

UNIVERSITY OF CALGARY

An Examination of Mental Time Travel and Its Role in
the Development of Foresightful/Prudential Intellect

by

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A THESIS

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Abstract

Mental time travel (MTT) has always been a crucial component of human cognition, but has not always been identified or supported in schooling. Recent advances in psychological science consider MTT to be responsible for future-oriented thought and action, particularly, the formation of foresight. Therefore, an innovative research trajectory for education is to enabling students to harness their MTT abilities and support the development of what could be called foresightful/prudential intellect. By enhancing the flexibility and the reach of MTT ability, education can enable students to develop foresightful/prudential reasoning skills in science, technology, engineering, and mathematics (STEM) domains, including the ability to carry out collaborative MTT. Some of these skills are ecological problem identification and solution, environmental decision-making, root-cause analysis, spatial reasoning, and evolutionary thinking.

This thesis first examines the evolution and development of MTT by combining studies in cognitive-developmental science, biological anthropology, and evolutionary neuroscience. A secondary examination reveals that although foresightful/prudential intellect is more closely associated with cognitive self-governance, clear benchmarks for assessing and supporting this intellect via MTT tasks need to be identified. A developmental study that used a dynamic system problem illustrates the ways foresightful/prudential reasoning manifests itself.

Quantitative and qualitative differences are found in school-aged children's and undergraduate students' episodic memory syntheses when they were asked how to prevent the problem from reoccurring. The results of this study suggest that foresightful/prudential reasoning skills in

environmental topics could be extrapolated to entire classrooms by designing MTT-based learning tools or tasks. Two prominent techniques are identified to show what these tools, tasks, or techniques could involve and how they could be designed. Finally, a teacher education agenda is discussed in alignment with the goals of MTT-based learning and fostering the development of foresightful/prudential intellect. This agenda needs to be approached in stages and with a sense of urgency given the current pace of anthropogenic environmental change.

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Memory is deceptive because it is colored by today's events.

Albert Einstein

Chapter 1: General Introduction

Old ideas give way slowly; for they are more than abstract logical forms and categories. They are habits, predispositions, deeply engrained attitudes of aversion and preference. Moreover, the conviction persists – though history shows it to be a mere hallucination – that all questions that the human mind has asked can be answered in terms of the alternatives that the questions themselves present. But in fact, intellectual progress usually occurs through sheer abandonment of questions together with both of the alternatives they assume, and abandonment that results from their decreasing vitalism and a change of urgent interest. We do not solve them; we get over them. Old questions are solved by disappearing, evaporating, while new questions corresponding to the changed attitude of endeavour and preference take their place.

John Dewey, 1910, p. 19, *The Influence of Darwin on Philosophy*

1.1. Background

The study of intelligence has been my lifelong passion. When I was a child, I was particularly impressed with the intelligent behavior of wild animals. Above all else, wild animals prefer ecosystemic sufficiency over technical efficiency in their daily affairs. The mother leopard does not need to make any improvements in her claws or teeth or legs, as they are sufficient in ambushing an antelope, impaling it, choking it, and claiming the prey that will aid her and her cub's survival for another week. It has been working for her, and it will continue to work for

her for many generations – provided that she and her offspring do not face further challenges due to our own unintelligent ways of thinking and behaving.

Seen from this perspective, my first understanding of intelligence has been that it defines a behavior and a way of thinking that preserves what is *working* for individuals or collectives. Later on, through much schooling, my initial understanding has been replaced with something else. The teachers were talking about intelligence with respect to being creative, smart, cunning, and getting ahead of others through competition and manipulation. In fact this definition was the direct opposite of what I observed in the animal kingdom. Intelligence, we are taught, is about outsmarting something or somebody; remaining content or sufficient with certain ways of doing things may be a sign of retardation. Then through more schooling in different quarters, I understood that this is a definition endorsed by a particular cultural point of view.

Later on, with further training in science, I extended this understanding, and came to see that this cutthroat view of intelligence could be linked with unsophisticated conceptualizations of humans as belligerent animals (Lorenz, 1966), having been considered on equal footing with aggressive primates such as common chimpanzees (*Pan triglodytes*). Today, increasing evidence in primatology points out that this is not the case, for *Homo sapiens* has selected its members against aggressive and overly competitive behavior widely seen among other anthropoid primates (de Waal, 2002; Wrangham, Wilson, & Muller, 2006; Gibbons, 2014). Subsequently, with some dilettante's training in cetacean behavioral ecology, I was prompted to revisit my childhood observations and reframe them. That in the long run, prudential behavior is intelligent behavior, since it preserves what is working for the organisms,

collectives, and their ecosystems. This behavior has been working for cetaceans for millions of years, long before the bipedal hominid emerged in the scene of evolution. This view offered me the understanding that intelligence, in an extravagantly social species such as ours, may not really refer to doing mental tricks and other kinds of acrobatics; intelligence is *practiced*. It is often practiced socially.

Seen from an evolutionary perspective, one cannot help but to recognize that intelligence may be more associated with the word *prudence* than words such as smart, bright, or keen. When we look at most families, schools, universities, business organizations, nation-states, and supranational agencies, we see various applications of prudential thought and action. In evolutionary terms, our species has recently specialized in building sophisticated and pervasive symbolic hierarchies, safeguards, barriers, and science-based technologies in order to preserve status quos, welfare systems, or secure access to monetary resources. *Homo sapiens* are capable of practicing prudence to prevent any violation to what we would like to see sustained in the future. However, this specialization comes with a grave cost; for one domain we have largely failed to practice prudential thought and action is that diverse and healthy natural ecosystems need to be preserved for the health, wellness, enjoyment, fulfilment, and security of future human and nonhuman generations.

Bolstered by an industrialist viewpoint, from early on, we learn to compete, rather than collaborate; we learn to engage in activities that compromise our life-support systems, rather than preserve it for future human and nonhuman generations; we learn to antagonize and try fighting off other groups, rather than cohabiting with them; we churn out technologies and embrace them uncritically, without fully understanding their risks and ramifications. We build

administrative systems which we cannot handle later on. As a result, in just about a few thousand years, we have compromised this planet's functioning ecosystems where previous human societies managed to keep them fairly sustainably for tens of thousands of years. Evolutionarily, this is an unprecedented situation, pointing out a species that does not behave intelligently with regards to maintaining its life support systems. When considering all these, 21st century citizenry must inevitably ask if the human species deserves to survive this century.

There is no single cure to what ails humanity. There are currently thousands of standalone ideas, policies, and technology proposals on offer to do something about declining freshwater sources, securing food, enhancing the human connection with nature, changing behavior of human collectives towards sustainable consumption, and switching to the use of renewable energy sources. On the other hand, there are only a handful of systematic educational research and development proposals that aim at harnessing the evolutionary powers of the human brain and develop natural technologies that can help route human cultural evolution towards a more viable path. Human brains possess the necessary biological ingredients to create healthier socio-ecological niches. However, education – the field responsible for training and developing human cognition – lacks the necessary attentional, motivational, organizational, and scientific-theoretic ingredients for cultivating a type of intelligence required to preserve or restore the integrity and healthy functioning of natural ecosystems in this century.

This is what I am interested in. Forged in the crucible of evolutionary cognition, this thesis examines a universal cognitive faculty named Mental Time Travel (MTT) and explores the possibilities for harnessing this faculty to support the development of a special type of

intelligence associated with prudential thought and behavior. The provisional name given to this capacity is foresightful/prudential intellect.¹ This term intends to invoke not an ability to forecast or predict, but an ability to harness MTT and cultivate a prudential problem identification and solution headspace. I believe this construct is a necessary educational solution to the current environmental sustainability predicament we are facing: on one hand we know that we have caused significant anthropogenic environmental changes by constructing an evolutionarily unprecedented socio-ecological niche, and we desire to continue with this trajectory. On the other hand, we are searching for solutions to remain human, maintain a quality of life, closer connection to the natural world, and long-term conservation of remaining biodiversity, which in effect requires significant changes in human behavioral and cognitive ecologies (Daly, 1996; Ehrlich & Ehrlich, 2012). The construct also necessarily questions and attempts to enhance some of the existing conceptualizations, theoretical commitments, and evidence-based research in regards to the goals of science and environmental education subjects.

In order to show and defend why educating for foresightful/prudential intellect – and using an MTT-based scientific-theoretic model in support of this effort – is a more viable and generalizable solution in the long run than the other alternatives on offer, the thesis employs evolutionary scientific groundwork. This base examines the evolved psychological and neurological mechanisms and various ecological adaptations underlying the formation of foresightful/prudential thought and behavior in *Homo sapiens*. This theory-driven research program attempts to establish prescriptions for novel trajectories in educational research and

¹ Throughout this text, I will use foresight and prudence side by side in order to avoid either term becoming associated with other constructs.

outline deliberate teaching strategies in support of this emergent intellectual ability, based upon an ecologically valid set of arguments that ineluctably transcend cultural and species boundaries.

1.2. Layout of the thesis

A frame such as *Mental Time Travel Research in Education and the Development of Foresightful/Prudential Intellect* presages a theory-driven effort and heralds a new research and development territory in educational research. Therefore, this thesis naturally evolved as a theory-building/theory-refinement effort, supplemented with conceptual (grammatical) investigations of relevant work and an illustrative empirical study. Theoretical and conceptual investigations are considered essential to establishing semantic clarity of the constructs on offer, as well, for identifying feasible models, instruments, and frameworks that can guide empirical questions (Machado, Lourenço, & Silva, 2000). As a theoretical-conceptual thesis, each chapter unfolds iteratively to explicate the rudimentary role of MTT in human cognition and its educability, incorporating both descriptive and normative theory building attempts (Godfrey-Smith, 2003, p.6). In brief:

- Chapter 2, *The Evolution of Mental Time Travel*, shows that MTT is a perennial, paradigmatic cognitive faculty that crosses species boundaries, and that future-oriented thought and behavior are dependent on the healthy functioning and sophistication of this faculty. The chapter specifically examines the evolutionary psychological, physiological, and cultural adaptations underlying MTT, such as how MTT evolved as a sister phenomenon of theory-of-mind ability, and demonstrates how MTT gained more

selective advantage to become instrumental to human learning, decision-making, and ecological problem identification and solution.

- Chapter 3, ***Foresightful/Prudential Intellect***, first examines the current accounts of intelligence, especially the general cognitive ability known as *g*, and Gardner's Multiple Intelligences. Upon examining these literatures, the chapter articulates foresight/prudence as a different intellectual capacity with different implications on learning and development. One crucial implication emerging from this differentiation is educating students for what I call *critoeconoesis*. This cognitive phenomenon refers to the ability to derive *emergent* ecological phenomenon by tapping into a "possibilities and alternatives" headspace and critically evaluate its consequences; for which MTT-based learning is an essential component. Engagement with dynamic system problems (also known as complex adaptive systems) is argued as the ideal context for educating students for this cognitive skill.
- Chapter 4, ***Developmental Readiness Assessment***, presents a preliminary, illustrative empirical work that developmentally examined students' engagement with a dynamic system problem. The study is partially designed as an MTT task, drawing on human interactions with natural and technological systems. The study invited Grade 5 and Grade 7 children and undergraduate students to engage in MTT and prompted them to offer preventative actions to the experienced problem. Findings synthesized from this exploratory study specifically suggest that there could be more benefit to engaging students with event-based root-cause analysis tasks (which are in essence MTT activities) as a tangible measure of supporting the development of foresightful/prudential intellect.

- Chapter 5, ***Two Techniques Associated with MTT-Based Learning***, examines two MTT-based methods/techniques that could assist the development of foresightful/prudential intellect: (1) Root-cause failure and success analysis, and (2) the prospective hindsight analysis. Drawing on the findings of the empirical work, this chapter illustrates how MTT-based learning could be implemented by virtue of designing educational technologies that enable students to investigate dynamic system problems. The chapter also attempts to identify some of the current ideological barriers to this type of learning.
- Chapter 6, ***Teacher Education and MTT-Based Learning***, is the final chapter where recommendations for teacher education are made. In particular, this chapter points out the benefits of preparing pre-service teachers to design MTT tasks for themselves and for their prospective students. One complementary suggestion here is that the subject of evolutionary cognition could become a more robust part of undergraduate teacher education programs. Evolutionary cognition holds the key constructs and theories that are essential to understanding the geographically-based, evolutionary complexity of human learning from childhood to the old age. Finally, the chapter conceptualizes a curriculum exemplar where MTT tasks are utilized with the goal of supporting the development of foresightful/prudential intellect.

