Using Engineering Challenges to Cultivate Scientific Creativity

James Vincent Hatch

University of Alberta

James Hatch, Department of Secondary Education,

University of Alberta.

In consideration of Master's project.

Supervisor Dr. Bonita Watt. University of Alberta.

Abstract

The current state of science education at the secondary level in Canadian schools demonstrates a general deficiency of creativity both in the way scientific concepts are taught and in the cognition developed by students. The purpose of this project is to provide a resource package designed to place youth in the middle space between being teachers and being students. The goal is to discover how this in-dwelling affects creativity in a science context.

The central research question is *How is creativity cultivated in a science-education context?* An exploration of the central research question will occur by way of four sub-questions: *How does a collective mind set contribute to the creative process? In what ways does the socio-cultural climate of a classroom contribute to the creative process? In what ways does complexity theory contribute to the creative process? Can creativity be cultivated by manipulating classroom power positions?*

The theoretical framework is concentrically modeled. The overarching paradigm is a postmodern world view. The theme of creativity within a postmodern worldview is defined using a three-criterion model. Social constructivism, as defined by Lev Vygotsky's theories of learning and development, forms the foundation on which the project rests. A fusion between Cultural Historical Activity Theory and Complexity Theory provides the contextual framework for the project.

TABLE OF CONTENTS

1.0 Introduction

1.1 Background

My interest in educational research has formed as a result of interactions between my personal history, my personal values, my cultural background and my professional career.

My personal history is a story of discovery. Curiosity lies at the heart of my spirit. My curiosity drives a desire to understand our world. All of my life experiences including formal schooling, adventure trips on the land, construction projects, sports, and many diverse employment experiences have provided opportunities for me to ask questions and seek answers. Some of these experiences provided more freedom and opportunity to express curiosity and creativity than others. My formal education contained the most rigid and limiting range of experiences. Involvements on the land, both as a leader and as a participant, provided many challenging situations that required creativity to overcome. Examples ranged from trip planning and logistics to difficulties encountered while on the land including encounters with wildlife, navigational difficulties and equipment malfunctions. The challenges presented by many of the construction projects that I have taken on over the years have tracked a similar trajectory of challenges. The initial challenge of planning such projects always requires extensive research and planning, but the surprise problems encountered during the project itself seem to overshadow the initial challenges associated with getting started. Successful navigation of these surprises consistently yielded the most significant learning experiences. I have had a wide range of employment experiences throughout my life previous to my involvement in education; examples include working as a cellar-hand in a small winery, working as a wilderness guide, managing a homeopathic medication production facility and working as a driller blaster. Generally speaking these jobs provided (and often demanded) flexibility, creativity and problem solving skills when overcoming challenges.

I value an inquiring mind state. At the core of my being is an inquisitive soul who exists in a state of questioning, always ready to take on the next challenge or problem waiting to be solved. Even with careful planning and consideration, complications arise and the complexities we encounter define and enrich our relationships with each other and with the natural world. Questioning the complexities we encounter generates useful knowledge by uncovering underlying connections between phenomena.

Coupled with an inquiring mind state is a passion for experiential science. Early in my academic career, an interest in natural science surfaced. The inter-workings of complex biological systems were always at the center of my focus growing up. I can remember guided and (unguided) animal and insect dissections and many independent plant projects that continually tantalized my curiosity. The precision of engineering design mystified my young mind and my curiosity was evident in many reverse engineering efforts that resulted in many devices and machines that would periodically go missing from my childhood home. As I grew into teenage-hood, the magic of chemical processes captured my imagination and inspired life-long learning as I continued to study chemistry during my post-secondary education.

A wide range of transferrable skills have developed from the diversity of my life experiences. Professionally, as a teacher, I seek philosophies and methodologies which provide frameworks that inspire learning. These skills, along with a life-long growth mindset, drive my desire to develop meaningful learning experiences for my students. As

I have grown into teaching, I have noticed that as I (continue to) transition from learner to educator, I am able to operate more creatively as my familiarity with subject matter becomes more refined. I believe that the act of teaching is what refines my own understanding and allows for more creative outputs. I want to explore whether this growth phenomenon is strictly a personal effect or whether this concept is transferrable to others, such as my students.

1.2 Purpose

Classic science education, where an expert expounds his or her expertise upon learners, results in a transfer of knowledge and ideas to learners rather than the development of critical thinking and creative skills. The purpose of this teacher-student resource project is to explore the effects on creativity when placing students in the middle space between being teachers and being students during creative engineering experiences.

1.3 Research Questions

Central Question:

How is creativity cultivated in a science-education context?

Sub Questions:

How does a collective mindset contribute to the creative process?

In what ways does the socio-cultural climate of a classroom contribute to the creative process?

How does complexity theory contribute to the creative process?

How can creativity be cultivated by manipulating classroom power positions?

2.0 Literature Review

2.1 Post-Modern Paradigm

In contrast to the modern world view in which classical science education was forged, the post-modern world view places value on multiple, simultaneous voices, truths and opinions. A post-modern perspective honours plurality and post-modern world is an ideal paradigm for this research because “In a postmodern world, boundaries and strict divisions between dualistic notions are blurred” (Koukkanen, 2000, p. 414). Postmodernism considers the collective as the central unit of participation rather than the individual. By replacing “I” with “We” we decentralize focus away from separate entities. The idea here is to examine the effect of dissolving classical teacher-learner paradigm and replacing it with a dynamic community learning structure.

Contemporary engineering and technological innovation benefit from the interface between people working together. The archetypical savant who develops ideas in isolation is an archaic and mythological character that has been replaced in contemporary settings by teams of developers. Projects get finished efficiently when participants act on behalf of the interests of the team as a whole and embody the “WE” spirit. This resource project attempts to direct participants towards the abolishment of individual effort in favour of collective efforts.

2.2 Defining Creativity

A lively debate over which specific criteria objectively delineate creativity is underway. Ambiguous definitions of creativity avoid the identification of specific criteria altogether. If creative action speaks for itself, why bother narrowing down the parameters? In 1950 Joy Paul Guilford, a pioneering researcher in creativity theory, proclaimed that "creativity refers to the abilities that are most characteristic of creative people" (Guilford, 1950). This ambiguous definition repeatedly appears in the literature and serves as a guide post to bring our minds closer to focus. However, if thorough research is to be performed based on assessments of creativity, a more tangible definition is required.

Contemporary research requirements demand that researchers challenge ambiguous definitions of creativity and redefine creativity through more palpable descriptions (Runco & Jaeger, 2012; Simonton, 2009). A small group of researchers are currently working with the idea that creativity can be explained using a single criteria. Single criteria definitions boil down to the idea that creative expressions are dependent on an original interpretation of an experience from an individual (Simonton, 2009). Examples of this type of creativity invoke the archetypical genius of Nikola Tesla, Wolfgang Amadeus Mozart and Michelangelo di Lodovico Buonarroti Simoni. Single criteria theories are useful because they draw across broad fields of experience from the sciences to the arts to the everyday, however, challenges result when huge collections of data get winnowed down to essential elements (Kaufman & Baer, 2009). Mark Runco (2009) and Dean Simonton (2009) contribute arguments about whether a single generic process accounts for creativity or whether creativity depends on the contextual domain.

Simonton (2009), the main proponent of a single criteria definition, offers a hypothesis that lies squarely on the creative person, rather than creative processes or products. Simonton (2009) asks readers to consider whether "the disposition of a creative scientist is distinguishable from that of the creative artist? Would Einstein and Picasso have received radically different scores on standard personality tests?" (p. 3). Simonton's research stimulates curiosity in the field as it appears to induce more questions than it answers. Critics of Simonton ask "how much of the messy variability of the domain specificity of creativity can be captured on a single dimension?" (Kaufman & Baer, 2009, p. 6) and point out that "creative talents are not normally distributed and are not universal capacities" (Runco, 2009, p. 463). A thriving debate continues regarding the definitive identification of creativity that may be easier to resolve though the inclusion of more than one variable. A single variable definition placed squarely on the creative person lies in conflict with the social component of this project, and therefore, a more detailed definition is required.

The most widely cited definition of creativity precipitated from Morris Stein's (1953) emphasis on understanding the creative process of creativity rather than focusing on individual creative persons. Stein's definition exists as a coupling between two criterion; originality and effectiveness. Originality is connected to unique, novel expressions and effectiveness is connected to utility. Using two parameters in this way increase the value of the definition for two reasons; firstly, it does not place emphasis on the individual, and secondly, it connects more appropriately with problem solving and engineering science.

Some creativity researchers include a third criteria when attempting to define creativity. Three-criterion definitions of creativity work in conjunction with the variables put forth by Stein (1953) but include *surprise* as part of equation. For many thinkers, novelty and usefulness alone do not sufficiently describe the essence of creativity (Klausen, 2010). As Klausen points out, creativity is often experienced by those who encounter a surprisingly creative product rather than a creative person or process. Thus creativity possesses an affective quality.

In order to amplify the likelihood that object-oriented creative outputs are generated, the efforts of the participants can be focused in a non-competitive way by relying on collective reciprocity and a sharing of ideas. Socio-cultural conditions can be considered so that meaning can be constructed in relation to the greater collective. Every student will have an opportunity to be creative and feed into the creativity of the collective. Constraining factors will be minimized in order to cultivate an emergent environment within the collective. By not strictly predefining the destination of the learning experience, students are encouraged to express unique ideas as they adjoin their input while working towards finding a solution to a problem. Creative solutions are akin to random the mutations responsible for natural selection. Beneficial elements give advantage and these new elements remain as part of the design. Extraneous or interfering elements bring about unfavourable consequences and are eliminated from designs.

2.3 The Foundation: Social Constructivism

Lev Vygotsky's (1978) emphasized the importance of culture and social context for cognitive development. The key mechanism of Vygotsky’s theory of social constructivism (1978) as it pertains to education is the Zone of Proximal Development (ZPD). The ZPD is the stage of learning where students require scaffolding to make learning progress (Kirsch, 2014).

