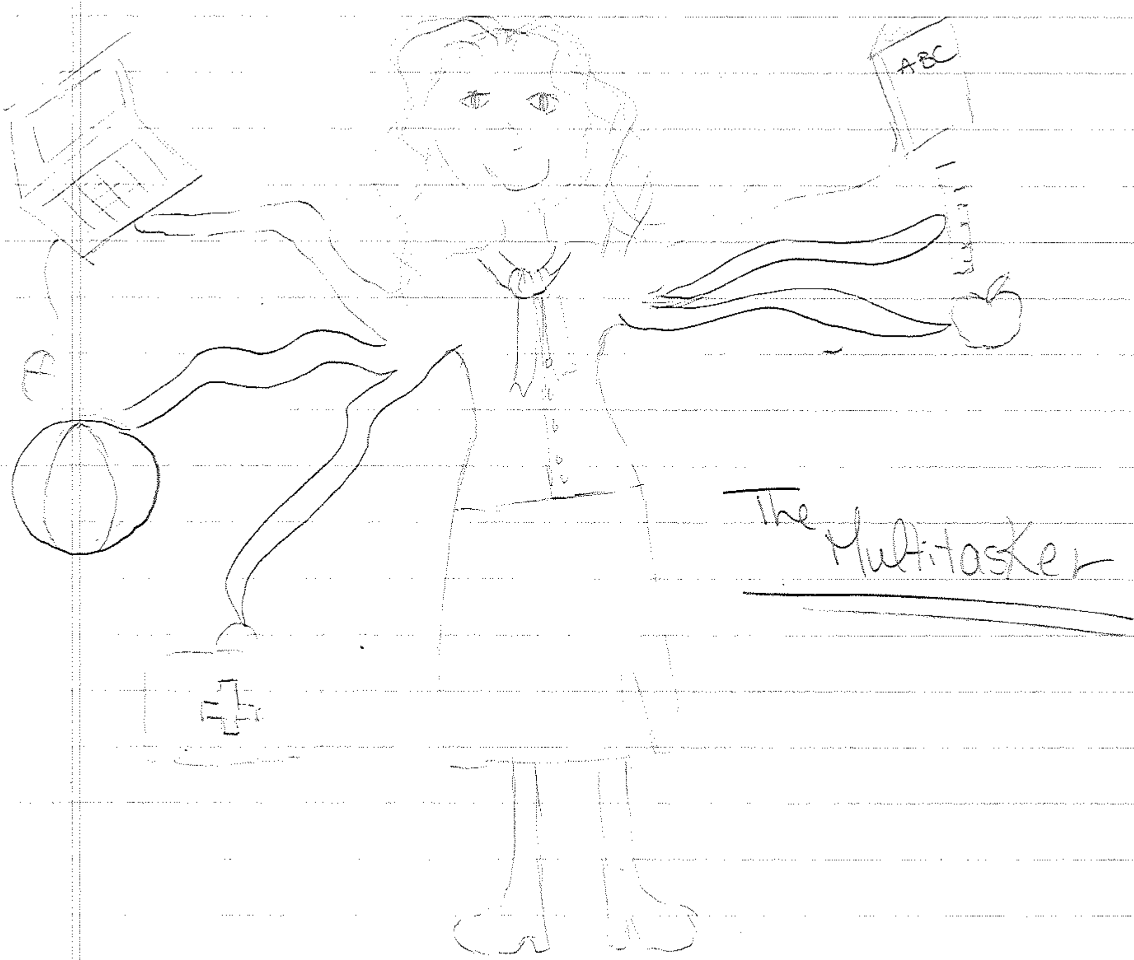

November, 18
Good morning, please take out your homework.
Miss Sullivan

[redacted]


Good Morning!
ME!!
November schedules
- Math
- ELA
- Science
- Social Studies
Belt


Welcome

[redacted]



Université Concordia University

CERTIFICATION OF ETHICAL ACCEPTABILITY FOR RESEARCH INVOLVING HUMAN SUBJECTS

Name of Applicant: Dr. Vivek Venkatesh

Department: Faculty of Arts and Science\Education

Agency: Fonds Québecois de la Recherche sur la Societe et la Culture

Title of Project: L'utilisation d'ontologies de domaines et de taches dans les environnements d'apprentissage

Certification Number: 10000252

Valid From: July 27, 2012 to: July 26, 2013

The members of the University Human Research Ethics Committee have examined the application for a grant to support the above-named project, and consider the experimental procedures, as outlined by the applicant, to be acceptable on ethical grounds for research involving human subjects.