1.3. The overarching goals of the thesis

1.3.1. Theoretical frame of mental time travel

One technical definition of mental time travel (MTT) is that it is a cognitive skill that either deliberately or spontaneously allows individuals to mentally place themselves in past, future, or counterfactual situations. As will be examined in Chapter 2, current advances in MTT research generally focus in the individual ability to case episodes of one's subjective image in those aforementioned situations. As such, the current theoretical refinement of MTT in relevant scientific literatures regularly draw on Endel Tulving's (2002) trademark conceptions, episodic memory and particularly, *autonoesis*, which moved the discussion increasingly towards establishing the alleged uniqueness of human mind, rather than articulating its potential applications in education. Accordingly, the ability to cast episodes of situations, events, incidents, systems, groups, strategies, or tasks in past, future, and counterfactual situations, and foresightfully or prudentially assess their past developments and emergent ramifications for future has not been visible in the existing research paradigm. As Tulving's term *autonoesis* does not sufficiently capture this latter cognitive competence, the thesis uses a new conception called *critoeconoesis* to articulate it.

The hypothesis that MTT, as an evolved, general cognitive faculty, could be responsible for the formation of foresightful, future-oriented thinking and behavior is primarily grounded in the research in behavioral ecology, cognitive neuroscience, and developmental science. There are currently growing numbers of observational and experimental studies that examine this hypothesis – these are reviewed and examined in Chapter 2. However, the proposal that active engagement with what could be called mental time travel based learning (MTT-based learning)

could lead to the development of foresightful/prudential intellectual capacity in various knowledge domains is a distinctly educational hypothesis that has not yet been visibly explored; and therefore, it constitutes the primary motivation of this thesis. In that regard, this thesis necessarily uses the assumptions, heuristics, experimental and observational evidential base of the first, evolutionarily based hypothesis when constructing the premise of the educational hypothesis, which can be called the foresightful/prudential intelligence hypothesis. In particular, this educational hypothesis on offer subsumes the evolutionarily based hypothesis and argues that although *Homo sapiens* possess an unusually flexible MTT ability and could use this ability to understand, assess, identify, and plot the long-term consequences of ecological problems, children do not innately possess the knowledge of how to harness the MTT ability when identifying or solving those problems. This point is elaborated by way of a developmental study offered in Chapter 4 where findings show that only a small number of participants have emerging cognitive flexibilities when addressing a complex ecological problem foresightfully/prudentially. This study is illustrated as a preliminary empirical base for the educational hypothesis and excavated the specific empirical questions that need to be investigated in future studies. In that respect, the educational hypothesis tentatively recognizes that foresightful/prudential intellect is an embryonic mental capacity, requiring the deployment of different types of educational tools, techniques, and discourses, such as those that engage learners with various MTT tasks. In addition, the investment of educational and developmental psychologies is especially crucial in order to identify the assessable components of foresightful/prudential intellect that can produce a scientifically informed curriculum design.

Albert Einstein is well-known with his thought experiments. He imagined himself riding a beam of light, trying to contemplate whether or not he can go faster than light. But he realized that no matter how fast he could go, he can never outpace it. This realization was the benchmark for his special theory of relativity (Kaku, 1995). For decades, many scholars and scientists wondered about the source of Einstein's impressive ability to ask very simple yet theoretically powerful questions. Throughout his early schooling life, Einstein was frequently scorned by his teachers for disrupting the classroom with his 'childlike' inquiries. In his later life, many attributed his skill in theoretical physics to his skill in abstract geometrical thinking as well as his skill in violin. Where scientists and educationalists continued to become fascinated with Einstein's genius in contemporary times, it seemingly did not occur to anyone that his genius could be strongly linked with his aptitude in MTT.

A general position of this thesis is that MTT is a foundational cognitive faculty underlying the technological and scientific genius of *Homo sapiens*. However, the fact that *Homo sapiens* are biologically prepared to engage in MTT does not indicate in any way that majority of its members innately know how to harness this skill to solve difficult conceptual problems as Einstein did. As shall be examined in Chapter 2, the primary cognitive resource underlying MTT, episodic memory, is an evolutionarily delicate memory system. Although we are able to use hindsight judgments or create episodes of ourselves and situations in future scenarios to solve the emergent problems of the present day preventatively, our episodic memory system often betrays us. We cannot accurately remember the particularities of how, when, and where a problem is solved in the past, just as we cannot robustly create continuing episodes of ourselves and our environments in future situations. The evolutionary vulnerability of episodic

memory is an underlying reason why the critical problems of our species are not resolved. One critical problem which runs in the background of this thesis is the problem of long-term environmental sustainability.

1.3.2. Ehrlich's problem: Towards a robust environmental education research

This thesis generally argues that what Albert Einstein did in the domain of physics could also be done in the domain of ecological problem identification and solving. The ability to execute what Einstein did (i.e. MTT) also constitutes a correlate intellectual faculty, which is called foresightful/prudential intellect in this thesis. In that sense, it could also be argued that foresightful/prudential intellect involves the elements of spatial/navigational reasoning, as well as it involves the elements of interpersonal skills, chiefly, the theory-of-mind ability. The development of this intellectual faculty could be supported in schooling by designing MTT-based learning tasks in various curriculum subjects ranging from mathematics (e.g. spatial reasoning) to social studies (e.g. policy analysis), where teachers make sure that students use their episodic memory system. However, this thesis argues that it is the domain of environmental education where MTT-based learning could make the broadest possible contribution.

Indeed, a common criticism of mainstream educational research by environmental education research is that it mobilizes students to develop skills that contribute to engineering and fabricating the planet's self-sustaining ecological niches for short-term financial gain (e.g. Orr, 1994; Gruenewald, 2003; Kidner, 2012) – with short-term, average human lifespan (i.e. 80 years) could be implied. Whereas environmental education argues that our priority needs to be

helping students develop skills that contribute to the long-term stewardship and restoration of natural ecosystems and the reculturation of human societies towards this goal – with long-term, the ecological lifespans of nonhuman niches, human niches, and their population cycles (i.e. 10,000 to 100,000 + years) are accounted for. As examined in Chapter 2, although MTT and foresight has played a major role in driving human evolution, it is not a mature ability insofar as all members of our species can effortlessly execute or apply to any problem – this means that biological evolution has just begun to sufficiently mature this skill. Therefore, in order to address this issue, we require not a new top-down policy or a curriculum per se, but rather a tangible cognitive-developmental trajectory.

For instance, as a construct for societal intelligence, “foresight intelligence” has already appeared in a seminal scientific proceeding. Paul and Anne Ehrlich (2013) defined this term as the ability to “systematically look ahead” and “guide cultural changes towards desirable outcomes such as increased socio-economic resilience” (p. 6). Although this definition is not particularly what could come to mind when thinking about educational questions, it could be used as a guideline. As an ecologist, Ehrlich (2011) contended that environmental education plays a critical role in order to effectively combat the compounding problems of overpopulation, overconsumption by the rich, climate change, and biodiversity loss. To guide this effort, Ehrlich (2011) argued that all standard curriculum topics should be dovetailed with environmental topics, such as transforming the “see Spot Run approach to early readers...into see the plant grow in the sun” (p. 10); or in middle-school mathematics subjects, exposing students to “exponential growth, so that they will not be able to understand interest rate problems but always remember that a long history of exponential growth does not imply a long

future of exponential growth” (p. 10). Ehrlich’s contention that environmental education for not being robust enough is noteworthy, since the research and development efforts conducted in this field scarcely focused on creating a critical scientific discourse that educates individuals on the evolved human psychophysical dependency on healthily functioning natural ecosystems. Indeed, most prominent discourses in environmental education either focus disproportionately on sociopolitical cultural change within mainstream education with the intention of increasing student participation in politically leaning environmental issues (e.g. Bowers, 2001; Jickling, 2001, 2013), or behavioral change that contemplates education more as a mechanical instrument to induce pro-environmental behavior (e.g. Hungerford & Volk, 1990; Disinger, 1993).

Among some of his suggestions, there is an additional strategy that Ehrlich briefly touched upon but did not elaborate further, which is the need to make use of cognitive-developmental science and systematically illustrate the problems associated with human learning through the lifespan. This strategy focuses not on the tip of the iceberg by introducing more environmental science or social policy discourse, but systematically attacking the bottom of the iceberg where we encounter problems of cognition, motivation, and memory (see figure 1.1.). Indeed theories illuminating the evolution and development of human cognition and the difficulty of its educability has received little to no attention in the field of environmental education. In the context of this thesis, a focus on MTT ability to cultivate foresightful/prudential intellect represents such effort.

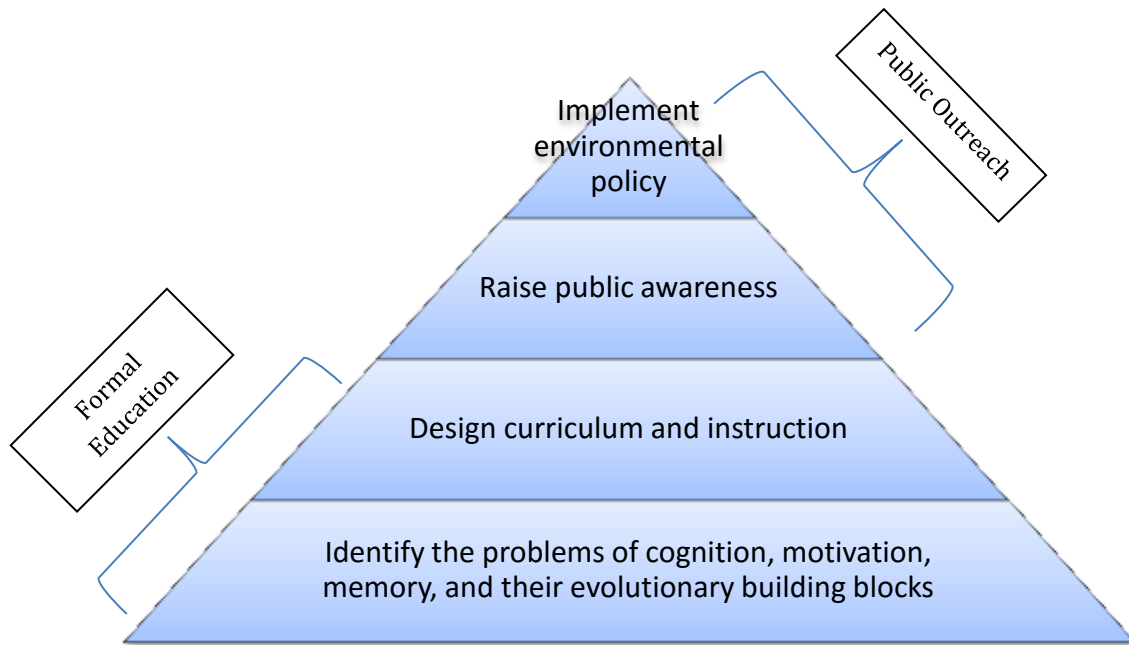


Figure 1.1. A pyramid/iceberg model exemplifying four levels where environmental education research is conducted

Due to its relevance, this thesis subsumes the Ehrlichs' definition, however, recognizing that the development of this intellectual capacity resonates more with the terms "prudence" and "providence," as opposed to forecasting. Indeed, in *Oxford Latin Dictionary* (Glare, 2012), the word "intelligence" is chiefly associated with four other concepts, including *sapientia* (read: sapient), *cerebrum* (read: cerebral, as related to brain), *prudentia* (read: prudent, foresightful), and *intelligentia* (read: thoroughly knowledgeable). Notice that the third word *prudentia* translates rather well as "with prudence" or "with foresight" or "with providence" (an even rarer form). As shown in Chapter 3, prudence is more associated with cognitive control, self-regulation, and "the ability to find relevant material in memory and deploy attention when needed" (Kahneman, 2011, p. 46) – where "finding relevant material in memory" refers to the MTT ability, "deploying attention when needed" indicates prudential action with translatability

into foresightful action. Therefore, prudence, foresight, and MTT are construed as the right ingredients for assessing intellectual development than various other intelligent tests currently on offer in educational circles.