A critical feature of Vygotsky's theory (1978) is that learning precedes development (Vygotski, 1978). This stands in contrast to the intuitive perception that developmental steps and stages provide capacity for learning. The relational interplay between the ZPD, learning and development is identified through the notion that "developmental processes do not coincide with learning processes. Rather, the developmental process lags behind the learning process; this sequence then results in zones of proximal development" (Vygotsky, 1978). This research attempts to boost the development of creativity by providing opportunities to learn as teachers and students within spirals of action focussing on zones of proximal development. In the first stage of the lessons contained in this resource package, the teacher provides the scaffolding for the students. In the second phase, students provide the support for a younger group of students as they are exposed to the concept. During the final stage, students return to the guidance of the teacher, hopefully, with new insights developed through the experience of teaching.

An educationally centered social constructivist framework concerns itself with developing social teaching approaches that contribute to students' conceptual growth. In a social context, conceptual understanding is catalyzed by giving students opportunities to reflect upon interpersonal interactions within learning experiences (Taylor, Fraser & Fisher, 1997). Considering these parameters pushes the classroom towards the student-centered learning environment which stands in contrast to the classical teacher-centered classroom experienced in many science classrooms. Direct instruction and teacher-centered environments can be understood, if not condoned, based on the objectivist perspective which views science as a bank of knowledge rather than a way of thinking. Objectivist attitudes also become apparent when teachers treat curriculum as a plan rather than an experience (Taylor, Fraser & Fisher, 1997). The learning opportunities outlined in this project are designed to restore science learning to a living and dynamic state and replace the oversimplified interpretation that science learning should be based on predetermined outcomes.

2.4 Problem Based Learning

A theoretical constructivist platform requires a complementary context in which to operate. Problem based learning (PBL) provides an ideal approach because of the features that mirror the constructivist outlook. Furthermore, problem based learning aligns itself with the three criteria definition outline in section 1.2. Problem based learning curricula place emphasis on experiences rather than basic understanding. The pursuit of student curiosity is preferred to adherence to a fixed curriculum. The materials used in PBL include the use of manipulatives beyond textbooks. Learning is rooted in interaction rather than repetition. Two-way dialogue is valued more than unidirectional dissemination of knowledge. The role of the teacher is that of a facilitator rather than the authority. A range of assessment strategies are used in place of tests based on definite correct or incorrect answers. Knowledge is dynamic rather than fixed. Finally, and most importantly, meaning is constructed socially, through group work, not individually (Aberšek, 2008).

Each of the lessons offered in this project challenge students with an authentic problem, based on real life applications. In this way, creativity will be activated while incorporating features common to problem based learning opportunities.

3.5 Complexity Theory and Emergent Curricula

Learning is a phenomenon far too complex to model using simple linear approximations such as teacher-to-student vectoring. Traditional educational settings oversimplify the process of learning by approximating learning as process where knowledge can be transferred from one person (often a teacher) to another person (typically named students) via some set of predetermined learning activities. Creative classrooms move past the idea of learning as downloaded information and installed skills; instead they utilize a more flexible environment where participants are encouraged to actively participate in creating the learning environment. If we view a classroom as a microcosm where self-expression is a critical feature within the framework, we more closely approximate the structure of the overall universe. In stark opposition to linear, deterministic models, the real universe has a self-organizing, paradoxical nature. Dynamic qualities allow for the emergence and evolution of newness. The emergence of newness is at the heart of creativity in a science-education context. Therefore by adopting complexity as the part of the classroom structure, we more closely resemble the structure of the overall universe. Moving away from linear passage of information allows for plurality of expression. By complexity to shape the educational landscape, we move towards novelty and surprise, two key ingredients in the three-criteria definition of creativity.

William Doll (2012) explains that despite the arrival and acceptance of a post-modern world view, where multiple truths are permitted to exist simultaneously, singular facts still act as a central pivot around which (science) education revolves. “The notion of facts existing as atomistic hardness, not as relations remains with us still and dominates our sense of educational basics” (Doll, p. 15). A dissonance exists here because as Doll (2012) points out learning is a complex phenomenon that “exhibits dynamic, creative steadiness” (p. 20) and continues by suggesting that this state possesses the power of transformation.

One specific field where creativity is seen as an advantageous yet underrepresented asset is engineering. An irony exists. If the benefits of creativity are obvious, then why is there a reluctance to adopt more transformative pedagogies designed to encourage creative thinking? Shanna Daly, Erika Jasyjowski and Colleen Seifert (2014) propose several explanations for this including a lack of instructional materials, limited time within demanding curricula, lack of instructor knowledge and the conservative nature of the engineering discipline itself. Despite the challenges, cultivating creativity in science-education promises to reinvigorate the discipline.

This teacher/student resource project centers on facilitating emergent expression in science and engineering contexts. If we treat learning as an open system, learning spontaneously moves towards states of higher order, differentiation and organization (Doll, 2012). By controlling the domain of learning without having rigid boundaries of where learning may lead, the self-organizing nature of a complex learning system can develop. During the research, socially constructed meaning will be examined as participants contribute as part of the collective. William Doll (2012) uses a beautiful analogy to illustrate the advantage of a collective mindset in education.

> As students work on various (texts), the aim is not for all to be on the same page at the same time, but, contrarily, for groups within the web to be on different pages, in different texts, at the same time. Embracing complexity, the aim is for a process of cross-fertilization, pollination, catalyzation of ideas. (Doll, p. 25)

At the heart of this perspective lies a realization that diversity in a classroom is advantageous if we place the deconstruction of homogeneity at the center of our instructional and educational efforts. The organic element of learning is alluded to here by Doll's choice of biological vocabulary.

Daly et al. (2014) continue adding to the discourse by suggesting that the learning environment affects the creativity of student outcomes. According to these researchers, one potent factor that adds to a creative space is the enculturation of risk taking. Open, creative explorations of ideas are supported by the acceptance of risk (Daly et al., 2014).

Others have continued on the theme of classroom culture by exploring how the classroom environment is connected to the emergence of meaning in the classroom. The purpose of Deborah Osberg and Gert Biesta's 2008 work was to explore how emergence of meaning in the classroom is determined by classroom enculturation. Osberg and Biesta describe how an emergent curriculum is an indwelling between curriculum-as-a-plan and curriculum-as-an-experience. Osberg and Biesta suggest that "if meaning is understood as emergent, and if educators wish to encourage the emergence of meaning in the classroom, then the meanings that emerge in classrooms cannot and should not be pre-determined before the 'event' of their emergence." (Osberg & Biesta, 2008, p. 314). By creating a space for emergence, educators set the stage for spontaneity and "the plurality of the space of emergence encourages the emergence of unique individuals” (Osberg & Biesta, p. 324).

In the spirit of fostering unique creative expressions, plurality will be cultivated so to avoid creating students who are replicates of the teacher. In other words to avoid the situation where “The ‘master’ has designed a pedagogy that will “reproduce the master’s style” (Osberg & Biesta, 2008, p. 319). The link between social constructivist framework and complexity theory will be explored. “Emergent epistemologies challenge the idea that meaning is ‘acquired’ and suggest instead that meaning is continuously made and remade through engagement with our world” (Osberg & Biesta, 2008, p. 325). Opportunities to learn, rooted in social interaction, will present themselves repeatedly throughout the spirals of investigation.

2.6 Cultural Historical Activity Theory (CHAT)

Cultural-Historical Activity Theory (CHAT) can be traced back to cultural-historical school of Russian psychology through contributions made by Vygotsky and Leontiev (Wikipedia, n.d.). According to CHAT, historical settings, bias and experiences must be identified and considered if an experience uses object-oriented activities to create activity systems (Engeström, 2014). Object-oriented activities are processes where participants are lead towards the creation of new artefacts or tools (Yamagata, 2009). This project places engineering design tasks as object-oriented activities in order to create scientific activity systems. The object-oriented activities will represent the unit of analysis.

Drawing a common thread from social constructivist theory and CHAT, the zone of proximal development (ZPD) will be used as a conceptual tool for exploring the complexities involved in participant learning. During each spiral of action, participants will assume three positions. Typically, the ZPD is experienced from either the supportive or receptive position. Participants who interact in ways outlined by this resource project will experience both variations of the ZPD as they receive and provide scaffolding. The first position places the participant as a student requiring scaffolding (operating as learners). The second position places participants in teacher roles providing scaffolding for another group of learners. The third repositions the participants as students. This variation in learning/teaching position will reduce the "unidirectional relationship (that is often) created between the organism and the environment" (Yamagata-Lynch, 2008, p. 19).

Activity system analysis utilizes an orienting activity that that allows participants to explore, examine and predict potential results of actions before they begin (Yamagata-Lynch, 2008). As opposed to treating the orienting activity as a separate entity from the object-oriented activity, this project treats the two as unity along a continuum. The students will have an opportunity to engage in an object-oriented activity, then be asked to teach the activity to a group of younger students and then revisit the object-oriented activity for a second time.

The purpose of Susan Kirch's 2014 work was to critically review *Science Education during Early Childhood: A Cultural-Historical Perspective*, a 2013 book written by Wolff-Michael Roth, Maria Ines, Mafra Goulart and Katerina Plakitsi. Kirch. In Kirch's review, she presents an historical summary which led to Vygotsky's philosophy of social constructivism. Kirch then compares and contrasts individual-constructivism and Vygotskian social-constructivism. Vygotsky reversed the educational paradigm of his era by hypothesizing that learning based on social interaction precedes cognitive development (Kirch, 2014). This reversal hinged on social interactions governed by the Vygotskian notion of the zone of proximal development (ZPD), a key mechanism within the fabric of social constructivism which describes the architecture of a learning/teaching scaffold. Kirch (2014) describes how Roth et al. interpret the use of the Cultural-Historical Activity Theory with respect to the development of emergent curricula in science education. From the perspective of Roth et al. (2013), society plays a critical role in the development of the individual. Roth et al. continue by suggesting that "the structure of the personality is a copy of social life in society" (Roth et al., 2013, p. 3). Therefore, by orienting our attention to the science classroom using a CHAT lens, we begin to see how peer interactions in a science classroom act as the axis around which learning rotates, rather than having the teacher as the pivot point.