Dr. James Pfaus, Chair, University Human Research Ethics Committee

UNIVERSITÉ Concordia UNIVERSITY

CERTIFICATION OF ETHICAL ACCEPTABILITY FOR RESEARCH INVOLVING HUMAN SUBJECTS

Name of Applicant:	Dr Vivek Venkatesh
Department:	Education
Agency:	N/A
Title of Project:	Improving the Design of Social Interactions in Online Courses: Case Studies of Educational and Informal Web-Based Communities
Certification Number:	UH2010-039-1
Valid From: April 5, 2012	to: April 4, 2013

The members of the University Human Research Ethics Committee have examined the application for a grant to support the above-named project, and consider the experimental procedures, as outlined by the applicant, to be acceptable on ethical grounds for research involving human subjects.

Dr. James Pfaus, Chair, University Human Research Ethics Committee

01/29/2009

McGill

Research Ethics Board Office
James Administration Bldg.
845 Sherbrooke Street West. Rm 429
Montreal, QC H3A 0G4

Tel: (514) 398-6831
Fax: (514) 398-4644
Website: www.mcgill.ca/research/researchers/compliance/human/

Research Ethics Board III
Certificate of Ethical Acceptability of Research Involving Humans

REB File #: 483-0413

Project Title: Transforming teacher training and improving students' academic achievement with advanced digital technologies

Principal Investigator: Prof. Roger Azevedo **Department:** Educational&Counselling Psychology

Co-investigators: Prof. S. Lajoie; Prof. N. Hall; Prof. A. Asghar (McGill)
Prof. V. Venkatesh (Concordia)

Collaborators: Dr. E. Charles (Dawson); Prof. P. Winer (Simon Fraser);Prof. T. Laferrière(Université Laval)
Mr. R. Marqui(EXOU)
Dr. F.Labonté; Ms. C. Chapdelaine (CRIM)

Approval Period: **June 3, 2013-June 2, 2014**

The REB-III reviewed and approved this project by delegated review in accordance with the requirements of the McGill University Policy on the Ethical Conduct of Research Involving Human Participants and the Tri-Council Policy Statement: Ethical Conduct For Research Involving Humans.

Lynda McNeil
Manager, Research Ethics

---

* All research involving human participants requires review on an annual basis. A Request for Renewal form should be submitted 2-3 weeks before the above expiry date.
* When a project has been completed or terminated a Study Closure form must be submitted.
* Should any modification or other unanticipated development occur before the next required review, the REB must be informed and any modification can't be initiated until approval is received.

Concordia UNIVERSITY
Real education for the real world

Human Research Ethics Committee
Office of Research
SGW Campus - GM 1000
t 514.848.2424 x 2425 • f 514.848.4290
ethics@alcor.concordia.ca

ANNUAL REPORT FOR RESEARCH INVOLVING HUMAN SUBJECTS

Please ensure that all questions are fully completed. Attach additional sheets if you require more space. Once completed, please return a signed hard copy to the HREC, c/o the Office of Research, S GM-1000.

STATUS REPORT DUE DATE:

SPF#: UH2009-051		ORIGINAL SPF APPROVAL DATE: June 2009
PROJECT TITLE: L'utilisation d'ontologies de domaines et de taches dans les environnements d'apprentissage		
PRINCIPAL INVESTIGATOR: Dr. Vivek Venkatesh		DEPARTMENT: Education
OFFICE ADDRESS: S-LB-578.10	TELEPHONE: ext. 8936	E-MAIL: Vivek@education.concordia.ca

QUESTIONS

1. Is data collection from human subjects still active in this protocol? YES ☒ NO ☐

   A. If no, when did the data collection phase end? December 2013

2. Is there currently primary data from this study in storage? YES ☒ NO ☐

   A. If yes, please give details on the format and location of this data storage, who has access to it, and the plan for its eventual disposal/destruction:

   Both electronic and paper copies of all data from the concept mapping phase of this research program are currently being stored at Concordia University, with the principal investigator, Dr. Vivek Venkatesh.

   At the moment, only principal members of the research team have access to the data collected, however, participants do have the option of reviewing their contributions. Research assistants, given adequate funding, will be granted access to data.

   Pending successful completion of the overall project (expected by December 2013), as per Tri-Council Policy, data will be archived for a minimum period of five years and then disposed of -- if all relevant academic contributions have been explored.