In addition, as opposed to the Ehrlichs' contention that this new intelligence construct needs to be construed as part of Gardner's (1999) contentious theory of multiple intelligences (MI theory), this thesis demonstrates that foresightful/prudential cognitive processes can be found in any of his multiple intelligences. As argued in Chapter 3, foresightful/prudential intellect frame is somewhat closer to the current orthodoxy of general intelligence (*g*) than MI theory, although standard IQ tests are by no means the appropriate way to assess the development of this cognitive capacity. The suggestion is that assessing how development of foresightful/prudential intellect develops and influences learning requires different types of research methodologies working together simultaneously. It is therefore vital that researchers prevent this construct becoming a slogan that produces loose, disorganized, unsubstantial, undisciplined ideas, offshoots, and frames that might generate the sort of pendulum effect so familiar to educational researchers (Wolfe & Poynor, 2001; Slavin, 2002). This thesis attempts to mitigate this unwanted possibility by growing the construct *out* from the recent advances in evolutionary cognitive science.

Despite varying degrees of contextual differences, the foresightful/prudential intellect frame is in alignment with many broader goals captured by the Ehrlichs in order to address the challenge of human predicament/sustainable development in this century (Ehrlich & Ehrlich, 2012). The list outlining what is required to address this evolutionary quandary consists of intertwined pedagogical objectives includes: the ability to assess the ramifications of

anthropogenic environmental changes; analyzing the root-causes of unresolved issues affecting human and environmental health; engaging in futuristic thinking towards routing society towards healthy interaction patterns with natural and technological systems; understanding where previous generations blundered in the making of current societies; and last but not least, assessing what we are *evolutionarily* trading off when we continue to wall ourselves in, accepting make-believe terms such as *Anthropocene* at face value, and continuing to distance ourselves from interactions with wild nature as previous ecological niches had originally intended for us.

With current technological and administrative policy innovation levels and the motivations of existing scientific paradigms, the agenda for solving the environmental sustainability predicament is slowly but steadily becoming a logical impossibility. Although Holling (2001) implied that this agenda can be successfully delivered in conditions where agents and systems innovate, experiment with opportunities and possibilities, and demonstrate rational behavior, human-made systems are currently assailed with destabilizing agents and conditions that cause unpredictable behavior at a systemic level, decay of psychophysical health, and poor institutional leadership and decision-making. The fact that we invest more mental and physical energy in controlling the symptoms (e.g. famine, religious conflicts, terrorism, soil degradation, climate change, financial regulations etc.) rather than the root-causes (e.g. overpopulation, agricultural land allocation, poor educational engagement) of the human predicament points out cognitive shortcomings related to judgment, decision-making, and problem-solving that are pervasive among societies' gatekeepers, stakeholders, and lay

people. Attention has therefore turned to education, the discipline with a core interest in engineering human cognition along a more desirable cultural evolutionary path.

In hindsight, we have already learned what is *not* working: Movements, such as sustainable development education, have proven themselves feeble, suffering from conceptual and semantic clarity problems. Curriculum theorist Jickling has persistently documented and demonstrated why the term sustainable development, as largely used in business and governmental circles, cannot be *educational* (see Jickling, & Spork, 1998; Jickling, 2001, 2006; Jickling & Wals, 2008, 2012). Originating from the 1978 Brundtland Report's "Our Common Future," the term has been associated with an environmental education agenda that promotes the need for continuing agricultural and industrial growth and educating future generations to fill jobs in these domains, while aiming to preserve natural ecosystems. As of today, this agenda has been elaborated further with an adjunct intellectual movement called neo-conservationism which openly bolstered the Anthropocene ideology in *Science* magazine (Kareiva et al., 2007), and argued that the solution to environmental sustainability predicament is the further domestication and regulation of the planet's remaining natural ecosystems². Just as the term Anthropocene, the term sustainable development too is built on a scientifically limited set of methods and assumptions that disregard the limits of the human capacity to learn or make prudential/foresightful decisions and judgments in destabilizing conditions. Sustainable development often works as a tacit shorthand or "magic bullet" that appeals easily to a lay human cognition that is evolutionarily primed to make imprudent and impulsive decisions and judgments (Kahneman, 2011).

² A recently published volume has addressed the flaws in this ideology (see Wuerthner, Crist, & Butler, 2014)

Sustainability by itself can be an important adjunct concept to foresightful/prudential reasoning and action; for in many public and industrial sectors there are concerted efforts to make their businesses last in the next few years or decades. But the term sustainable development, as it stands, is incapable of driving educational agendas, as it is yet to acknowledge some of the core difficulties on human learning that are known from cognitive-developmental research. At the very best, the term manifests itself more as a top-down environmental policy rhetoric that is largely uninformed of the evolved complexity of human mind and associated learning and motivation difficulties. Asserting that sustainable development should drive educational agendas also presupposes that human cognition has an innate drive towards engaging in continuous ecosystems engineering, neglecting other scientific discourses that illustrate that our species became entrapped in an ecological niche destruction activity (Laland, Odling-Smee, & Feldman, 2000), or that human cognition is generally prone to make impulsive, reactionary decisions on issues they have little understanding about (Kahneman, 2011). An additional issue is also that our species has been experimenting with the industrial system in the last 200 years. Therefore, it is reasonable to infer that majority of the members of *Homo sapiens* have not produced sufficient hindsight in this system to a degree that they can easily trust in what can be called 'sustainability best practices.' In fact, we sold our sufficiently working hunting and gathering economy model in favor of this actively evolving, ecologically destructive system. Our only reliable point of reference is our matured evolutionary heuristics and biases that we earned in our previous socio-ecological niches, and how we adapt them to the urban-industrial niches. But they are also contradicted by novel forms of biopsychological adaptations to those niches (see Parlar, 2010). There are a few evolved

psychological items about human cognition that are currently pervious to further mutual modifications of the industrial niches and current organizational behavior, whether they come in the form of abuse or support.

Foresightful/prudential intellect, which is considered as a product of the general cognitive faculty of MTT, is one of those very few items that currently require the attention of education. The universality of MTT ability makes it obvious that foresightful/prudential reasoning is part of our species' general intelligence that could manifest itself in multiple domains – more in some domains (e.g. how to run a private business) and less in others (e.g. how to preserve our national parks as unspoiled as possible for the education and enjoyment of future generations). As I show in the next chapter, we can safely construe that foresightful/prudential intellect is a perennial capacity that almost every human brain (with the exception of outliers with specific sorts of brain lesions and other pathologies) is predisposed to. However, it is equally clear that this biopsychological potential does not develop properly in some of those domains – the fact that we are currently facing anthropogenic climate change attests to this. In that sense, I argue that more could be gained through building an appropriate scientific vocabulary around the development of foresightful/prudential intellect rather than handing this topic over to the domain of intelligence testing. To support this effort, formal education requires deliberate and equally foresightful curricula, pedagogies, and teacher education programs. In my judgement, science and environmental education are the most urgent domains where the benefits of this cognitive-developmental agenda can be reaped.

1.3.3. On intelligence

“War is too important to be left to generals,” Georges Clemenceau famously declared. By the same token, intelligence is too important a construct to be left to one distinct gatekeeper who can warp it to fit particular (pre)conceptions. To begin with, intelligence, as a dynamic phenomenon, is a concept that defies investigation from any one perspective. On this subject, one can routinely find publications in a number of psychological, anthropological, biological, financial, business, and engineering annals and journals, with its associated individual, social, cultural, and systemic variants (e.g. Humphrey, 1976; Marino, 1995; Lefebvre, 2000; Goleman, 2001; Rendell & Whitehead, 2001; Sternberg, 2002; Boesch, 2007). Intelligence is a topic of perpetual fascination, in large part because it often has direct ramifications on innovation, creativity, professional competency, decision-making and judgment capacity, problem identification and solution, and so on. As a transdisciplinary construct, it is by default an applied concept – an intelligent person is capable of changing curricular orientations, student learning, teacher motivations, as well as organizational and workplace dynamics. However, what we mean by “intelligence” when identifying that person is a much tortured issue. The diversity occasioned by human gene-culture coevolution inevitably led to intellectual and behavioral differences among individuals and generations (Feldman & Laland, 1996), making intelligence a difficult but a rudimentary subject of educational inquiry (Sternberg, 2002). This thesis attempts to bring a degree of resolution to this problem by characterizing intelligence with foresightful/prudential thought and action.

1.4. The needed theory of knowledge paradigm

In the past few decades, one of the most significant advances in evolutionary sciences has been the formulation of niche construction theory (NCT) (Odling-Smee, Laland, & Feldman, 2003), now considered as *the extended evolutionary framework* (Laland et al., 2014). The standard Neo-Darwinian explanation of natural selection theory argues that genetically heritable traits favoring survival and reproductive advantage to individuals are passed on to next generations and become more pervasive in a population (Maynard Smith & Szathmary, 1997). The classical example where peppered moths changed their wing patterns from light color to dark color as a response to industrial pollution and accordingly increased their survival chances against predators represents how this mechanism of adaptation/fitness in a changing environment works (Rudge, 2005). On the other hand, NCT postulates that organisms can *adapt* their environments to their needs and add a new inheritance mechanism called *ecological inheritance*. The ecological inheritance mechanism postulates that species can construct niches that induce unforeseen changes in selection pressures and in some cases, offset or alter an otherwise normal natural selection process (Kendal, Tehrani, & Odling-Smee, 2011). As Laland and colleagues (2000) exemplified:

Organisms may niche construct in ways that counteract natural selection, for example, by digging a burrow or migrating to avoid the cold, or they may niche construct in ways that introduce novel selection pressures, for example, by exploiting a new food resource, which might subsequently select for a new digestive enzyme. (p. 133)

NCT posits that certain organisms actively shape their own evolution, including their genetic and cultural evolutions by way of constructing the types of ecological niches they leave to their offspring. The gist of NCT is that organisms do not passively change in response to their environments, but rather are changed by their own activities within those environments.

NCT is currently considered as one of the most prominent evolutionary scientific theories explaining how *Homo sapiens* has driven its own evolution through constructing multiple socio-ecological niches, as well, a prominent catalyst for integrating social, biological, and ecological sciences into a synthetic discipline (Laland, Odling-Smee, & Feldman, 2000). Especially in recent times, NCT received much attention from both social sciences and natural sciences, due to the fact that the theory, on Laland and colleagues' (2000) own accord, offers "a more useful and more acceptable evolutionary framework for the social and other human oriented sciences (henceforth the human sciences) than standard evolutionary accounts" (p. 171). It could be argued that NCT aims to resolve the fabricated incompatibility between social theory and evolutionary theory (Baldwin, 1902; Wilson, 1999).

In education, NCT implies that evolutionary perspectives on understanding and knowing the world can be more meaningfully embedded in curriculum. Especially, in the domain of environmental education, NCT could find ample applications if curriculum can successfully reconcile both social science (including human geography, anthropology, psychology) and natural science (including evolutionary biology, chemistry, and geology) aspects of environmentally-relevant topics (cf. Ehrlich & Ehrlich, 2013). This reconciliation could be successfully achieved if the environmental education curriculum starts with not disparate topics of human impact on natural environments or why 78% nitrogen concentration in the Earth's

atmosphere is the right amount for life to thrive, but the stages of human niche construction. Since the Plio-Pleistocene, the ancestors of *Homo sapiens* have engineered seven types of socio-ecological niches: (1) a terrestrial omnivore niche, (2) a low-end scavenging niche, (3) a high-end scavenging niche, (4) a hunting-and-gathering niche, (5) a herding niche, (6) an agricultural niche, and (7) an urban-industrial niche (Bickerton, 2009, p. 109). This is also important since today some geological scientists argue that with the 7th niche being constructed, humans might have turned themselves into a major geological force around the world (Smith & Zeder, 2013; Steffen, Grinevald, Crutzen, & McNeill, 2011; Zalasiewicz, Williams, Haywood, & Ellis, 2011). Simultaneously, it is equally clear to these researchers that the active evolution of this 7th niche is not viable in the next few centuries due to compounding unpredictable associations between human cultural needs, technological sophistication and pervasiveness, and energy conversion and consumption levels. The current advance of NCT at the interface of ecology and evolutionary biology (Odling-Smee, Laland, & Feldman, 2003) thus necessarily compels us to consider a more robust science and environmental education curriculum that must strive to synthesize social and natural science aspects of our relationship with the natural ecosystems.