This project assumes the social constructivist stance where socially constructed learning leads to development. This view stands in contrast to the individual constructivist stance where individuals create meaning by reflecting on isolated, personal thoughts and actions. CHAT theory will be used to design activity systems that will be used as the lesson plans are implemented.

3.0 Lesson Plans

The lesson plans contained herein are all formulated according to a three-part, universal design. The three part lesson is a system borrowed from The Literacy and Numeracy Secretariat's 2007 document entitled *The Three-Part Lesson in Mathematics*

Co-planning, Co-teaching and Supporting Student Learning. The first section of a three part lesson is called the *Minds On* segment. The *Minds On* portion is designed to entice and engage learners in social interaction and previous knowledge is activated. During this preliminary step, students are challenged to think critically and revisit strategies for solving problems (Literacy and Numeracy Secretariat, 2011).

The *Action* segment provides the substance of the lesson and is designed to function as the apparatus which allows for group-based inquiry learning to occur. Students are engaged in small groups to solve problems. The *Action* section also contains formative assessment strategies that are formulated using observation and anecdotal note-taking (Literacy and Numeracy Secretariat, 2011).

The third phase is the *Consolidation* phase. During *Consolidation* the teacher facilitates the sharing of ideas, brings learning together and constructs a framework for summative assessments. (Literacy and Numeracy Secretariat, 2011). Sharing might include a discussion of novel solutions and the identification of (common) misconceptions.

The curricular outcomes (academic and learning skills) are based on expectations published in documents produced by the Ontario Ministry of Education (2008, 2007). By linking the academic expectations between the two grades featured in each lesson, we assure that curriculum expectations will be fulfilled. The learning skills contain a mixture of individual and socially oriented expectations. By explicitly assessing the learning skills, we honour the social constructivist standpoint, reinforce real-life employability skills and activate metacognitive awareness.

Academic curricular outcomes and learning skills require context in order to morph from curricula-as-plans into curricula-as-experiences. The lesson plans described below are designed to provide such context. Multiple levels of learners are represented. Differentiated and multi-modal elements are included in the design in order to accommodate a range of strengths, abilities and interests.

3.1 Electric Vehicle Lesson Plan

Information	
Subject: Science/Engineering/Electricity/Motion	**Theme :** Electric Vehicles
Level : Grade 9 Academic Science/Grade 6 Science	**Time :** 5 x 75 minutes

Curriculum Expectations

Specific Curricular Outcomes

Grade 9 Science.

Scientific investigation skills and career exploration.

- A1.10: Draw conclusions based on inquiry results and research findings, and justify their conclusions.
- A 1.5: Conduct inquiries, controlling some variables, adapting or extending procedures as required, and using standard equipment and materials safely, accurately, and effectively, to collect observations and data.

Physics: Characteristics of electricity.

Understanding Basic Concepts.

- C 3.4: Identify the components of a simple DC circuit (e.g., electrical source, load, connecting wires, switch, fuse), and explain their functions.

Grade 6: Electricity and Electrical Devices.

Developing Investigation and Communication Skills

- 2.2: Design and build series and parallel circuits, draw labeled diagrams identifying the components used in each, and describe the role of each component in the circuit

- 2.5: Use technological problem solving skills to design, build, and test a device that transforms electrical energy into another form of energy in order to perform a function.

Learning Skills and Work Habits

Responsibility.
- takes responsibility for and manages own behavior

Organization.
- devises and follows a plan and process for completing work and tasks;
- establishes priorities and manages time to complete tasks and achieve goals;
- identifies, gathers, evaluates, and uses information, technology, and resources to complete tasks

Independent Work.
- independently monitors, assesses, and revises plans to complete tasks and meet goals;
- uses class time appropriately to complete tasks

Collaboration.
- accepts various roles and an equitable share of work in a group;
- responds positively to the ideas, opinions, values, and traditions of others;
- works with others to resolve conflicts and build consensus to achieve group goals
- shares information, resources, and expertise and promotes critical thinking to solve problems and make decisions

Initiative.
- looks for and acts on new ideas and opportunities for learning;
- demonstrates the capacity for innovation and a willingness to take risks;
- demonstrates curiosity and interest in learning;
- approaches new tasks with a positive attitude

Self-regulation.
- identify learning opportunities, choices, and strategies to meet personal needs and achieve goals;
- perseveres and makes an effort when responding to challenges

Learning Goals and Evaluation Criteria

Learning Goals: Design, build and test small functional electric vehicles.

Evaluation Criteria

Grade 9.

I identify and describe the components of DC powered electric vehicles.

I analyze the design of an electric vehicle and make suggestions for improved designs.
I build an DC powered electric vehicle.
I make improvements to the design electric vehicles based on observation and planning.

Grade 6.

I design and build electric vehicles using series and parallel circuits.
I draw diagrams that describe electric vehicle circuits.
I test an electric vehicle that transforms electrical energy into kinetic energy.

Assessment

Assessment for Learning (diagnostic)

How do electric motors work? (concept maps)

Assessment as Learning (formative)

- Design plan
- Lesson plan
- Improvement Plan
- Learning skills and work habits self-assessment (RUBRIC)
- Creativity Assessment (RUBRIC)

Assessment of Learning (summative)

- Interview
- Vehicle Performance Review
- Creativity Assessment (RUBRIC)

Learning Context

Learning Environment

Secondary Classroom ➔ Elementary Classroom ➔ Secondary Classroom

Differentiation

Control the availability of parts using different constraint mechanisms

- Trivia game
- Classroom currency

Resources Electric car building kit should include (but not be limited to): • Batteries (1.5 V and 9 V) • Battery cradles • Leads with clamps • Wire • LEDs • Incandescent bulbs • buzzers • Switches/buttons • Electric motors	• Duct tape • Carboard/box cutter • Popcicle sticks • Assorted Gears • Axels • Wheels • Pulley wheels • Elastic bands • Assorted hardware

Teaching Approach

Lesson Overview

In this lesson, students are challenged to construct small electric vehicles (or models with some moving parts) using small DC electric motors. Senior students will be given an opportunity to design, build and test vehicles. An exemplar will be provided. During the second phase of the activity cycle, the senior students will teach a lesson to a group of grade 6 students. The engineering activity may include building new vehicles or refining existing vehicles depending on the needs and abilities of the group. During the final phase, senior students will return to the challenge and attempt a second vehicle, hopefully with renewed creativity and innovation.

Minds On

- View video *Simplified Explanation of How Electric Cars Work* Video, (Electricformula, 2011)
- Create concept maps that describe the generalized function of electric vehicles

Planning Phase

- Review available parts
- Draw out designs on paper

Action

- Construct prototypes with available parts in pairs or individually
- Test Vehicles (students may devise a race track or other testing criteria)
- Assess creativity using RUBRIC
- Develop approach and teach lesson to grade 6 students
- Deliver lesson
- Complete Learning skills and work habits self-assessment RUBRIC

Consolidation

- Redesign new prototypes
- Build and test vehicles
- Conduct individual interviews
- Re-assess creativity using the creativity RUBRIC

3.2 Wind Turbine Lesson Plan

Information	
Subject: Science/Engineering/Dynamics/Forces	**Theme :** Wind Turbines
Level : Grade 12 Academic Physics/Grade 4 Science	**Time :** 3 x 75 minutes

Curriculum Expectations

Specific outcomes

Grade 12: Physics University Preparation

Scientific Investigation Skills

- A1.5: Performing and Recording : conduct inquiries, controlling relevant variables, adapting or extending procedures as required and using appropriate materials and equipment safely accuratfely and effectvely to collect observations and data.

Dynamics

Relating Science to Technology, Society, and the Environment

- B1.2: Assess the impact on society and the environment of technological devices that use linear or circular motion.

Developing Skills of Investigation and Communication

- B2.4: Predict, in qualitative and quantitative terms, the forces acting on systems of objects and plan and conduct an inquiry to test their predictions.

Grade 4 : Understanding Structures and Mechanisms, Pulleys and Gears

Relating Science and Technology to Society and the Environment

- 1.2: Assess the environmental impact of using machines with pulleys and gears, taking different perspectives into account and suggest ways to minimize negative impacts and maximize positive impacts.

Developing Investigation and Communication Skills

- 2.3: Use technological problem-solving skills to design, build, and test a pulley or gear system that performs a specific task

Understanding Basic Concepts

- 3.2: Describe how rotary motion in one system or its components is transferred to another system or component in the same structure.

Learning Skills and Work Habits

Responsibility

- takes responsibility for and manages own behavior

Organization

- devises and follows a plan and process for completing work and tasks
- establishes priorities and manages time to complete tasks and achieve goals
- identifies, gathers, evaluates, and uses information, technology, and resources to complete tasks

Independent Work

- independently monitors, assesses, and revises plans to complete tasks and meet goals
- uses class time appropriately to complete tasks

Collaboration

- accepts various roles and an equitable share of work in a group
- responds positively to the ideas, opinions, values, and traditions of others
- works with others to resolve conflicts and build consensus to achieve group goals

- shares information, resources, and expertise and promotes critical thinking to solve problems and make decisions

Initiative

- looks for and acts on new ideas and opportunities for learning
- demonstrates the capacity for innovation and a willingness to take risks
- demonstrates curiosity and interest in learning
- approaches new tasks with a positive attitude

Self-regulation

- identify learning opportunities, choices, and strategies to meet personal needs and achieve goals
- perseveres and makes an effort when responding to challenges

Learning Goals and **Evaluation Criteria**

Learning Goals

Design and build wind turbines capable of raising a load.