   B. If No, please give details as to when this data was disposed of or destroyed, and what method was used to do so.

3. What is the current funding status of this project?

☒ Funded	Agency:	F00847	Funding Period:	Ends in June 2012 – one year extension automatically granted
	Grant Type:	Nouveau chercheurs	Grant Number:	F00847
☒ Funding Sought	Agency:	Accelerator funds	Funding Period:	Till December 2013
☐ Unfunded				

4. Have there been changes to any of the following elements since this protocol originally received ethics approval that have not been submitted as a modification? To answer this question, please refer to your original SPF # «SPF».

	YES	NO		YES	NO
Appreciable Risk	☐	☒	Sample Size	☐	☒
Consent Process	☐	☒	Target Population	☐	☒
Research Methodology	☒	☐	Research Team	☐	☒
Treatment of Participants	☒	☐	Research Location	☒	☐
			Other	☐	☒

5. If you answered YES to any of the above, please explain what changes have been made, and why they were not submitted as a modification.

Changes are quite recent and have therefore not been submitted as modifications seeing as how they are currently pending/yet to be fully implemented and integrated into the program of research.

The following additions/modifications are being considered and integrated into the overall research program:

Data collection will take place in two distinct settings—at McGill University's "Laboratory for the Study of Metacognition and Advanced Learning Technologies (SMART Lab)" and in instructor Kamran Shaikh's classroom at Concordia University (EDUC382: Teaching Science Concepts in the Elementary Classroom).

There will be two groups for this study:

- Group 1: Consists of Mr. Shaikh's students from past cohorts of EDUC382.
- Group 2: Consists of students from Mr. Shaikh's Fall 2012 "EDUC 382: Teaching Science Concepts" cohort.

Group 1 (From June 2012 to September 2012):

At McGill's SMART Lab, after completing a science beliefs questionnaire, participants will be asked to engage in a metacognitive exercise—participants' eye movements and facial gestures will be tracked while they explore and dissect student-generated, nature of science concept maps.

Other forms of data to be collected include: participants' concept map categorizations, Think-Aloud protocols as well as post-activity science belief questionnaires and interviews.
Ethical approval has already been obtained as part of grant number VS1117

Group 2 (From September 2012 to December 2012):

In "EDUC 382: Teaching Science Concepts in the Elementary Classroom", students will be asked to complete a science beliefs questionnaire prior to a short discussion on the principles of the Nature of Science. Students will then be given access to the student-generated Nature of Science concept maps and will be asked to complete a short learning activity—depending on the nature of the cohort, students will either:

a. Be grouped according to their responses on the pre-beliefs questionnaire and then asked to collaboratively construct a Nature of Science concept map.
b. Be grouped randomly and will be asked to collaboratively construct a Nature of Science concept map.

Other forms of data to be collected include: individual and group interviews, group and individual observations (to be conducted by research participants), Think-Aloud protocols, developed Nature of Science concept maps and post-activity science beliefs questionnaires and interviews.

6. Since original ethics clearance, have any adverse events (such as complaints, injuries, problems or complications) been experienced by any participants as a result of involvement in the study?

YES ☐ NO ☒

7. If yes, please describe any adverse events in the space below.

INVESTIGATOR ACKNOWLEDGEMENT

Please check the category into which the project falls:

☒ **CONTINUING PROJECT**
I acknowledge that this project will continue according to the description in the application for which ethics clearance originally was granted and in compliance with Concordia University Policy for the Ethical Review for Research Involving Humans and the Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans. Any subsequent modifications to this project are indicated on this form or have been submitted for prior ethics clearance by the Human Research Ethics Committee. Any adverse events occurring during the conduct of this research will be reported immediately to the Office of Research.

☐ **COMPLETED PROJECT**
I acknowledge that this project was completed according to the description in the application for which ethics clearance originally was granted and in compliance Concordia University Policy for the Ethical Review for Research Involving Humans and the Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans. Any subsequent modifications to this project are indicated on this form or were submitted for prior ethics clearance by the Human Research Ethics Committee. Any adverse events that occurred during the conduct of this research have been reported to the Office of Research.

☐ **TERMINATED PROJECT**
I acknowledge that this project has been terminated prior to completion, and that completed portions remained in accordance with the description of the application for which ethics clearance originally was granted and in compliance Concordia University's Policy for the Ethical Review for Research Involving Humans and the Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans. Any subsequent modifications to this project are indicated on this form or were submitted for prior ethics clearance by the Human Research Ethics Committee. Any adverse events that occurred during the conduct of this research have been reported to the Office of Research.

Signature of
Principal Investigator: ______________Vivek Venkatesh______________ Date:
_______________July 16, 2012_____