In the context of this thesis, where the development and educability of foresightful/prudential intellect is examined vis-à-vis the framework of MTT, the evolution and function of MTT is examined within the framework of NCT. In that sense, this thesis constructs a bridge between evolutionary accounts of human cognition (including its cultural origins) and more practical concerns of educationalists in learning, cultural change, and motivation. NCT is used to evaluate the function and evolution of MTT, since each constructed niche occasions

different ecological inheritance pressures that can affect selection for human intellectual fitness and mental flexibility. As Suddendorf (2010) explained, “natural selection cannot work on accuracy of past recollections *per se*, but only what episodic memory does for present and future survival and reproduction” (p. 99); therefore, he argued that “it is not the accuracy of our predictions *per se* that have been selected for, but fitness benefits” (Suddendorf, 2010, p. 103). This argument suggests that natural selection did not select MTT ability for accuracy in forecasting and hindcasting, but for its ability to enhance the flexibility and reach of human cognitive skills *with respect* to the dynamics of constructed socio-ecological niches. In that sense, a discourse driven by MTT in educational circles should not occupy itself with the accuracy of students’ intellectual judgments and problem solving skills, but enabling those judgments and skills to become fitter (read: foresightful/prudential) in the current complex and unpredictable climate.

MTT ability, especially in regards to foresightful/prudential reasoning, is to some degree contingent on its benefits for individual cognitive-developmental fitness, such as ecological problem identification and solution. However, the current and future generations that are fated to be burdened with the environmental short-sightedness of previous generations require different problem-identification and solution skills to secure an ecologically sustainable future. These strategies will not develop according to a mechanistic plan natural selection predetermined, since natural selection did not predict the development of foresight so that human species can combat its current environmental problems (Dawkins, 2000); rather, it is education, as a cultural evolutionary actor, that needs to facilitate ways of harnessing MTT to enhance foresightful/prudential problem solving, and showing where this skill could be applied

to identify and solve the problems endemic in the current human niches. These strategies could include how we come to understand the world, the human place in nature, and our ability to act in consideration with the future of nonhuman species.

The development of a foresightful/prudential intellectual capacity in current and future generations necessarily requires a theory of knowledge that is firmly anchored to the biophysical realities of the planet. As Deacon and Cashman (2009) argued, religion cannot provide this basis since most religions distract humans from taking action towards correcting the short-sighted decision-making tendencies of previous policy-makers and stakeholders. Within the domain of organized religion, we are generally taught to use our MTT abilities to project episodes of ourselves and others achieving immortality and imaginary pleasures; they insist that individuals must detach the human agent from the natural world or its biological needs. Therefore, doctrinal theology can make little contribution to the development of foresightful/prudential intellect when applied to reconcile the biophysical realities of the planet with the socio-ecological realities of the current human societies. Post-structuralist or postmodern theories could be equally damaging since some assert nature as a socially constructed entity³. These theories have provided more license to types of architectural design, planning and decision-making that continue to decimate wilderness areas that could have otherwise provided a healthier long-term connection to humans (for extensive critiques, see Kahn, 1999; Kellert, Heerwagen, & Mador, 2008). I thus argue that the only theory of knowledge candidate that can assist in building the foresightful/prudential intellect argument is evolutionary science.

³ For a more robust critical examination of this issue, see the work of Kidner, 2000, 2001, 2012.

1.4.1. A review of the existing educational ideologies

Where do our current ideological adherences stem from in education? Are they capable of articulating foresightful/prudential intellect or residues from a bygone age and time that are insufficient to address the emerging complexities of the contemporary cultures of education? In order to address these questions, we need to first take a look at the history of ideas that influenced contemporary educational research.

Kohlberg and Mayer (1972) identified three educational ideologies that continued to dominate 20th-century education since earlier forms of apprenticeship-based education and standardized curricula. These are cultural transmission, romanticism, and progressivism. It is well-known in the field of education that cultural transmission had been the dominant ideology in Western educational tradition, emphasizing society before child, and the need to discipline the child according to the needs of social order so as to accomplish “educational ends” that are “the internalization of the values and knowledge of the culture” (Kohlberg & Mayer, 1972, p. 454). Under the influence of this ideological precept, children were often thought to be – literally speaking – retarded adults, who spoke half-language and possessed half-bodies, appeared to be slightly savvier than most other animals. Educators’ major source of reference for a child’s mental and physical capabilities was often Abrahamic religious texts wherein children are portrayed as sacred beings, yet morally incomplete, and therefore are innocent and must be subsequently tamed. As Davis and colleagues (2014) wrote:

Development through lifespan wasn’t a topic of particular interest prior to the 1900s. In fact, it could be argued that such “stages” in life as infancy and adolescence are recent inventions...For example, prior to 1600s children were often portrayed as miniature

adults in paintings, their clothing was a scaled-down version of adult fashions, their furniture was adjusted for size but not function, and so on. (p. 73)

Political theorist and activist Jean-Jacques Rousseau's book *Emile* (1762/1979) was the first European text to introduce a stage-based developmental model, contending that children's education needed to be considered with respect to their cognitive readiness. Moved by his own romantic view on inequality, as Gene Myers (2007) notes, "Rousseau took as his task to show how society and person might be rebuilt aright on natural provisions – essentially to harmonize the child of nature with the needs of society as much as possible" (p. 25). But even for Rousseau his romantic educational philosophy on child development was still in alignment with biblical texts, as he saw "[i]nnocent, natural, and good, the animal-like child easily [falling] prey to the vanity and corruption of society" and that "only carefully calculated child rearing such as Rousseau outlined in *Emile* can mitigate it" (Myers, 2007, p. 25). Along the way, Rousseau also argued that socio-emotional, physical, and moral development must also be the aim of education, if there is to be any chance of generating a responsible and healthy citizenry.

A more scientific basis of human development did not appear until the work of American psychologist James Mark Baldwin. Baldwin's developmental theories derived from his keen observations of his own children. He conducted simple and subtle experiments with them. His articulate writing, complex opinions, and broad thinking on the nature of human development as a psychological, sociocultural, and evolutionary process had subsequently burned vivid impressions in John Dewey, Jean Piaget, Lev Vygotsky, Larry Kohlberg, and many other contemporary developmental scientists. Unlike Rousseau and many other modern/postmodern thinkers who came before him and wrote about human development,

Baldwin's reference point was empirical science, specifically, Darwin's theory of evolution by natural selection. As in Henry Plotkin's (2010) words, for Baldwin "the only acceptable form of psychology was one wholly built upon a theoretical basis compatible with, if not directly derived from, Darwinian evolutionary thinking" (p. 49). In the spirit of Darwin, Baldwin went against vitalism, religious dogma, Cartesian dualism, other forms of dichotomizations in science and theory of knowledge, as well as postmodern discourses in education and human development back in the early 20th century (Richards, 1987; Ferrari, 2003; Wozniak, 2009). Unknowingly, and in a somewhat pseudo-Lamarckian way, he was also a prominent figure in giving foundations to a central idea in NCT that young individuals inherit ancestral niches (i.e. their social heredity) and go on changing the patterns of those niches with respect to their emerging needs (Weber & Depew, 2003). It is therefore possible to imagine that had his career had not end abruptly (see Wozniak, 2009), contemporary educational psychology could have been less Cartesian and more Darwinian.

Baldwin's theoretical work in human development had subsequently been taken up by John Dewey who initiated the progressivist educational ideology. As Kohlberg and Mayer (1972) pointed out, unlike Rousseau's romantic view,

the progressives do not assume that development is the unfolding of an innate pattern or that the primary aim of education is to create an unconflicted environment able to foster healthy development. Instead, they define development as a progression through invariant ordered sequential stages (p. 454).

"Thus the educational goal" of Dewey's progressivism, Kohlberg and Mayer (1972) asserted, "is the eventual attainment of a higher level or stage of development in adulthood,

not merely the healthy functioning of the child at a present level” (p. 454). Although Dewey went on to influence educational theory on his own accord in the United States, in Europe, Baldwin’s empirical initiatives were taken up for further investigation by Jean Piaget. Piaget was extensively recorded and documented his interactions with children and developed a stage-based theory, especially for educators, to use. He pioneered the structural-developmental theory, semistructured interview techniques (Piaget, 1929, 1983), and attempted to show systematically that children are not delayed adults. He demonstrated that children have ideas of their own and construct their own knowledge of the world around them. Piaget’s main influence in education is the realization that a child’s intelligence should not be trifled with but rather taken seriously.

By the time Piaget was making his debut among North American audiences, in Soviet Russia, a learning psychologist named Lev Vygotsky (1978) was simultaneously developing a research program on human development. The most notable distinction of Vygotsky from Piaget was his consideration that language was essentially a collaborative device central to development (Kohlberg & Wertsch, 1987). Vygotsky demonstrated that only through appropriate adult scaffolding could a child’s socio-cognitive potential, not *what the child is*, be tapped. For Vygotsky, development needed to be understood in a socio-cultural context, such as family environment, classroom, or one’s country, where the responsible adults are tasked with taking advantage of a pedagogical zone he called “Zone of Proximal Development” (ZPD). It is in this zone where the adult adjusts the vocabulary, tools, and other objects child engages with “by intuiting exactly what he or she is ready to learn” (Donald, 2002, p. 138). Thus elaborates Donald (2002), pedagogy as understood by Vygotsky is better called “mindsharing”

(p. 144) that which is a central component in theory-of-mind ability found universally in *Homo sapiens* and many other mammals (Whiten, 1998).

Today, more educationalists have begun to acknowledge that although Piaget's stage-based theory and learning tasks are beneficial to the learning of symbol-centric tests and challenges, such as those seen in science and mathematics topics, Vygotsky's work appears to be more relevant to understanding children's collaborative learning of those topics in formal (i.e. classroom) and informal (i.e. non-classroom) educational settings. Educational research based on Vygotsky's work has also repeatedly confirmed the value of engaging children in peer-to-peer interactions, which enhances communication and mindsharing (e.g. Forman & Cazden, 1985), as well as socio-cognitive problem-solving abilities (for review see Mercer, 2013). Researchers studying learning and cognition outside the educational research circles also acknowledge that Vygotsky's socio-cultural theory clears up otherwise debatable issues, including the evolution of language, specialized human cognitive abilities, such as shared intentionality (Tomasello et al. 2005).

Both Piaget's and Vygotsky's contributions to understanding human development continue to have currency in their own rights; both researchers, in their writings, carry the vision of James Mark Baldwin for understanding how humans learn, develop, and succeed or fail to enact their potentials. However, in many ways, they also do not. Baldwin's (1909) vision for developmental science was to steer its advances with respect to the Darwinian evolutionary epistemology. Through this attitude, he wanted to settle (1) the long-standing Cartesian dualism and dichotomized thinking that structured the content of contemporary social, natural, and physical science curricula; (2) standard social science model drawing on postmodern theory

and their perfunctory rejection of evolutionary perspectives; and (3) the arguments on vitalism, creationism, and intelligent design that now haunts science education (Taylor & Ferrari, 2011). None of these long-standing and crucial conceptual issues were fully embraced by Piaget and Vygotsky, or other archetypal developmentalists such as Larry Kohlberg and Carol Gilligan⁴. They persist, and continue to make dangerous advances at the expense of both humanity and the natural world.

1.4.2. Justification for an educational ideology consistent with evolutionary science

That, there has never been a robust public school and higher education curriculum that aimed at teaching students how to be foresightful/prudential about the human interactions with natural and technological systems so that they can be firmly anchored to the biophysical realities of the planet may in many ways be a Baldwinian problem. It might be argued that this situation is due to an inability of curriculum researchers to construe the true virtue of Darwinism as something akin to E. O. Wilson's (1984, 1993) biophilia hypothesis – that is, the partly innate, partly socially learned tendency to affiliate with life and lifelike processes⁵. Indeed, a pedagogy based on the biological continuity of human beings to the nonhuman world has not been a point of inquiry in curriculum studies until relatively recently (Shepard, 1997; Abram, 1997; Gruenewald, 2003). If anything, the aim of a progressive ideology in education was to train individuals' minds so that they can think for themselves. This approach corresponded to the more robust needs of the early 20th century: to produce a countermeasure

⁴ Larry Kohlberg and Carol Gilligan are the two most prominent researchers in moral development whose work built largely on Piaget's work.