Evaluation Criteria

Grade 12

I conduct inquiries of wind turbine design by exploring variables that contribute to their functionality.
I assess the impact of wind turbines on the local society and the environment.
I predict, in qualitative and quantitative terms, the forces acting on wind turbines.

Grade 4

I can assess the environmental impact of wind turbines and suggest ways to minimize negative impacts and maximize positive impacts.
I use problem-solving skills to design, build, and test a wind turbine system.
I describe how rotary motion in one system is transferred to another system in a wind turbine.

Assessment

Assessment for Learning (diagnostic)

Brainstorm

- What is energy ?
- How many forms of energy can we name ?
- How can we change one form into another ?

Assessment as Learning (formative)

- Design plan
- Lesson plan
- Improvement Plan
- Learning skills and work habits self-assessment
- Assess creativity using the creativity RUBRIC

Assessment of Learning (summative)

- Conduct individual interviews
- Free-body diagrams
- Re-assess creativity using the creativity RUBRIC

Learning Context

Learning Environment

Secondary Classroom ➔ Elementary Classroom ➔ Secondary Classroom

Differentiation

- Provide a cut out model for an easier challenge.
- Use 3D printing.

Resources

- wooden sticks
- bendable wire
- string
- paperclips
- rubber bands
- toothpicks
- aluminum foil
- plastic wrap
- tape
- wooden dowels
- paper

Teaching Approach

Lesson Overview

Senior students will design, build and test wind turbines using the materials supplied. As a group, they will plan a lesson for an elementary grade 4 class that features and highlights concepts outlined in the curricular expectations. During the second phase, elementary students will have an opportunity to build and test their designs. Following, the senior students will revisit to the challenge, hopefully with renewed creativity and innovation.

Minds On

Group Work: Gallery walk

- What is energy ?
- How many forms of energy can we name ?
- How can we change one form into another ?

Teacher presents powerpoint "Working with Wind Energy" (IEEE, 2010)

Action

Review challenge requirements, procedure and materials

- In teams of two students develop and sketch designs
- Students construct initial design
- Students perform test
- Assess creativity using RUBRIC
- Design lesson for elementary group
- Deliver elementary lesson
- Complete Learning skills and work habits self-assessment RUBRIC

Consolidation

- Senior students return to challenge and attempt to create an improved design
- Perform a Windmill Efficiency Review
    - Cost of materials
    - Speed (rotations per minute)
    - Power (time to wind weight)
    - Students define their own version of efficiency:

      EX: Possible measure of efficiency:

      Eff. = (Cost of materials) / (time [sec] to lift weight)
- Interview: Are two designs that have the same rotational speed equally as "good"?
- Re-assess creativity using the creativity RUBRIC

Lesson adapted from PBS's *Windmills: Putting Wind Energy to Work* Lesson, (PBS Learning Media, n.d.)

3.3 Personal Flotation Devices Lesson Plan

Information	
Subject: Science/Engineering/Density/Bouyancy	**Theme:** Personal Flotation Devices
Level : Grade 8 Science/Grade 2 Science	**Time :** 3 x 75 minutes

Curriculum Expectations

Specific Curricular Outcomes

Grade 8: Understanding Matter and Energy: Fluids

Relating Science and Technology to Society and the Environment.

- 1.1: Assess the social, economic, and environmental impacts of selected technologies that are based on the properties of fluids

Developing Investigation and Communication Skills

- 2.4: Investigate applications of the principles of fluid mechanics.

Understanding Basic Concepts

- 3.2: Describe the relationship between mass, volume, and density as a property of matter.

Grade 2: Understanding Matter and Energy: Properties of Liquids and Solids

Developing Investigation and Communication Skills

- 2.4: Use scientific inquiry/experimentation skills to investigate liquids and solids in terms of their capacity for buoyancy and/or absorption.

Learning Skills and Work Habits

Responsibility

- takes responsibility for and manages own behavior

Organization

- devises and follows a plan and process for completing work and tasks
- establishes priorities and manages time to complete tasks and achieve goals
- identifies, gathers, evaluates, and uses information, technology, and resources to complete tasks

Independent Work

- independently monitors, assesses, and revises plans to complete tasks and meet goals
- uses class time appropriately to complete tasks

Collaboration

- accepts various roles and an equitable share of work in a group
- responds positively to the ideas, opinions, values, and traditions of others
- works with others to resolve conflicts and build consensus to achieve group goals
- shares information, resources, and expertise and promotes critical thinking to solve problems and make decisions

Initiative

- looks for and acts on new ideas and opportunities for learning;
- demonstrates the capacity for innovation and a willingness to take risks;
- demonstrates curiosity and interest in learning;
- approaches new tasks with a positive attitude

Self-regulation

- identify learning opportunities, choices, and strategies to meet personal needs and achieve goals;
- perseveres and makes an effort when responding to challenges

Learning Goals and Evaluation Criteria

Learning Goals

Analyze and design personal floatation systems.

Evaluation Criteria

Grade 8

I assess the social, economic, and environmental impacts of flotation devices that are based on the properties of fluids.
I investigate applications of the principles of fluid mechanics as it pertains to personal flotation devices.

I can describe the relationship between mass, volume, and density as a property of matter as it pertains to buoyancy.

Grade 2

I use scientific inquiry/experimentation skills to investigate liquids and solids in terms of their capacity for buoyancy.

Assessment

Assessment for Learning (diagnostic)

- Brainstorm
  - -What things around us float ?
  - -Why do things float ?

Assessment as Learning (formative)

- Design plan
- Assess creativity using the creativity RUBRIC
- Lesson plan
- Improvement Plan
- Learning skills and work habits self-assessment

Assessment of Learning (summative)

- Interview (Floatation Device Performance)
- Re-assess creativity using the creativity RUBRIC

Learning Context

Learning Environment

Intermediate Classroom ➔ Junior Classroom ➔ Intermediate Classroom

Differentiation

- Repeat experiments using different liquids.
- Add turbulence to the water

Resources

- water source
- bucket or sink area
- soup or vegetable cans
- paper cups
- straws
- rubber bands
- paper clips
- plastic bags
- glue and tape
- corks
- foam pieces
- string
- foil
- hose
- small containers
- balloons

6. Teaching Approach

Lesson Overview

Grade 8 students are given the challenge of developing a personal floatation device (PFD) or life vest out of everyday materials that can provide enough support to float an unopened can of soup or vegetables for at least one minute. The device must be in one attached piece and able to be affixed to the can within a 20 second period and some part of the can itself must be touching the water. During the second phase of the lesson, grade 8 students plan and conduct a lesson for a group of grade 2 students. Finally, the grade 8 students revisit to the challenge, ideally with renewed creativity and innovation.

Minds On

- How important are PFDs?
- Read news article “Life jackets could have prevented half of boating fatalities”,
- Think/Pair/Share
  - -What things around us float?
  - - Why do things float?

Action

- Students (in groups of 2 or individually) draw diagrams of the PFD they will build for the can (include list of all the materials you will need for the construction phase)
- Students build the PFD.
- Students practice putting it on and taking it off the can within the 20 second limit
- Studnets test their PFD along with other student teams and earn points depending on the bouyancy time an the adherance to requirements
- Assess creativity using RUBRIC
- Complete Learning skills and work habits self-assessment RUBRIC

Consolidation
- Students re-design and attempt to create an improved project   - Conduct individual interviews   - Re-assess creativity using the creativity RUBRIC
Lesson adapted from Try Engineering's *Lifevest Challenge* (IEEE, n.d.)

3.4 Chemical Engineering Lesson Plan

Information	
Subject: Science/Chemistry/Engineering	**Theme :** Chemical Engineering
Level : Grade 10 Academic Science/Grade 5 Science	**Time :** 5 x 75 minutes

Curriculum Expectations

Specific Curricular Outcomes

Grade 10 Science

Chemistry: Atoms, elements and Compounds

Developing Skills of investigation and communication.

- C 2.5: Plan and conduct an inquiry to identify the evidence of chemical change (e.g., the formation of a gas or precipitate, a change in colour or odour, a change in temperature)

Understanding Basic Concepts

- C 3.3: Describe the types of evidence that indicate chemical change (e.g., changes in colour, the production of a gas, the formation of a precipitate, the production or absorption of heat, the production of light)

Grade 5: Understanding Matter and Energy: Changes in Matter

Relating Science and Technology to Society and the Environment

- 1.2 : Assess the social and environmental impact of using processes that rely on chemical changes to produce consumer products, taking different perspectives into account *(e.g., the perspectives of food manufacturers, consumers, landfill operators, people concerned about the environment)*, and make a case for maintaining the current level of use of the product or for reducing it

Understanding Basic Concepts

- 3.7: Identify indicators of a chemical change *(e.g., production of a gas, change in colour, formation of precipitate)*
- 3.8: Distinguish between a physical change and a chemical change *(e.g., a physical change can be reversed [ice to water to ice], whereas a chemical change creates new substance[s] [wood to smoke and ash])*

Learning Skills and Work Habits

Responsibility
- takes responsibility for and manages own behavior

Organization
- devises and follows a plan and process for completing work and tasks
- establishes priorities and manages time to complete tasks and achieve goals
- identifies, gathers, evaluates, and uses information, technology, and resources to complete tasks

Independent Work
- independently monitors, assesses, and revises plans to complete tasks and meet goals
- uses class time appropriately to complete tasks

Collaboration
- accepts various roles and an equitable share of work in a group
- responds positively to the ideas, opinions, values, and traditions of others
- works with others to resolve conflicts and build consensus to achieve group goals
- shares information, resources, and expertise and promotes critical thinking to solve problems and make decisions

Initiative
- looks for and acts on new ideas and opportunities for learning
- demonstrates the capacity for innovation and a willingness to take risks
- demonstrates curiosity and interest in learning

- approaches new tasks with a positive attitude

Self-regulation

- identify learning opportunities, choices, and strategies to meet personal needs and achieve goals
- perseveres and makes an effort when responding to challenges

Learning Goals and **Evaluation Criteria**

Learning Goals

Engineer a chemical product based on the chemistry of double displacement reactions in aqueous solutions.