⁵ Much has been written about this hypothesis in the past (Kellert & Wilson, 1993; Kahn, 1999, 2011; Kahn & Kellert, 2002; Myers, 2007) and I too also attempted to elaborate what it means (Parlar, 2014b); as such I will not be dealing with this topic here.

against the shortcomings of standardized education, pushing for equal opportunities around literacy and gender issues, moral and character education, among a few others. Environmental sustainability was not a phrase in most teachers' vocabularies or in any provincial curriculum documents. Neither was the recognition that the industrial system is a socio-ecological niche that evolves at the expense of its own human engineers and is by definition, hostile to the nonhuman ecosystems that its human engineers depend on. The extinction of a few keystone species was inconsequential to the human progress and unfolding of the mathematical and artistic genius of *Homo sapiens* in accomplishing things that were hitherto unknown in nature. Anthropogenic environmental change and its impacts on nonhuman ecosystems, let alone our cognitive ecology, were not acutely *felt*, and was in the foresight of only a select few scientists and public intellectuals. Formal curricula did not have to occupy any one of these concerns, since anthropogenic environmental changes and population growth were not *perceived* as a threat to physical securities (e.g. food, water, clean air, safe workplace and dwelling environments) as well as psychological securities (e.g. regular access to diverse and healthy natural environments, little surveillance and monitoring during international travel, among a few).

Indeed, the belief that *Homo sapiens* can continually populate and refabricate an ostensibly infinite planet to suit its *immediate* needs through science-based technology is not easily distinguishable from the religion-based idea that the human presence on this planet is eternal. We did not have to be foresightful/prudential in our dealings with the natural world, when waging ideological as well as physical battles largely couched in capitalism versus communism or religion versus secularism, populating the planet in service of ideological wars;

or, when sending Neil Armstrong and his crew to Moon had an *immediate* payoff for the Cold War efforts. Deforestation of Amazonia, declining fresh water sources, intolerable air pollution in multiple geographies, toxicity in both physical as well as cognitive ecologies were simply the casualties needed to carry ourselves towards an allegedly *better* future. By using standardized, uniform education, human cognitive energies were single-mindedly mobilized for accumulating the necessary monetary resources for short-term payoff in the benefit of a small segment of human societies. Formal education contributed to directing these cognitive energies to places where *society* needed. As one math teacher had memorably dictated in my classroom during Grade 10, “if you want to be highly-paid engineers, doctors, and lawyers just like your fathers, do not waste your time on poetry, nature, and philosophy.” The emphasis has shifted from an economy of knowledge based around embodied surroundings (Ingold, 2000) towards an economy of knowledge based on *building* things.

Only in recent times have ecological-evolutionary scientists begun to report that this unprecedented niche construction could be perceived as *niche destruction* (Laland et al., 2000) in a sense that *Homo sapiens* is in the process of destructing its (1) hunter-gatherer niches by sidelining or supplanting indigenous livelihood models and epistemologies, and (2) the socio-ecological niches of nonhuman species by constructing agricultural, industrial/urban niches which interrupt or annex nonhuman species’ habitat corridors. Some natural and social science models used to study this unprecedented phenomenon draw attention to a plausible Malthusian-like trajectory (e.g. Myers, 1993; Daily & Ehrlich, 1996; Harte, 1996; Diamond, 2006; Pirages & DeGeest, 2003) – that populations cannot increase geometrically as though they are on an infinite plane (Malthus, 1798/2008). The mathematical models currently being built by

the niche construction theorists John Odling-Smee, Kevin Laland, and Marcus Feldman provide a necessary scientific interpretive footing to how such a trajectory could be avoidable in the next few centuries, one suggestion being that *Homo sapiens* must manage to artificially accelerate its cultural evolution (Ehrlich & Ehrlich, 2013). Another suggestion, which lies at the kernel of this thesis, is for the deliberate training of human cognition for foresightful/prudential decision-making, judgment, problem identification and solution, learning, and motivation. This thesis thus aims to promote a research program for how this suggestion in point could be achieved by the efforts of education – teacher education, curriculum studies, and educational and developmental psychologies as the main enactors of this goal.

Although progressive education has made significant inroads in otherwise difficult agendas of the 20th century, it is insufficient for contemplating and assessing the bigger, evolutionary picture which the circumstances of the present day demands. More than a century and a half after Darwin, who had noticed the brutally honest truth in Thomas Malthus' (1798/2008) *Essay on the Principle of Population*, contemporary educational discourses continue to opt a business-as-usual trajectory that is unwilling to deliberately train human intellect to become foresightful/prudential in the domain of human interactions with natural and technological systems (HINTS)⁶. Malthus' foresightful insight helped both Darwin and Wallace to think evolutionarily. This was the way of thinking that ultimately culminated in their co-discovery of evolution by natural selection *in* the natural world – a point provocatively suggesting that learning to think evolutionarily might be compatible with learning to think and behave foresightfully/prudentially, and vice versa.

⁶ HINTS is presently the name of Dr. Peter Kahn's lab at the University of Washington. I believe it could also be construed as an appropriate knowledge domain.

For most of the 20th century, educational researchers have overlooked Baldwin's and Dewey's original insights in regards to the significance of evolutionary science on the transformation of theory of knowledge and human mind. Instead, evolution was largely rendered into a topic to be taken and passed in biology curricula (Dobzhansky, 1973), often, with limited success. Educationalists decided to listen to myopic decision-makers who promised great *progress* in material wealth, freedom, and justice – a decision that in effect led us to unwittingly forego the natural ecosystems whose integrity and healthy functioning has always been in the *long-term* interest of our species.

Today, evolution education is largely regarded as the black sheep of educational research due to its inextinguishable battles with Intelligent Design (Taylor & Ferrari, 2011), which resulted in learners *disengaging* from the very content of evolutionary biology (Jablonka et al., 2007; Depew, 2010). What is more troubling is that evolution education has never formulated an explicit curricular goal of fostering the development of evolutionary or foresightful/prudential reasoning and action, evident by most of its researchers' almost single-minded focus on teaching the mechanical logic underlying natural selection (e.g. Samarapungavan & Wiers, 1997; Evans, 2008; Berti et al. 2010). Indeed, especially in the public scenery, evolution education has generally failed to demonstrate the cognitive-developmental benefits of learning natural selection, and more specifically, in formal education where it is yet to engage students in the production of insight on the myopia endemic in many of our undertakings as a species in the past and present day (see French, 2012).

Darwin's statement on evolution can be interpreted as an educational statement that fills an absence, suggesting an agenda for the evolution of human consciousness towards more

pressing matters. It is a brutally honest account (and a direction) for a society that lost touch with the biophysical realities of the planet, and instead, placed tremendous trust in its own symbolic conventions. We can be biophilic in our own rights; we can be attracted to great outdoors, birding societies, and would favor their preservation in the long-run (Pyle, 2003); but the niche we constructed to regulate our socio-ecological dynamics are not constructed to compel its individuals to behave foresightfully or prudentially in ecosystemic affairs. In a rather paradoxical sense, this fact posits the underlying logic of natural selection as a phenomenon (Dawkins, 2000).

When we consider the underlying intellectual force behind Darwin's theory (that is Malthus' essay) it becomes clear that Darwin's idea was a statement that concerns the future of *Homo sapiens* – specifically, that the constructed human socio-ecological niches selected for unusually large neocortices that spontaneously enable its members to foresee the ramifications of our ways of thinking and social behaviors on the whole ecosystems. It is education that teaches us how to do this. Unfortunately, previous educational ideologies have completely sidestepped this issue since back in the early 20th century the environmental predicament was not acute. There was no *need* to be foresightful/prudential in that area, let alone to champion robust evolutionary thinking. There was no need for environmental education that dovetailed with Darwin's point. Thus, as Bowers (2003) pointed out, Dewey's adherence to Darwin to validate his pragmatic philosophy did not possess an environmental educational decree. This also potentially explains not only the late emergence of environmental education in the history of the field of education but also its development as a reactionary counter-cultural movement (Blumstein & Saylan, 2011) that unvaryingly scorned all forms of science-based educational

proceedings during its inception (see Lucas, 1980; Robottom, 1987; Ashley, 2000), insofar as in some quarters, it attempted to dislodge itself from the *taint* of formal education (e.g. Weston, 1996; Stevenson, 2007), but can still remain educational in its own right (Jickling, 2003).

Today, the environmental predicament *is* acute – and, considered systemically, the most potent means to tackle it is through education. Unlike its impractical aspirants, we have not yet developed hyperspace engines that could allow us to explore outer space, establish colonies on other planets, and give relief to the planet-earth and its future human and nonhuman generations. This very fact points out that the time has come for us to use our large brains in different ways. We need to become foresightful/prudential now more than ever. We need to perform evolutionary reasoning on many of our environmental decision-making duties, and to educate a generation that learns how to use this reasoning and route their young and imprudent race towards an environmentally sustainable course. We need a thoroughly Darwinian approach in reconfiguring our discourses on what we claim to be educating for.

However, such assertions do not come without historical baggage. As the history of sciences sadly showed, the myopic applications of Darwin's theory in social policy resulted in his cousin Francis Galton's eugenics, and other pseudo-scientific, crypto-Lamarckian discourses (e.g. Spencer's survival of the fittest) that were used to bolster dangerous socio-political conventions such as National Socialism in Germany, rather than *challenging* their faulty premises (Laland & Brown, 2011). In biology, Darwin's theory, as taken up by the adherents of Modern Synthesis, became instrumental in setting up a Cartesian biological science curricula that had the effect of teaching students a set of dichotomies such as nature versus nurture, genotype versus phenotype, innate versus socially learned, activity versus passivity, among a

few (Oyama, 2000, 2003). Whereas, the true educational virtue of Darwinism was indeed something akin to Wilson's biophilia – that is, the articulation of human place in nature, promotion of evolutionary, foresightful/prudential reasoning and action, and if anything, learning recursively from the fate of long extinct species, as well, to tame parochial decision-making and judgment. The theory was deeply an environmental one for a society that never thoroughly recognized untrammelled, wild nonhuman environment as a significant evolutionary cognitive resource, let alone the continuation of this cognitive source as a benchmark for its sustainability. Sadly, especially in the field of human development, it still does not. Articulation of human place in nature is still not considered a viable developmental goal, evident in lack of publications on child development and nature, indeed, not even an “index citation on the subject” (Kellert, 2013, p. 136) in recent encyclopedic volumes on developmental psychology.

Furthermore, as demonstrated by Davis et al. (2014), our deliberate learning experiences are still scaffolded by virtue of the interpretational frame of “me and other humans,” not “me and the nonhuman environment,” or as I call, “my evolution and the evolution of other life forms.” This is clearly a socio-cognitive challenge, showing the culturally-steered heuristics and biases of the adult human brain drawing its cognitive sources from the small complexities of everyday social life (Dunbar, 1995, 1996). The scarcity of this level of thinking points out why our MTT abilities could be harnessed in ways that individuals learn to account for the ramifications of every human advance for the nonhuman environment and its inhabitants.

Holding all these intertwined complexities in mind, alongside how symbolic language and human cognition coevolved to reduce situational and navigational uncertainties (Bickerton,

2014), it should be more convincing that educational research in 21st century requires a vastly sophisticated evolutionary-educational inquiry that must suspend short-termist human interest in favor of a sustainable momentum in other domains. Indeed, this inquiry may lead us not necessarily to sustainable development, but something more akin to *suspendable development* or *environmentally foresightful/prudential progress and growth*. Suspension, not sustainability, could be the logical outcome for engaging in foresightful/prudential reasoning and action about growth and progress in certain domains. It could be that suspension in certain areas, such as population growth, consumption levels, and unbridled technological sophistication is a logical necessity to achieve progress in other equally important quarters. By extension, such suspension could provide educational research with a breathing space and quarters for maneuvering so that it can get ahead of its race with the most acute ecological-evolutionary security challenges.

As I show in this thesis, harnessing our MTT ability as a way of cultivating foresightful/prudential intellect is a logical educational solution that offers a plethora of research and development opportunities. Along the way, this thesis also demonstrates ways of enhancing the teaching practice, and ways of assessing intellectual development with tools and models that coincide with the scientific goals of understanding human intelligence *in* dynamic systems.

Chapter 2: Mental time travel: Its emergence and evolution

Knowing how something originated often is the best clue to how it works.

Terry Deacon, 1997, p.23

2.1. Introduction

This chapter examines the evolutionary origins of mental time travel (MTT) and aims to demonstrate that foresightful/ prudential intellect is an epiphenomenon of this perennial and universal cognitive faculty. The functional formation of MTT in human cognitive executive suite is explained by virtue of analyzing and combining various scientific concepts and phenomenon offered by evolutionary modelling of human cognitive development. In that sense, the formation of MTT might best be examined through two overarching disciplinary frames: (1) Behavioral and cognitive ecology which deals with the ecological aspects of MTT, and (2) Brain, memory, and language, which deal with the neuropsychological aspects of MTT. Through these frames, the chapter aims to build a progressive scientific groundwork and vocabulary which educationally relevant questions regarding MTT-based learning and the development of foresightful/prudential intellect can utilize.

2.2. Section 1. Behavioral and Cognitive Ecology

2.2.1. *Theory-of-mind*

Psychological science traditionally surmised that natural selection favored higher cognitive abilities in human beings because they had to solve demanding ecological problems, and therefore they needed bigger brains to match those demands. Even in educational psychology, this contention is implicitly maintained (e.g. Sweller, 2004). In the field of behavioral ecology, this argument is known as the ecological hypothesis (Parker & Gibson, 1977; Gibson, 1986; Harvey & Crebs, 1990). Examples of those ecological problem solving abilities include motor skill sophistication to avoid predation, visual-color categorization to recognize ripe fruits, auditory specialization to discern the safe sounds and signs from unsafe, spatial-navigational mastery for prospecting new territories, and extending the breadth of dietary resources through constructing new socio-ecological niches (Dunbar, 1998; Reader, Hager, & Laland, 2011).

One of the recent additions to this criterion was *theory-of-mind*, sometimes also known as *mindreading* ability among behavioral ecologists (Whiten, 1998, 2000). In its narrow technical sense, theory-of-mind refers to the ability to understand and anticipate others' intentions, beliefs, thoughts, assumptions, and actions (Premack & Woodruff, 1978; Whiten, 1996, 1997). It has also been considered an essential component of natural pedagogy (Donald, 2002). More broadly, it refers to the ability to "imagine that the world could be other than it is, to imagine that someone else could have a false belief about the world" (Dunbar, 2004, pp. 68 – 69). As conducive to its evolved social function, theory-of-mind is a vital component of general anthropoid primate intelligence, helping individuals safely sail through the social

complexity challenges (Dunbar & Sutcliffe, 2007), especially when understanding, reading, or anticipating others' needs, emotional states, and problem-solving strategies. A situation in which "Lori believes [1] that Dave knows [2] that Anaaya wants [3] that Jacob tells [4] Cora to imagine [5] that Twinkle Toes has a mind of its own" is an example of human theory-of-mind, involving five-order intentionality (see Figure 2.1.). In this case, the connection between Lori and the house cat Twinkle Toes is almost too distant to meaningfully bridge; nonetheless, factual investigations have revealed that human beings can push theory-of-mind tasks up to five-order intentionality with relative ease (Kinderman, Dunbar, & Bentall, 1998, cited in Dunbar, 2004). For anything beyond the fifth stage, most participants face cognitive failure.

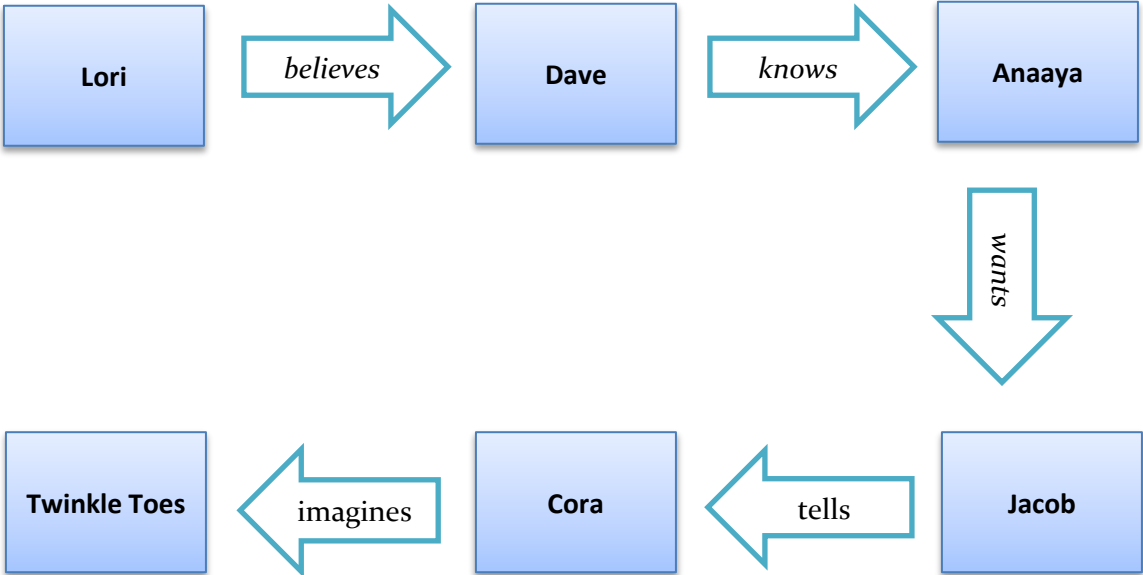


Figure 2.1. Level 5 theory-of-mind ability. Partly adapted from Dunbar (2004).

Theory-of-mind is also one of the enduring quests within developmental science, reflected through many ambitious research programs aimed at understanding how and when

mindreading ability emerges in children. The most notable investigation technique is called the “false-belief task,” requiring a child to grasp or anticipate that another person believes in something that the child believes to be false (Baron-Cohen, Leslie, & Firth, 1985). The Sally-Anne test – or Location Change test – is the classical example here: In front of two children, an experimenter first hides a doll in Location X, and then asks one of the children to leave the room. Second, the experimenter moves the doll to Location Y in front of the remaining child. Third, the experimenter asks the child where the other child will anticipate the toy to be hidden when she comes back. If the child says Location Y, she fails the test. If she says Location X, she passes the test, as this is indicative of her understanding that the other child would *believe* that the doll is in Location X. This ability appears to develop spontaneously around the age of three or four (Chandler, Fritz, & Hala, 1989; Perner, Leekam, & Wimmer, 1987; Dunbar, 2000) – incidentally, the same time frame when children also begin engaging in MTT, in episodic projection to past and future (e.g. Welch-Ross, 1995; Perner, 2000; Nelson, 2001; Levine, 2004; Suddendorf & Busby, 2005).

In evolutionary terms, the existence of sophisticated theory-of-mind in humans and other primates offers an explanation to why “one or more ecological problems (survival, foraging, child rearing) are more effectively solved *socially* than by an individual’s unaided efforts” (Dunbar & Schultz, 2007, p. 650). In a sense, theory-of-mind serves to improve the chances of at least two individuals within a group when they will have to solve an ecological problem. But primates (including hominids) is one of the most socially complex biological orders ever known; with increasing social complexity, one must expect other kinds of protracted challenges such as the task of *how-to-get-along* with your aiders with whom you

may not necessarily sympathize. Thus along with physical ecological problems that you must solve to maintain the socio-ecological niche as healthy and stable as needed, this order is additionally burdened with the task of handling, if not downright anticipating, their own social complexity challenges. Dunbar (1998) regards this particular fact as the underlying cause for why primates evolved larger brains and sophisticated theory-of-mind abilities over the course of their biosocial evolution. As the young members of this order grow up, they learn to engage in protracted social play, plan (for tactical deception, manipulation, coalition making), and come to each other's help when a need arises (Humphrey, 1976; Hauser, 1997; Whiten & Byrne, 1997; Russon, 1997).

One term that I developed to explain the emergent phenomenon encountered in primate social ecology is *socio-ecological allostasis* (cf. Schulkin, 2011), combining *allo*, "change," and *stasis*, "same." Socio-ecological allostasis is thus intended to invoke something like "adaptation with respect to changes within the same socio-ecological context." This concept flags that socially complex species such as primates regulate their own psychophysical adaptations in anticipation of changes within their socio-ecological niches. In effect, this anticipation often leads to the social behavior known to evolutionary biologists as *reciprocal altruism*, or simply the behavior of "if you scratch my back, I'll scratch yours" (Trivers, 1971; Connor, 1995). Socio-ecological allostasis offers a new layer to reciprocal altruism. It refers to a deliberate organizational management scheme and could be considered as an epiphenomenon of advanced theory-of-mind skills, indicating one of the most rudimentary forms of a foresightful/prudential state of being. Due to an extravagant social complexity that allowed members of this order to excel at "understanding categories of third-party relationships"

(Tomasello, 2000, p. 167), primates needed to engage in more robust MTT activities. They needed to become more foresightful/prudential as well as hindsightful in their dealings than any other terrestrial mammal, especially when remembering *who-has-done-what-with-whom* and when anticipating *whom-might-do-what-with-whom* in the future.

Theory-of-mind ability resides at the kernel of primate cognition (Premack & Woodruff, 1978; Boesch, 2012) and should be considered as a prominent underlying cause for why primate MTT ability is specifically concerned with accounting for and anticipating the behaviors of other group members. This concern should be contrasted with the food-caching behavior observed in Scrub Jays (Clayton & Dickinson, 1998) which is “vulnerable to decay, to parasitism, and to plundering by observant conspecifics” (Kummer & Goodall, 1985, p. 205). Instead, our biological order harnesses its theory-of-mind ability to excel at “by far the most elegant form of storage,” namely “new knowledge or skill in communication or ecological techniques” (Kummer & Goodall, 1985, p. 205).

This point leads us to a question that is not well emphasized by learning researchers: Is theory-of-mind ability necessary when identifying and solving ecological problems that are *not* here-and-now? Is it necessary for not only anticipating one’s learning needs, but also the needs of the socio-ecological niche in which one is nested? For instance, Kummer and Goodall (1985) noted that our genetic cousins, common chimpanzees (*Pan troglodytes*) possess a congenital lack of knowledge of how to build tools. Where beavers engineer dams and termites build their mounds without having to invent new technologies (Odling-Smee et al., 2003), “chimps are remarkably ill-equipped with innate technologies” (Kummer & Goodall, 1985, p. 203). Instead,

the chimp beats the termite by learning to tease him from his mound. Instinct is like a key fitting a single lock. A key is easy to use. The poor a priori competence of primates is comparable to a pick-lock. Its use requires and therefore promotes a kind of skill which eventually permits the opening of many locks. (p. 203)

Indeed, if compared with how other mammals encounter and solve their ecological problems, chimps – along with humans – would be considered cognitively lethargic. But they are more inventive than other industrious mammals such as beavers. It could be that the chimps' innovative strength lies in their ability to not invent new skills individually, but in their ability to actively share the knowledge relevant to innovation with others creating an early form of distributed cognitive network (Donald, 2002). They become foresightful/prudential with respect to this form of storage, albeit to a limited extent.

In addition, it could be argued that by excelling at anticipating those third-party social relationships, sensing the tensions and agreements between group members, and configuring their behaviors accordingly (Tomasello & Call, 1997), the lazy – but clever! – chimps tend to extrapolate their inevitably future-oriented social behavior to pedagogical ones. In order to compensate for the infant congenital lack of knowledge associated with their material culture, chimp adults must occasion ragtag social learning strategies to sort their infants out. Occasionally, direct teaching is required for the pupil to attain a basic form of mastery in a manufactured piece of environment. Boesch's (2012) field observation offers a case in point:

Salomé [the mother chimp] did not leave nuts behind for [her son] Sartre to crack when he was 2 or 3 years old, but regularly did so when he was 5 years old. Thus *it looks like she was reacting to the ability level that her son had reached. Moreover, every now and*

then, she would even arrange the nut-cracking anvil by leaving the hammer balanced on the root and placing an intact nut in the roundish trace of wear on the anvil before she want to gather more nuts. This seemed to work well because in the majority of cases Sartre would take the hammer and hit the nut with it, and at 5 years old of age, he was strong enough to successfully break them. In this way, Salome *stimulated* her son to learn about what makes a good hammer and how to use it. (pp. 136-137, my emphasis)

The act of stimulation occasioned by Salomé is a way of adjusting Sartre's ability to crack open nuts through very subtle semiotic acts. It is a basic form of pedagogy, requires theory-of-mind ability, albeit limited (Donald, 2002, p. 144). But the important thing here is that such skill can continue to exist and be refined so long as adults foresee the availability of a socio-ecological niche dependent on material culture. The skill is not the output of an innate, preprogrammed compulsion to teach nut-cracking behavior to a youngling by preconfiguring the tools of trade. Sartre simply benefits from the availability of a socio-ecological heredity (cf. Baldwin, 1896) that has been constructed by the ancestors of Salomé. It is in this dynamic ecological hereditary system where younglings just like Sartre, play and experiment with touchable, hittable, and biteable objects; observe how others distinguish ripe fruits from unripe ones, the carnivore from herbivore, the safe from unsafe; imitate and copy the behavior of adults; evade facing uncertainty; and deflect disequilibrium (Boyd & Richerson, 1988; Laland, 2004; Kendal et al. 2005) – just as human infants do (Thelen & Smith, 1994). As Baldwin (1897) noticed more than a century ago, observation and imitation are quite literally the foundational blocks of early learning in humans in socio-ecologically dynamic systems. It turns out to be the case among young chimps as well (McGrew, 1992; Boesch, 2012). Relying on a niche at whose

center material culture and technology actively shape the behavioral, cognitive, and learning ecologies of its members, the subtle pedagogical strategies emerged to accommodate these needs prevent atrophy and detrimental effects on the development of individual's psychophysical processes – and by extension, to the health of the entire community. They are rudimentarily foresightful/prudential behaviors.