Evaluation Criteria

Grade 10

I plan and conduct inquiries to identify the contributing factors that lead to of the formation of solid precipitates.
I describe the evidence that indicates that a chemical change has occurred.
I can design initial conditions to produce a solid precipitate of my own design.

Grade 5

I assess the social and environmental impact of using processes that rely on chemical changes to produce consumer products, taking different perspectives into account and make a case for maintaining the current level of use of the product or for reducing it.
I identify indicators of a chemical change.
I distinguish between a physical change and a chemical change.

Assessment

Assessment for Learning (diagnostic)

- Brainstorm : Which industries make chemicals ? What kinds of chemicals are produced ? What are the purposes of the chemicals ?

Assessment as Learning (formative)

- Design plan

- Lesson plan
- Improvement
- Assess creativity using RUBRIC
- Learning skills and work habits and RUBRIC

Assessment of Learning (summative)

- Conduct individual interviews
- Re-assess creativity using the creativity RUBRIC

Learning Context

Learning Environment

Intermediate Classroom ➔ Junior Classroom ➔ Intermediate Classroom

Differentiation

Increase challenge: Offer preliminary lessons on organic synthesis and challenge students to design organic molecules

Decrease challenge: Use acid/base chemistry as the basis and challenge students to engineer solutions of a targeted pH

Resources

- Water souble ionic compounds
- required laboratory glassware
- solubility table
- activty series

Teaching Approach

Lesson Overview

During this lesson, students will be exposed to the idea that chemicals can be engineered. There is a significant amount of pre-learning required before this experience can be a meaningful learning episode. Senior students will need a reasonable understanding about how to: name ionic compounds, write chemical formulas, write chemical equations, predict solubility and predict the outcomes of double displacement reactions.

Minds On

- Re-activate previous knowledge : predicting double replacement reactions
- Watch Double Displacement Reaction of Ammonium Chloride and Sodium Hydroxide Video (Hybrid Librarian, 2015)
- Demonstration: Aqueous lead nitrate and aqueous potassium iodide

Action

- Design a chemical sysnthesis that results in the production of a desired ionic compound
- Begin chemical formulas paying attention to availbility of chemicals
- Develop lab procedure including solution preparation and safety considerations
- Conduct the synthesis
- Creativty assessment (Rubric)
- Design lesson for grade 5 class (precipitation reactions)
- Complete Learning skills and work habits self-assessment RUBRIC

Consolidation

- Revisit challenge and attempt to engineer a new substance
- Conduct individual interviews
- Re-assess creativity using the creativity RUBRIC

3.5 Chairlift Lesson Plan

Information	
Subject: Science/Engineering/Mechanics	**Theme : Chairlift Challenge**
Level : Grade 8 Science/Grade 4 Science	**Time : 3 x 75 minutes**

Curriculum Expectations

Specific Curricular Outcomes

Grade 8 Understanding Structures and Mechanisms, Systems in Action.

Relating Science and Technology to Society and the Environment

- 1.2: Assess the impact on individuals, society, and the environment of alternative ways of meeting needs that are currently met by existing systems, taking different points of view into consideration

Developing Investigation and Communication Skills

- 2.3: Use scientific inquiry/experimentation skills to investigate mechanical advantage in a variety of mechanisms and simple machines
- 2.4: Use technological problem-solving skills to investigate a system *(e.g., an optical system, a mechanical system, an electrical system)* that performs a function or meets a need

Understanding Basic Concepts

- 3.5: Understand and use the formula work = force x distance ($W=F\times d$) to establish the relationship between work, force, and distance moved parallel to the force in simple systems

Grade 4 Structures and Mechanisms, Pulleys and Gears

Relating Science and Technology to Society and the Environment

- 1.2: Assess the environmental impact of using machines with pulleys and gears, taking different perspectives into account and suggest ways to minimize negative impacts and maximize positive impacts

Developing Investigation and Communication Skills

- 2.3: Use technological problem-solving skills to design, build, and test a pulley or gear system that performs a specific task

Understanding Basic Concepts

- 3.1: Describe the purposes of pulley systems and gear systems
- 3.2: Describe how rotary motion in one system or its components *(e.g., a system of pulleys of different sizes)* is transferred to another system or component *(e.g., a system of various gears)* in the same structure
- 3.3: Describe how one type of motion can be trans- formed into another type of motion using pulleys or gears *(e.g., rotary to linear in a rack and pinion system, rotary to oscillating in a clock pendulum)*

Learning Skills and Work Habits

Responsibility

- takes responsibility for and manages own behavior

Organization

- devises and follows a plan and process for completing work and tasks
- establishes priorities and manages time to complete tasks and achieve goals
- identifies, gathers, evaluates, and uses information, technology, and resources to complete tasks

Independent Work

- independently monitors, assesses, and revises plans to complete tasks and meet goals
- uses class time appropriately to complete tasks

Collaboration

- accepts various roles and an equitable share of work in a group
- responds positively to the ideas, opinions, values, and traditions of others
- works with others to resolve conflicts and build consensus to achieve group goals
- shares information, resources, and expertise and promotes critical thinking to solve problems and make decisions

Initiative

- looks for and acts on new ideas and opportunities for learning;
- demonstrates the capacity for innovation and a willingness to take risks
- demonstrates curiosity and interest in learning
- approaches new tasks with a positive attitude

Self-regulation

- identify learning opportunities, choices, and strategies to meet personal needs and achieve goals
- perseveres and makes an effort when responding to challenges

Learning Goals and **Evaluation Criteria**

Learning Goals

Design a pulley/lift system that safely delivers an egg to a predetermined elevated location.

Evaluation Criteria

Grade 8

I assess the impact of chairlifts on individuals, society, and the environment by taking different points of view into consideration

I use scientific inquiry and experimentation skills to investigate mechanical advantage in a

variety of mechanisms and simple machines
I use technological problem-solving skills to investigate a chairlift system
I understand and use the formula work =force x distance (W=F×d) to establish the relationship between work, force, and distance moved parallel to the force in simple systems

Grade 4

I assess the environmental impact of using chairlift machines, taking different perspectives into account and suggest ways to minimize negative impacts and maximize positive impacts
I use technological problem-solving skills to design, build a chairlift system using a pulley or gear system that performs a specific task
I describe the purposes of pulley systems and gear systems
I describe how rotary motion in one system or its components is transferred to another system or component *(e.g., a system of various gears)* in the same structure
I describe how one type of motion can be transformed into another type of motion using pulleys or gears

Assessment

Assessment for Learning (diagnostic)

- Brainstorm Questions:
  -Where do we see chair lifts and gondolas?
  -What are the Pros and Cons of chair lifts and gondolas?

Assessment as Learning (formative)

- Design plan
- Build system
- Assess creativity using RUBRIC
- Lesson plan
- Learning skills and work habits self-assessment RUBRIC

Assessment of Learning (summative)

- Improvement Plan
- Re-design and rebuild
- Interview
- Chairlift Performance Review
- Creativity RUBRIC

Learning Context	
Learning Environment Intermediate Classroom ➔Junior Classroom ➔ Intermediate Classroom	
Differentiation Increase the Challenge: Students design a crank system that utilizes mechanical advanrage to generate motion Decrease the challenge: give access to a premade pulley system (clotheline style)	
Resources • String • floral wire • pipe cleaners • bendable aluminum wire • straws • paper towel tubes paper clips • tape • balloons	• glue • string • foil • plastic wrap • pulleys • gears • eggs

Teaching Approach
Lesson Overview During this learning experience, intermediate level students will be challenged to design build and test a lift system capable of carrying an egg. Following, the grade 8 students will teach a lesson to a group of grade 4 students. To complete the activity cycle, the grade 8 students will return to the engineering challenge, hopefully with renewed creativity.
Minds On • Groups read "Chairlifts and gondolas : the Pro and Cons" • Students choose a side and a friendly debate ensues **Action**

- Teams of 3-4 students will consider their challenge, and consider how the available materials might be used to create a chair lift
- Teams develop a detailed drawing showing their lift design including a list of materials they will need to build it and the chair the egg will ride in
- students build their lift, and test it under teacher supervision
- Complete Learning skills and work habits self-assessment Rubric
- Assess creativity using the Creativity Rubric
- Design and deliver a lesson to be delivered to a group of grade 4 students

Consolidation

- Students should observe the chair lifts that other teams create
- Students attempt to improve their designs and test new design elements
- Teams reflect on the challenge, and present their experiences to the class
- Conduct individual interviews
- Re-assess creativity using the creativity RUBRIC

Lesson adapted from Try Engineering's *Chair Lift Challenge,* (IEEE, n.d.)

3.6 Folding Matters Lesson Plan

Information	
Subject: Science/Math/Engineering	**Theme :** Folding Matters
Level : Grade 9 Academic Science/Grade 7 Structure	**Time :** 3 x 75 min

Curriculum Expectations

Specific Curricular Outcomes

Grade 9 Science

Earth and Space Science: the Study of the Universe

Relating Science to Technology, Society, and the Environment

- D1.1: Assess, on the basis of research, and report on the contributions of Canadian governments, organizations, businesses, and/or individuals to space technology, research, and/or exploration

Grade 7 Understanding Structures and Mechanisms, Form and Function

Relating Science and Technology to Society and the Environment

- 1.1: Evaluate the importance for individuals, society, the economy, and the environment of factors that should be considered in designing and building structures and devices to meet specific needs

Developing Investigation and Communication Skills

- 2.4: Use technological problem-solving skills to determine the most efficient way for a structure to support a given load.