2.2.2. Learning by extrapolation

It is helpful to consider MTT an offspring of theory-of-mind. Over the course of hominid cognitive evolution, these two abilities often worked jointly to manage social complexity and secure resources. However, they have lately begun to diverge. Where it is impossible to consider theory-of-mind without MTT, it is possible for MTT to independently occur without the activity of theory-of-mind. Theory-of-mind tasks virtually involve an MTT activity, since we anticipate the intentions and beliefs of others by subjectively accounting for their previous behaviors and intentions. However, to retain the particularities of *where, when, and for what purpose* we learned to craft the multipurpose hand axe does not always require us to relate to another person. In fact, it may require us to relate more to a specific locale, object, geography, ecosystem, or climatic condition. Therefore, it could be argued that MTT is particularly well-suited to solving environmental and technical problems by virtue of enabling individuals to draw on hindsight – a taken-for-granted past learning that suddenly becomes important to solving a novel ecological problem.

Climate change adaptation offers a good case in point, and here, we can apply our own MTT skills to explain the role and function of MTT in ecological problem solving. Picture a

hunter-gatherer tribe that is compelled to relocate to cooler geographies from a warming geography. At the onset of migration, this group will be psychophysically *pre-maladapted* to dwell in a geography dominated by sub-zero temperatures. The geography is abundant with food and water, solving a basic security problem. Over time, the climate of this geography gets cooler to the point of creating permanent winters, but the group does not risk migrating to other geographies due to the established hunting, gathering, and scavenging practices. They will once again adapt to the conditions. But rather than passively adapting to the changing climate by wearing more layers of animal skin, it would be less costly to *adapt* the environment to the group. Hunting is a vastly costly behavior that occasionally results in adult male casualties (Panter-Brick, Layton, & Rowley-Conwy, 2001). Rather than hunting more animals with the primary aim of collecting their skins to overcome the climate change problem, building a new form of shelter to keep the cold out would be far less costly. Accordingly, hunters might become compelled to experiment with building an igloo-like structure that shelters their families.

Clearly, this experimentation will not happen in a way that some invisible force hands down the blueprints of *how-to-build-an-igloo-like-shelter* to individual human brains. Rather, we should expect these individuals to harness their MTT abilities and communicate a situation that is not *here-and-now*, perhaps by observing the ringed seals that hide under the ice and breathe through constructed holes. Extrapolating the ringed seal's adaptive behavior and learning from it could lead to construct igloos. Indeed, we owe much of our natural engineering genius not to innate technologies, but our ability to successfully observe and imitate other species (Ingold, 1989, 2000). For this to happen, the species requires the MTT ability and a form

of language that enable its members to communicate an *episode* that is experienced only once. Over time, thanks to this ability, and using this ability to adapt the environment to their emergent needs, the group can become adept at inhabiting a geography where they were virtually inept a few hundred years ago.

This scenario is an example of how niche construction takes place in our species. Most of our pre-agricultural and herding niche construction efforts were largely guided by keenly observing how other species construct their own niches. This behavior persisted even in the modern world when children imitate other animals when building dams and forts (Shepard, 1997) – although it has never been considered as potentially significant for the development of foresightful/prudential intellect. Niche construction activities of many terrestrial omnivorous species like primates are prominent and generalized by virtue of its effects on interspersed habitat corridors and novelty effects in genetic inheritance trends. As an example, a recent mathematical modelling effort conducted by Wiles and colleagues (2005) demonstrated that anthropoid primates stopped synthesizing their own ascorbic acid (i.e. Vitamin C) over 40 million years ago when they deliberately *begin* acquiring this substance from fruits. By constructing a socio-ecological niche at whose center fruit-eating lifestyle is the new norm, the species gradually lost its ability to endogenously synthesize its own ascorbic acid. Gradual adaptation to this new dietary supplement ensnared anthropoid primates in a fruit-based diet, resulting in L-gulonolactone-oxidase (LGO) – the enzyme responsible for the endogenous production of ascorbic acid – becoming masked from normal selection. Gradually, its function was redistributed to “a complex of genes supporting the ability to acquire [ascorbic acid] exogenously” (Wiles et al. 2005, p. 178). Deacon (2010) further elaborated that one of the most

dramatic ramifications of this adaptation was the unforeseen emergence of three-color vision in primates, and a relaxation of natural selection due to species' emergent response to acquiring ascorbic acid exogenously and learning new procedures for foraging and consuming this resource. A consequence of this adaptation has been that future generations gradually came to not inherit a functional LGO, yet began inheriting a socio-ecological niche where fruit-based diet and the rituals surrounding how to sustain this diet is a biosocial necessity.

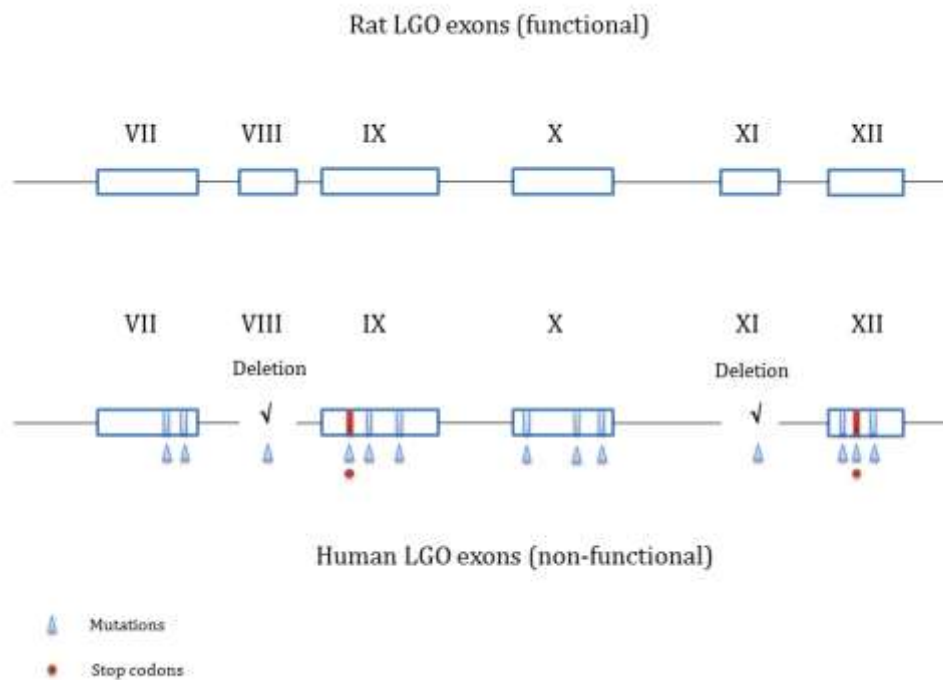


Figure 2.2. Comparison of functional LGO (in rats) and non-functional LGO (in humans). The study was originally conducted by Nishikimi et al. (1994). Model sourced from Deacon (2009b).

On the other hand, niche construction theorists and modellers such as Odling-Smee and his colleagues (2003) have not yet developed the vocabulary needed to explain certain phenomena encountered in a species' learning activities during niche construction. A term offered by Baldwin (1902), *psychophysical parallelism*, can be adapted to describe a fraction of this ability to *make oneself home*. In Baldwin's terms, psychophysical parallelism posits that "changes in consciousness are accompanied by organic changes, in the brain and nerves" (p. 10). Adapting one's environment to suit needs undoubtedly contributes to changes in a group's consciousness and socio-ecological activities. Where anthropoid primates became genetically adapted to a fruit-based lifestyle, the cultural side of the phenomenon points out the type of mechanism Baldwin described. The emerging knowledge of using one's limbs to pick a fruit, to peel the skin from it with fingers and teeth, and to recognize whether its ripe or not by smelling it or visually discerning the ripe ones are a suite of novel learning strategies that also *ensure* that the species will continue to get Vitamin C rich fruits and learn how to do these things via extrapolation. Here MTT ability becomes a more robust need due to the requirement for remembering the particular conditions for a fruit's ripeness, various locales where it grows in abundance or scarcity, and developing strategies for defending this resource against other competitors, and eventually extrapolating these strategies to other areas.

Without doubt, such cognitively taxing activity can also come with ill consequences. In contemporary times, humans have adapted natural environments to suit the needs of actively evolving cultural niches to an extent that this adaptation has been considered exceedingly dysfunctional (Kellert, 2013; Parlar, 2014a). In effect, we are compelled to solve problems occasioned by this new form of adaptation. In order to avoid maladaptation, improvised social

learning strategies are used as a catalyst for accelerating new cognitive adaptations within a cultural niche, which in effect enhances the adaptability/fitting of the group in that physical niche (Boyd & Richerson, 1995; Boyd, Richerson, & Henrich, 2011). A sophisticated MTT ability is again required to *identify* and extrapolate how better conditions could be engineered.

Unlike many other terrestrial mammals and birds that could not contemplate the possibility of prospecting new territories, *reporting back* those novel places and the individual episodes of those places to their group, and synthesizing that experience only to turn it into knowledge and practice, symbolic-language-using hominids are able to story a distant situation/possibility through a *back-and-forth* communication, learn recursively from experienced scenarios, stories, and possibilities, and mobilize their group members to take action towards desired directions. Gradually, learning becomes an extrapolative activity where individuals can voluntarily project or rehearse a hunting situation as a measure of securing its future success. This extrapolative learning (or learning by extrapolation) also enables recalling, sampling, and imitating hundreds of particularities that could facilitate their survival/adaptation in various geographies, ratcheting the cumulative cultural evolution towards a direction consistent with the current and anticipated needs of the group (Tomasello, 1999; Vale, Flynn, & Kendal, 2012). At first glance, learning by extrapolation may be related to the evolved tendency of human cognition to make impulsive associations based on limited factual knowledge (Morewedge & Kahneman, 2010). However, with MTT ability ratcheting the cultural evolution via learning by extrapolation, individuals develop abilities to make deliberate associations between three time frames in two *separate* situations:

- The problems that are known from the past; the problems that are currently experienced; and the problems that could be encountered in the future.
- The observed problems of other species/cultures; the observed problem identification and solution in other species/cultures; the imagined problems that other species/cultures could encounter.

Through deliberate associations, the problem solver's cognitive fitness is enhanced. The problem solver not only analyzes and anticipates the conditions of its own groups, but also the conditions experienced by other species, groups, or cultures. In that regard, MTT ability not only harnesses the theory-of-mind ability in the solution of concrete environmental problems, making cultural learning more robust than it had been; it is also made more *flexible* by observing the problems of other species/cultures and constructing parallels, and extrapolating them in ways that enhance the capacity of recursive learning.

2.2.3. Offline thinking and mimesis

In the current cognitive science literature, there are two additional concepts that elaborate learning by extrapolation as embedded in the MTT ability: offline thinking and mimesis. Offline thinking is a term introduced by evolutionary psycholinguist Derek Bickerton (2009, 2014) to capture the allegedly unique human ability to mentally escape from here-and-now. Bickerton's methodology in establishing the theoretical distinctions in that regard is simple yet compelling. He first elaborated offline thinking by showing what *online* thinking is. Online thinking, argued Bickerton (2014),

occurs when an individual is involved in some specific activity, and that activity is the focus of thought. A bat finding its way around a deep cave, a hawk diving on a fast-moving rabbit, or a human driving a complex route through heavy traffic are all engaged in online thinking. (p. 79)

Online thinking refers to activities where what one does is consistent with what one thinks. “Offline thinking,” according to Bickerton (2014) “occurs when the topic of thought has nothing to do with the thinker’s current behavior” (p. 79) – such as, a student sitting in a classroom and mentally contemplating a trick to be excused from the class for the rest of the day, or walking back and forth in the hallway, imagining the kinds of questions that could be asked in the math exam. The behaviors (sitting and walking) are disconnected from what is happening in the student’s mind (contemplating a trick, worrying about the math exam), insofar as the student appears to be “logged off” from reality, engaged in offline mental activity.⁷ It could be that offline thinking (and by extension, spontaneous MTT) emerging as an unintended consequence of the evolution of symbolic language came to facilitate reducing uncertainties, anxieties, and unpredictability. Evolutionarily speaking, encountering threatening math and science topics, for many students, could be similar to being forced to share territory with a large predator (cf. Tobias & Weissbrod, 1980; Temple & Neumann, 2014). If offline thinking is an adaptation to overcome this problem, then it could be argued that MTT ability had a similar original function as well.