Understanding Basic Concepts

- 3.1: Classify structures as solid structures, frame structures, or shell structures
- 3.6: Identify and describe factors that can cause a structure to fail

Learning Skills and Work Habits

Responsibility

- takes responsibility for and manages own behavior

Organization

- devises and follows a plan and process for completing work and tasks
- establishes priorities and manages time to complete tasks and achieve goals
- identifies, gathers, evaluates, and uses information, technology, and resources to complete tasks

Independent Work

- independently monitors, assesses, and revises plans to complete tasks and meet goals
- uses class time appropriately to complete tasks

Collaboration

- accepts various roles and an equitable share of work in a group
- responds positively to the ideas, opinions, values, and traditions of others
- works with others to resolve conflicts and build consensus to achieve group goals
- shares information, resources, and expertise and promotes critical thinking to solve problems and make decisions

Initiative

- looks for and acts on new ideas and opportunities for learning
- demonstrates the capacity for innovation and a willingness to take risks
- demonstrates curiosity and interest in learning
- approaches new tasks with a positive attitude

Self-regulation

- identify learning opportunities, choices, and strategies to meet personal needs and achieve goals
- perseveres and makes an effort when responding to challenges

Learning Goals and Evaluation Criteria

Learning Goals

I analyze and design collapsible solar voltaic systems suitable for space travel applications.

Evaluation Criteria

Grade 9

I assess and report on the contributions of Canadian governments, organizations, businesses, and/or individuals to space technology, research, and/or exploration.

Grade 7

I evaluate the importance for individuals, society, the economy, and the environment of factors that should be considered in designing and building structures and devices to meet specific needs.
I use technological problem-solving skills to determine the most efficient folding structure to support a solar array.
I classify structures as solid structures, frame structures, or shell structures.
I identify and describe factors that can cause a structure to fail.

Assessment

Assessment for Learning (diagnostic)

- Discussion : What factors do engineers need to consider when designing space tools ?

Assessment as Learning (formative)

- Design plan
- Build and test structure

- Assess creativity using RUBRIC
- Lesson plan
- Improvement Plan
- Learning skills rubric

Assessment of Learning (summative)

- Interview
- Folding Solar Array Performance Review
- Creativity RUBRIC

Learning Context

Learning Environment

Secondary Classroom ➔ Intermediate Classroom ➔ Secondary Classroom

Differentiation

- Decrease the challenge : Offer a larger box for the finished project.

Resources

- aluminum foil boxes with metal rip bar removed for safety
- aluminum foil
- tape
- cardboard
- rubber bands
- rulers
- popsicle sticks
- pipe cleaners
- paper clips
- glue
- scissors
- balsa wood
- cotton balls
- paper
- fabric
- plastic rods
- straw

Teaching Approach

Lesson Overview

Senior students work in teams to develop solar panels that fold into a small box and then deployed to its original size. The unfolded "panel" will be constructed out of everyday items including aluminum foil and must be at least 30 cm by 90 cm when unfolded. Senior students take ideas generated in the experience and plan a lesson for a grade 7 class. After the teaching experience, the grade 9s will revisit the challenge and attempt to improve their designs.

Minds On

- Group discussion: What factors do engineers need to consider when designing space tools?
- Explore NASA article on Canadarm Robotic Arm, Dean (2011)
- Explore Canadian Space Agency's Canadarm2 Website, (2016)
- Origami: boats
- Brain Storm: Where do we see folding?
  (Images : Parachutes, Insect wings, packaging, ***space travel)***

Action

- In small groups of 2-3 students use given materials construct folding solar arrays designed to match given parameters
- Students build and pack their solar panel into a small box and unfold it to determine damage or functionality.
- Assess creativity using RUBRIC
- Plan lesson for intermediate class
- Deliver lesson, then redesign
- Work Habits self assessment RUBRIC

Consolidation

- Conduct individual interviews
- Re-assess creativity using the creativity RUBRIC

Lesson adapted from Try Engineering's *Folding Matters* Lesson,(IEEE., n.d.)

3.7 Water Rockets Lesson Plan

Information	
Subject: Science/Engineering/Rocketry	**Theme:** Water Rockets
Level: Grade 11 Academic Physics/ Grade 6 Science	**Time:** 3 x 75 min

Curriculum expectations

Specific Curricular Outcomes

Grade 11: Physics University Preparation

Scientific investigation Skills and career exploration

- A1.5: Conduct inquiries controlling relevant variables adapting or extending procedures as required and using appropriate materials and equipment safely, accurately and effectively to collect observations and data.

Kinematics

Developing Skills of Investigation and Communication

- B2.8: Use kinematic equations to solve problems related to the horizontal and vertical components of the motion of a projectile (e.g., a cannon ball shot horizontally off a cliff, a ball rolling off a table, a golf ball launched at a 45^{o} angle to the horizontal)

Understanding Basic Concepts

- B3.3: Describe the characteristics and give examples of a projectile's motion in vertical and horizontal planes

Forces

Developing Skills of Investigation and communication

- C2.1: Use appropriate terminology related to forces, including, but not limited to: *mass, time, speed, velocity, acceleration, friction, gravity, normal force,* and *free-body diagrams*
- C2.2: Conduct an inquiry that applies Newton's laws to analyse, in qualitative and quantitative terms, the forces acting on an object, and use free-body diagrams to determine the net force and the acceleration of the object

Understanding Basic Concepts

- C 3.1: Distinguish between, and provide examples of, different forces (e.g., friction, gravity, normal force), and describe the effect of each type of force on the velocity of an object
- C3.4: Describe, in qualitative and quantitative terms, the relationships between mass, gravitational field strength, and force of gravity

Grade 6: Understanding Structures and Mechanisms: Flight

Developing Investigation and Communication Skills

- 2.1: Follow established safety procedures for using tools and materials and operating flying devices *(e.g., aim flying devices away from each other when launching them; fly kites and airplanes a safe distance from overhead hydro wires)*
- 2.4: Use problem-solving skills to design, build, and test a flying device *(e.g., a kite, a paper airplane, a hot air balloon)*

Understanding Basic Concepts

- 3.5: Describe ways in which flying devices or living things use unbalanced forces to control their flight

Grade 6: Understanding Earth and Space Systems: Space

Developing Investigation and Communication Skills

- 2.2: Use problem-solving skills to design, build, and test devices for investigating the motions of different bodies in the solar system

Learning Skills and Work Habits

Responsibility
- takes responsibility for and manages own behavior

Organization
- devises and follows a plan and process for completing work and tasks
- establishes priorities and manages time to complete tasks and achieve goals
- identifies, gathers, evaluates, and uses information, technology, and resources to complete tasks

Independent Work
- independently monitors, assesses, and revises plans to complete tasks and meet goals
- uses class time appropriately to complete tasks

Collaboration
- accepts various roles and an equitable share of work in a group
- responds positively to the ideas, opinions, values, and traditions of others
- works with others to resolve conflicts and build consensus to achieve group goals
- shares information, resources, and expertise and promotes critical thinking to solve problems and make decisions

Initiative

- looks for and acts on new ideas and opportunities for learning;
- demonstrates the capacity for innovation and a willingness to take risks;
- demonstrates curiosity and interest in learning;
- approaches new tasks with a positive attitude

Self-regulation

- identify learning opportunities, choices, and strategies to meet personal needs and achieve goals
- perseveres and makes an effort when responding to challenges

Learning Goals and **Evaluation Criteria**

Learning Goals

Analyze, design and build water powered rocket systems.

Evaluation Criteria

Grade 11

I conduct inquiries by controlling relevant variables as required and using appropriate materials and equipment safely.
I use kinematic equations to solve problems related to the horizontal and vertical components of the motion of a rocket.
I describe the characteristics and give examples of a rocket's motion in vertical and horizontal planes.
I use appropriate terminology related to forces, including, but not limited to: *mass, time, speed, velocity, acceleration, friction, gravity, normal force,* and *free-body diagrams.*
I conduct an inquiry that applies Newton's laws to analyse, in qualitative and quantitative terms, the forces acting on a rocket, and use free-body diagrams to determine the net force and the acceleration of the object.
I distinguish between, and provide examples of, different forces (e.g., friction, gravity, normal force), and describe the effect of each type of force on the velocity of an object.
I describe, in qualitative and quantitative terms, the relationships between mass, gravitational field strength, and force of gravity.

Grade 6

I follow established safety procedures for using tools and materials and operating flying devices.
I use problem-solving skills to design, build, and test a flying device.
I describe ways in which a rocket uses unbalanced forces to control their flight.

I use technological problem-solving skills to design, build, and test rockets.

Assessment

Assessment for Learning (diagnostic)

Discussion and formal lesson

- What is the difference between flight and rocketry ? (Venn diagrams)

Assessment as Learning (formative)

- Design plan
- Assess creativity using RUBRIC
- Learning skills self assessment
- Lesson plan
- Improvement Plan

Assessment of Learning (summative)

- Interview
- Rocket Performance Review
- Kinematic Equations
- Free-body diagrams
- Creativity RUBRIC

Learning Context

Learning Environment

Secondary Classroom ➔Outdoors ➔
Elementary Classroom ➔ Outdoors ➔
Secondary Classroom ➔Outdoors

Differentiation

- Allow senior students to design and build a lauchpad.
- Increase the challenge by adding lauch goals (ie. land on a pad using two different angles but using the same launch pressure).

Resources

- Prefabricated launch pad
- Plastic bottles of varioius sizes
- Box board
- Utility knives with cutting boards

- scisors
- Duct tape
- Water
- Bicycle pump OR air compressor (dependiagn on lauch pad design)
- Plasticine
- Packing tape

Teaching Approach

Lesson Overview

Senior students will design, build and test water rockets. An exemplar will be provided. The group then creates a lesson for a group of grade 6 students who will then do their best to design, build and test water rockets. The senior students will then return to challenge with new insights and attempt to build ultimate rockets.

Minds On

- Play "Angry Birds" and discuss parabolic trajectories.
- Draw Free body diagrams: Object in Flight versus Rocket Motion

Action

- Display lauch pad and compare with free body diagrams
- Draw designs and prepare a list of required materials
- Build and test rockets
- Assess creativity using RUBRIC
- Prepare lesson for elementary students
- Deliver lesson to ele
- Learning skills work habits RUBRIC

Consolidation

- Conduct individual interviews
- Draw free body diagrams
- Practice kinematic equations
- Re-assess creativity using the creativity RUBRIC

3.8 Pneumatic Rocket Lesson Plan

Information

Subject: Science/Engineering	**Theme :** Pneumatic Rockets
Level : Grade 11 Physics (University Prep)/Grade 6	**Time :** 5 x 75 minutes

Curriculum expectations

Specific Curricular Outcomes

Grade 11: Physics University Preparation

Scientific investigation skills and career exploration

- A1.5: Conduct inquiries controlling relevant variables and adapting or extending procedures as required and using appropriate material and equipment safely accurately and effectively to collect observations and data.

Kinematics

Developing Skills of Investigation and Communication

- B2.8: Use kinematic equations to solve problems related to the horizontal and vertical components of the motion of a projectile.

Understanding Basic Concepts

- B3.3: Describe the characteristics and give examples of a projectile's motion in vertical and horizontal planes.

Forces

Developing Skills of Investigation and communication

- C 2.1: Use appropriate terminology related to forces, including, but not limited to: *mass, time, speed, velocity, acceleration, friction, gravity, normal force,* and *free-body diagrams.*
- C 2.2: Conduct an inquiry that applies Newton's laws to analyze, in qualitative and quantitative terms, the forces acting on an object, and use free-body diagrams to determine the net force and the acceleration of the object.

Understanding Basic Concepts

- C3.1: Distinguish between, and provide examples of, different forces (e.g., friction, gravity, normal force), and describe the effect of each type of force on the velocity of an object.
- C3.4: Describe, in qualitative and quantitative terms, the relationships between mass,

gravitational field strength, and force of gravity

Grade 6: Understanding Structures and Mechanisms: Flight

Developing Investigation and Communication Skills

- 2.1: Follow established safety procedures for using tools and materials and operating flying devices
- 2.4: Use problem-solving skills to design, build, and test a flying device

Understanding Basic Concepts

- 3.5: Describe ways in which flying devices or living things use unbalanced forces to control their flight

Grade 6 Understanding Earth and Space Systems, Space

Developing Investigation and Communication Skills

- 2.2: Use problem-solving skills to design, build, and test devices *(e.g., a sundial, a model of the earth's rotation around the sun)* for investigating the motions of different bodies in the solar system

Learning Skills and Work Habits

Responsibility

- takes responsibility for and manages own behavior

Organization

- devises and follows a plan and process for completing work and tasks
- establishes priorities and manages time to complete tasks and achieve goals
- identifies, gathers, evaluates, and uses information, technology, and resources to complete tasks

Independent Work

- independently monitors, assesses, and revises plans to complete tasks and meet goals
- uses class time appropriately to complete tasks

Collaboration

- accepts various roles and an equitable share of work in a group;
- responds positively to the ideas, opinions, values, and traditions of others
- works with others to resolve conflicts and build consensus to achieve group goals
- shares information, resources, and expertise and promotes critical thinking to solve problems

and make decisions

Initiative

- looks for and acts on new ideas and opportunities for learning
- demonstrates the capacity for innovation and a willingness to take risks
- demonstrates curiosity and interest in learning
- approaches new tasks with a positive attitude

Self-regulation

- identify learning opportunities, choices, and strategies to meet personal needs and achieve goals
- perseveres and makes an effort when responding to challenges

3. Learning Goals and Evaluation Criteria

Learning Goals

Analyze, design and build air powered rocket systems.

Evaluation Criteria

Grade 11

I conduct inquiries by controlling relevant variables as required and using appropriate materials and equipment safely.
I use kinematic equations to solve problems related to the horizontal and vertical components of the motion of a rocket.
I describe the characteristics and give examples of a rocket's motion in vertical and horizontal planes.
I use appropriate terminology related to forces, including, but not limited to: *mass, time, speed, velocity, acceleration, friction, gravity, normal force,* and *free-body diagrams.*
I conduct an inquiry that applies Newton's laws to analyse, in qualitative and quantitative terms, the forces acting on an rocket, and use free-body diagrams to determine the net force and the acceleration of the object.
I distinguish between, and provide examples of, different forces and describe the effect of each type of force on the velocity of an object.
I describe, in qualitative and quantitative terms, the relationships between mass, gravitational field strength, and force of gravity.

Grade 6

I follow established safety procedures for using tools and materials and operating flying devices.
I use technological problem-solving skills to design, build, and test a flying device.
I describe ways in which a rocket uses unbalanced forces to control their flight.

I use technological problem-solving skills to design, build, and test rockets.

Assessment

Assessment for Learning (diagnostic)

- Venn diagrams : Comparing water and pneumatic rockets

Assessment as Learning (formative)

- Design plan
- Assess creativity using RUBRIC
- Lesson plan
- Learning skills self assessment
- Improvement Plan

Assessment of Learning (summative)

- Interview
- Rocket Performance Review
- Creativity RUBRIC

Learning Context

Learning Environment

Secondary Classroom ➔Outdoors/Gymnasium ➔
Elementary Classroom ➔ Outdoors/Gymnasium ➔
Secondary Classroom ➔Outdoors/Gymnasium

Differentiation

- Increase the challenge bay adding launch goals (ie: land on a pad using two different angles but the same launch pressure)
- Allow senior students to design and build a launch pad

Resources

- Prefabricated launch pad
- Loose leaf paper of vairous dimensions
- Box board
- Duct tape

- Bicycle pump OR air compressor (depending on lauch pad design)
- Packing tape

Teaching Approach

Lesson Overview

Senior students will design, build and test paper rockets. The group then creates a lesson for a group of grade 6 students who will then do their best to design, build and test paper rockets. The senior students will then return to challenge will new insights and attempt to build the ultimate rocket. An exemplar will be provided.

Minds On

View video: Five Strangest Ways to get into Space
(This is Genius, 2014)

Compare and contrast pneumatic apparatus with water/air rocket apparatus used in previous experience

Action

- Draw design and develop a list of required materials
- Build and test rockets
- Creativity Rubric
- Develop lesson plan for elementary students
- Learning skills work habits RUBRIC

Consolidation

- Conduct individual interviews
- Draw free body diagrams
- Practice kinematic equations
- Re-assess creativity using the creativity RUBRIC

4.0 Conclusion

4.1 Reflection

This project was initially framed as an action based research project for EDSE 512: Research Project in Secondary Education. At the time of inception, the project was designed to engage various levels of students in learning together. I was teaching in Northern Canada, in a small town stuck in a perpetual state of recovery resulting from the effects of colonialism and residential schooling. The spirit of the project was inspired by a desire to find a way to re-install a sense connectedness between the townspeople and the school. The project was meant to mix various ages of learners together at the school level. The intention was to eventually use the project as a mechanism to entice adult learners from the community to participate in healthy and fun educational experiences centered at the school.

As my time in the North came to a close, I believed the essence of the project rested on a valid impetus; therefore I sought ways to extend the spirit of the project towards my (current) teaching career in South Western Ontario. The first school I arrived at had a similar structure (K to Grade 12) and similar size (250 students) and I realized that although there were many profound differences in the students and the educational climate, the project was still interesting and valuable. In the future, I hope for opportunities to implement the resources directly. I also intend to propagate the spirit of the project by challenging students to act as teachers, thus, promoting exchanges between students of different ages.

4.2 Assessment Rubrics

Table 4.1
Learning Skills and Work Habits self-assessment rubric

Criteria	Level 1	Level 2	Level 3	Level 4
Responsibility I take responsibility for and manage my own behavior	**Never**	**Sometimes**	**Usually**	**Always**
Organization I devise and follow a plan and process for completing work and tasks.. I establish priorities and manage time to complete tasks and achieve goals. I identify, gather, evaluate, and use information, technology, and resources to complete tasks.	**Never**	**Sometimes**	**Usually**	**Always**
Independent Work I independently monitor, assess, and revises plans to complete tasks and meet goals. I use class time appropriately to complete tasks.	**Never**	**Sometimes**	**Usually**	**Always**
Collaboration I accept various roles and an equitable share of work in a group. I respond positively to the ideas, opinions, values, and traditions of others. I work with others to resolve conflicts and build consensus to achieve group goals. I share information, resources, and expertise and promotes critical thinking to solve problems and make decisions.	**Never**	**Sometimes**	**Usually**	**Always**
Initiative I look for and act on new ideas and opportunities for learning. I demonstrate the capacity for innovation and a willingness to take risks. I demonstrate curiosity and interest in learning. I approach new tasks with a positive attitude	**Never**	**Sometimes**	**Usually**	**Always**
Self-regulation Identify learning opportunities, choices, and strategies to meet personal needs and achieve goals. I persevere and make an effort when responding to challenges	**Never**	**Sometimes**	**Usually**	**Always**

***adapted from Ontario Ministry of Education (2010)**

Table 4.2
Creativity rubric

	Criteria	Description	LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4
Generating Ideas	Fluency Flexibility Originailty Elaboration	Number of ideas Shift Thinking New ideas Adding details	Student generates many new ideas, adapts thinking, and elaborates using detail with limited effectiveness.	Student generates many new ideas, adapts thinking, and elaborates using detail with some effectiveness.	Student generates many new ideas, adapts thinking, and elaborates using detail with considerable effectiveness.	Student generates many new ideas, adapts thinking, and elaborates using detail with a high degree of effectiveness.
Exploring Ideas	Breaking Ideas down Combining themes Revisiting Outcomes	Comparmentalize concepts for understanding Combiningideas/ seeing connectino between ideas Observatios to generate insights	Student breaks ideas down into parts, connects common themes and uses observations to generate insight with limited effectiveness.	Student breaks ideas down into parts, connects common themes and uses observations to generate insight with some effectiveness.	Student breaks ideas down into parts, connects common themes and uses observations to generate insight with considerable effectiveness.	Student breaks ideas down into parts, connects common themes and uses observations to generate insight with a high degree of effectiveness.
Inquiring Attitude	Identifying Problems Fantasy and Imagination Comfort with Ambiguity Taking Risks	Defining problems Considering unreal/impossible ideas Openess to uncertainty	Student identifies problems, uses imaginative thinking, operates within ambiguous circumstances and takes risks with limited effectiveness.	Student identifies problems, uses imaginative thinking, operates within ambiguous circumstances and takes risks with some effectiveness.	Student identifies problems, uses imaginative thinking, operates within ambiguous circumstances and takes risks with considerable effectiveness.	Student identifies problems, uses imaginative thinking, operates within ambiguous circumstances and takes risks with a high degree of effectiveness.
Metacognition	Cognitive Intropsection Intuition Awarness	Identify thinking process/patterns Listening to one's own inner voice	Students understands and follows intuitive thoughts with limited effectiveness.	Students understands and follows intuitive thoughts with some effectiveness.	Students understands and follows intuitive thoughts with considerable effectiveness.	Students understands and follows intuitive thoughts with a high degree of effectiveness.

***adapted from Daly et. (2014)**

References

Aberšek, B. (2008). Future for Science and Engineering Education. *Problems of education in the 21st century*, *6*, 9-17.

Bredin, M. (1993). Ethnography and communication: Approaches to aboriginal media. *Canadian Journal of Communication*, *18*(3). Retrieved from http://www.cjc-online.ca/index.php/journal/article/view/757/663

Canada Space Agency. (2016). *Canadarm2, the Canadian robotic arm of the international space station.* Retrieved from http://www.asc-csa.gc.ca/eng/iss/canadarm2/default.asp

CBC News. (2016, June 7). *Lifejackets could have prevented half of boating fatalities, Canadian red cross study finds.* Retrieved from http://www.cbc.ca/news/canada/saskatoon/life-jackets-could-have-prevented-half-of-boating-fatalities-canadian-red-cross-study-finds-1.3620727

Daly, S., Mosyjowski, E., & Seifert, C. (2014). Teaching creativity in engineering courses. *The Research Journal for Teaching Engineering Education. 103*(3), 417–449.

Dean, Brandi. (2011, September 6). *Space shuttle canadarm robotic arm marks 25 years in space.* Retrieved from http://www.nasa.gov/mission_pages/shuttle/behindscenes/rms_anniversary.html

Doll, W. (2012). Complexity and the culture of curriculum. *Complicity: An International Journal of Comlexity and Education, 9*(1), 10-29.

Electricformula. (2011, March 12). Simplified explanation of how electric cars work. [Video File]. Retrieved from https://www.youtube.com/watch?v=dFWEc7Ytq44

Engeström, Y. (1999). Innovative learning in work teams: Analyzing cycles of knowledge creation in practice. In Y. Engestrom, R. Miettinen & R.-L. Punamaki (Eds.) *Perspectives on Activity Theory*, (pp. 377-404). Cambridge: Cambridge University Press.

Engeström, Y. (2014). *Interview with Professor Yrjö Engeström: Part 1*. [Video File] Retrieved from https://www.youtube.com/watch?v=LCumH6Q4XKc.

Gall, M. D., & Borg, W. R. (1989). *Guide for preparing a thesis or dissertation proposal in education*. New York: Longman.

Adams, C. (2014). Interview by E. Goble, E. [Video File]. Research methodologies: Action research, University of Alberta, Faculty of Education. Retrieved from http://player.vimeo.com/video/86518743

Guilford, J P. (1950). Creativity. *American Psychologist, Jan* (1950), 444-454.

Hybrid Librarian. (2011, December 11). Double displacement reaction of ammonium chloride and sodium hydroxide. [Video File]. Retrieved from https://www.youtube.com/watch?v=HvVUtpdK7xw

Institute for Electrical and Electronic Engineers. (n.d.). Chair lift challenge. [Lesson Plan]. Retrieved from http://tryengineering.org/sites/default/files/lessons/chairlift.pdf

Institute for Electrical and Electronic Engineers. (n.d.). Folding matter.s [Lesson Plan]. Retrieved from http://tryengineering.org/sites/default/files/lessons/folding.pdf

Institute for Electrical and Electronic Engineers. (n.d.). Lifevest challenge. [Lesson Plan]. Retrieved from http://tryengineering.org/sites/default/files/lessons/lifevest.pdf

Institute for Electrical and Electronic Engineers. (2010). Working with wind energy [Power Point Slides]. Retrieved from https://www.ieee.org/documents/Wind_Energy.ppt

Kaufman. J.C., & Baer, J. (2009). Is one dimension enough? A response to Simonton's varieties of (scientific) creativity. *Perspectives on Psychological Science*, *4*(5), 466-467. doi:10.1111/j.1745-6924.2009.01153.x

Kirch, S. (2014). Integrating Vygotsky's theory of relational ontology into early childhood science education. *Cultural Studies of Science Education, 9*(1), 243-254. doi:10.1007/s11422-013-9532-5

Kirk, J., & Miller, M.L. (1986). *Reliability and validity in qualitative research.* Beverly Hills: Sage Publications.

Klausen, S, H. (2010). The notion of creativity revisited: A philosophical perspective on creativity research. *Journal of Creativity Research*, *22*(4), 347-360. doi:10.1080/10400419.2010.523390

Kuokkanen, R. (2000). Towards an indigenous paradigm from a SAMI perspective. *The Canadian Journal of Native Studies*, *20*(2), 411-436.

Lima, J. P., Ostermann, F., & Rezende, F. (2014). Marxism in Vygotskian approaches to cultural studies of science education. *Cultural Studies of Science Education, 9*(3), 543-566. doi: 10.1007/s11422-013-9485-8

Literacy and Numeracy Secretariat. (2010). *The three part lesson in mathematics; co-planning, co-teaching and supporting student learning.* Retrieved from http://www.curriculum.org/secretariat/coplanning/files/CoPlanningGuide.pdf

Miller, D. (1992). *The experiences of a first-year college president: An ethnography.* (Unpublished doctoral dissertation) University of Nebraska: Lincoln.

Ontario Ministry of Education. (2010). *Growing success: Assessment, Evaluation and Reporting in Ontario schools.* Retrieved from http://www.edu.gov.on.ca/eng/policyfunding/growSuccess.pdf

Ontario Ministry of Education. (2008). *The Ontario curriculum, grades 9 and 10: Science, 2008*. Retrieved from http://www.edu.gov.on.ca/eng/curriculum/secondary/science910_2008.pdf

Ontario Ministry of Education. (2008). *The Ontario curriculum, grades 11 and 12: Science, 2008*. Retrieved from http://www.edu.gov.on.ca/eng/curriculum/secondary/2009science11_12.pdf

Ontario Ministry of Education. (2007). *The Ontario curriculum grades 1-8: Science and technology, 2007.* Retrieved from http://www.edu.gov.on.ca/eng/curriculum/elementary/scientec18currb.pdf

Osberg, D., & Biesta, G. (2008). The emergent curriculum: navigating a complex course between unguided learning and planned enculturation. *Journal of Curriculum Studies*, *40*(3), 313-328. Retrieved from http://dx.doi.org/10.1080/00220270701610746

Public Broadcasting Service Learning Media. (n.d.). Windmills: Putting wind energy to work. [Lesson Plan]. Retrieved from http://www.pbslearningmedia.org/resource/phy03.sci.engin.design.lp_windmill/windmills-putting-wind-energy-to-work/

Rodrigues, A., Camillo, J., & Mattos, C. (2014). Quasi-appropriation of dialectical materialism: A critical reading of Marxism in Vygotskian approaches to cultural studies in science education. *Cultural Studies of Science Education*, *9*, 583–589. doi:10.1007/s11422-014-9570-7

Roth, W.M., Goulart, M.I., & Plakitsi, K. (2013). *Science education during early childhood: A cultural-historical perspective*. Dordtrecht: Springer.

Runco, M.A. (2009). Simplifying theories of creativity and revisiting the criterion problem. *Perspectives on Psychological Science, 4*(5), 462-465. doi:10.1111/j.1745-6924.2009.01156.x

Simonton, D.K. (2009). Varieties of (scientific) creativity: A hierarchical model of domain-specific disposition, development, and achievement. *Perspectives on Psychological Science*, *5*(5), 441-452. doi: 10.1111/j.1745-6924.2009.01152.x

United Nations Educational, Scientific and Cultural Organization. (2003). *Ethnographic action research*. Retrieved from http://eprints.qut.edu.au/4399/1/4399.pdf

Taylor, P. C., Fraser, B. J., & Fisher, D. L. (1997). Monitoring constructivist classroom learning environments. *International Journal of Educational Research*, *27*(4), 293–302. doi:10.10/S0883-0355(97)90011-2

This is Genius. (2014, 30 January). *Five Strangest Ways to get into Space* [Video File]. Retrieved from https://www.youtube.com/watch?v=OHF7RqqOE6w.

Vygotsky, L. (1997). Interaction between learning and development. In M. Gauvain, & M. Cole (Eds.), *Readings on the development of children, 5th ed, (*pp. 22-29). New York: Freeman.

Wikipedia (n.d.) *Cultural-historical activity theory (CHAT)*. Retrieved from https://en.wikipedia.org/wiki/Cultural-Historical_Activity_Theory_(CHAT)

Yamagata-Lynch, L.C. (2010). *Activity systems analysis methods: Understanding complex learning environments*. doi:10.1007/978-1-4419-6321-5_2