According to Bickerton (2009), offline thinking enabled our ancestors to put their forethought abilities in manufacturing unprecedented tools and equipment. They observed the

⁷ This is one of the chief reasons why certain forms of behaviorism did not work in education. Evolutionarily speaking, we have effectively separated behavior from thought.

natural arsenal of other animals, such as the claws of a leopard, teeth of lions, tusks of elephants, and sharp beaks of birds. They then engaged in offline thinking and contemplated how to manufacture prosthetic devices that resemble the natural extensions of those predators. They took advantage of their ability to share and store knowledge through social practice, finding psychophysical parallels in between two otherwise unrelated objects. The hand axe was not invented due to a lucky accident. Conducive to our ecologically generalist tendency to learn by extrapolating, we *needed* the all-purpose hand axe to help us with our scavenging and hunting efforts (Ingold, 2014), to practice purposeful imitation of other predators. “The whole system” for inventing tools and refining their use over time, argued Bickerton,

required forethought and planning. Forethought and planning in turn demand that you work not with physical objects but with your ideas of those objects – concepts you can move around in your mind to make new patterns and create marvelous and unprecedented things. (2009, p. 204)

The second concept I consider as an elaboration of offline thinking is *mimesis*. “Mimetic skill or mimesis,” argued Donald (1991), “rests on the ability to produce conscious, self-initiated, representational acts that are intentional but not linguistic” (p. 168), and should be considered as different from imitation and gestures, since it “adds a representational dimension to imitation” (p. 169). Mimesis is the re-enactment of a perceived event in one’s mind, combined with physical gestures and activities. Thus, one of the clearest examples of mimesis, according to Donald (2013) is the ability to engage in planned or spontaneous *rehearsal* of gestures, and procedures in mental space – a feat that is virtually non-existent in

any documented nonhuman animal. As in Donald's (2013) notable example, although primatologists observed chimpanzees throwing projectiles at each other when they engaged in inter-group fighting, there appears to be no recorded observation or a neuroimaging study where a chimpanzee is seen *rehearsing* this activity on its own or with another chimp. On the other hand, a ballerina rehearsing her choreography in her headspace stage by stage for next week's performance is an example of mimetic capability.

Notice that the ability to rehearse something in one's mind indicates offline thinking, and should be considered an exemplar of how we learn to practice or create something by extrapolating not a problem observed in the real world, but what we *imagine* in our mind. Like Bickerton, Donald (1991) argued that this ability to *escape* temporarily and voluntarily from the immediate world had an unforeseen consequence: it became instrumental in the domain of technological innovation and enhancing *Homo sapiens'* ecological problem solving ability further. Mimetic culture was essential for our ancestors to go past an innovation threshold where chimpanzees and their stone hammers, anvils, and termite rods simply could not pass – they need not pass. Moreover, mimesis was also necessary for our ability not only to innovate, but also to *refine* a pre-existing relationship with a manufactured piece of environment – to build tools to make tools.

2.2.4. Future-oriented teaching behavior

The development of intelligence in a material-culture-dependent species like ours clearly depends on the environments where we live (Boesch, 2012). For whatever specialized intelligence the socio-ecological niche requires, societies require teachers to unbridle that

biopsychological capacity. Through teaching modern humans were able to sophisticate their MTT abilities.

NCT suggests that an animal (including a human animal) does what it has to do, within the constraints of its existing environment, to make itself at home (read: constructing a niche) (Odling-Smee, Laland, Feldman, 2003). This suggestion negates an earlier ecological postulation that *Homo sapiens* are nicheless organisms that “exist in environments which [they] did not evolve” and that they “are an exotic organism even in our place of origin, wherever that might be” (Evernden, 1993, p. 109). It is not necessarily that we are nicheless or natural aliens for that matter. It is more likely that we have unwittingly *alienated* ourselves from previous human socio-ecological niches by engineering new types of niches. More often than not, what other animals learn is relevant to their immediate survival needs, as related to securing stable supplies of food, water, shelter, including a mate, and a community to affirm their existence in a biologically diverse planet such as ours. Other animals can only think ahead with respect to those basic needs. They can only *teach* their infants and peers with respect to those needs. These conservative behaviors are widely observed among teaching species such as cheetahs (Caro & Hauser, 1992) and meerkats (Thornton et al., 2007). As an evolutionary rule of thumb goes, necessity is the mother of invention, and unless an animal feels impelled to invent something novel in an otherwise healthy, stable, sustainable socio-ecological niche, it would harbor conservative behaviors. Many nonhuman animals, just as chimps stay at the conservative end of the spectrum in order to sustain their niches. For them this is sufficient. Similar can be said of hunter-gatherer human societies; they have predominantly remained at the conservative end of the spectrum for most of their existence (Panter-Brick et al. 2001; Lee

& Daly, 2004). As Brody (2002) documented among Inuit communities in the Arctic, change is perceived as an ominous development. Change is not feared religiously; it is feared because it threatens to overthrow sustainable interaction patterns with their livelihood source: the game, the land, and the free space to wander about, explore, and teach their children how to become human.

Modern humans' socio-ecological niches have taken an evolutionarily unprecedented turn due to an increasingly flexible MTT ability – first with the invention of agriculture (Larsen, 2000), then with the expansion brought forth by urban-industrial niches. Both these niches required members to use offline thinking and to suspend their genetically-driven learning tendencies via offloading conscious control in the computational circuitry of the brain (Deacon, 1997). Calendar tracking, calculation, and controlled experiments were required to successfully cultivate food from the soil. Today, similar techniques are widely used to make a living in the industrial-urban niches. Unlike our hunter-gatherer predecessors, we mostly operate not on the land, but in distributed cognitive networks. We are technical experts not in tracking the game, but in writing computer codes that help analyze networked information and conduct business in virtual reality. What we learn in and outside school should not only be relevant to our immediate survival needs, but also be relevant to *needs* that did not exist a decade ago – as well as *needs* that are yet to be seen. In fact, as some educational researchers who argue for the revitalization of apprenticeship model have observed, what we learn in schools under the rubric of standardized educational model does not seem relevant at all to some of our most basic needs (Collins, Brown, & Newman, 1989; Gardner, 2006).

To recall Sartre and his mother: Sartre's zone of proximal development takes place in a forest, where the teacher and the pupil's external cognitive resources derive from a non-manufactured environment. In ecological terms, this is sufficient. There is no need for Salomé to invent other kinds of pedagogies to give her son a technical edge over other chimp infants. There is no culture gap among chimps that may lead them to specialize in different professions and engage in long-term competition for resources. The chimpanzee socio-ecological niche does not *demand* other technologies to be invented when everything else is in order and providing chimps with their basic needs. As well, biologically, teaching is a costly behavior since it steals precious time from individuals who could have otherwise focused on other endeavours (Hoppitt et al. 2008; Hoppitt, & Laland, 2013). But the natural teaching instinct is socio-ecologically allostatic, priming the would-be teachers to unbridle others' biopsychological potentials *in anticipation* for preserving what has been working for the species. Smaller the group, the better the success rate in this scheme. Therefore, as a teacher, Salomé does not have to *foresee* a future where her son's survival may be in jeopardy, since she does not inhabit a socio-ecological niche that is likely to change radically anytime soon – she cannot *foresee* such change, as her existing theory-of-mind ability does not allow her to engage in far-reaching MTT. It is sufficient within the niche. She just needs to know about the social intentions of other chimps in the vicinity, as well as the intentions of predators to give adequate footing to Sartre's development. Until recently, Salomé was not aware that there is another species of primate outside the Tai forest that desires to hunt its species down to extinction – and, in its stead, build another niche by harnessing atypical technologies and an unprecedented communication system that she cannot even remotely conceive of. Salomé does not have to engage in

foresightful/prudential reasoning, nor foster this cognitive potential in her son beyond what is currently sufficient.

A human teacher, on the other hand, has to. Consider the following example that took place between me and a 10 year old in a Grade 5 science class where I was engaged in a developmental investigation. I immediately dictated my interaction as follows:

Harry: [Raises his hand, looking at me]

Ugur: What's up?

H: I don't know how to open this website.

U: Hmm...you need to drag that link from this page [pointing the webpage] and paste it in here your browser [pointing the browser].

H: [He tries a few times but fails at it] *How* do you do that?

U: Let me show you.

Harry struggled with navigating the computer's mouse omnidirectionally due to an odd configuration of his mouse's Y axis (when dragged forward, the pointer of the mouse went down on screen), indicating that his spatial-navigational reasoning requires a little bit more practice. When I came back to check on him, he was ready to give up. Instead of operating the mouse or reconfiguring the mouse's axis in the control panel (which was somehow not accessible), I showed him a series of keyboard shortcuts to perform the task successfully. After that, Harry looked at me and said:

H: Can I tell you something? I don't like computers.

U: How come?

H: Because it's so tiring to use them.

This case is a very good example that how-to-use computer (an ecological-technical challenge), overcome a spatial-navigational problem (odd Y-axis configuration) or the specialized linguistic jargon (e.g. drag, copy, paste, edit, format) does not come built-in. Harry struggles, to an extent that he resigns by stating that he found the whole process “tiring.” Anthropologically-speaking, this is hardly anything that is different from what occurs among young chimps. By engaging in naturally primed help-seeking behavior (Karabenick, 1998), Harry relied on me (the adult) to compensate for his congenital lack of readiness as related to computer learning (a material-culture tool) and overcoming a spatial-navigational challenge. The computer is an external symbolic storage technology which our society demands children to learn comprehensively for their survival in a heavily virtual (read: digitalized) economic livelihood system. It would have been much easier for adults for children to simply possess these skills innately! But no innate/genetic learning on Harry’s part. Today, the evidence converges on the ground that *Homo sapiens* is a self-domesticated ape who made itself evolutionarily dependent on lifelong social learning (Livingston, 1994; Deacon, 2010; Gibson, 2014; Wilkins, Wrangham, & Fitch, 2014). By doing that, it inadvertently prolonged its lifespan developmental stages; lately, through formal education (Charlton, 2007). Harry relied on me to *show* him that particular skill – which I now, as a teacher, anticipate that he will vary this skill. As he practices further, he might create his own personal tricks of trade.

But is this sufficient? Harry is engaged in the use of a material-culture object (i.e. computer) that is continuously re-designed to accommodate its cognitively-lethargic users’ evolved heuristics and biases. The teacher himself, if foresightful/prudential, is compelled to *show* the child more than what that child may have needed only a decade ago when computers

had more simple functions – attentive to the fact that should this child fall behind peers in the development of these key skills, he could fall behind others and compromise his future career opportunities in STEM related, computer-heavy jobs. By engaging in MTT, the teacher could extrapolate that the child’s learning must be groomed in accordance with a problem that is anticipated but yet to be seen.

Or take this pedagogical attitude to a broader level: Perhaps the classroom teacher or the parent, by virtue of their own education, have *learned to foresee* a future where children’s survival *will* likely be in jeopardy, since they inhabit a socio-ecological niche that has in recent times become inherently unstable and unpredictable. A foresightful, prudent adult will know that there are existential threats at large that emerged as unintended consequences of its predecessors’ short-sighted socio-ecological activities. These include climate change, biodiversity loss, wilderness destruction, degrading air, water, and land quality, overpopulation, rising youth and young adult underemployment, overconsumption by the rich, to cite but a few. These changes have been wrought by a species that in evolutionary terms, has inadvertently engaged in *niche destruction* at a global scale (Laland et al., 2000), having lost collective foresight and prudence for the conditions for living sustainably. If foresightful/prudential, teaching needs to be deliberate, intentional, driven by hyperecological sensibilities, as opposed to something more along the lines of “let students be” kinds of pedagogy (on this issue, see Kirschner, Sweller, & Clark, 2006). It needs to be so that the pedagogy and its content domain helps to unbridle a different kind of intelligence in pupils of a sort that could allow them to see larger evolutionary and historical trends required to identify and solve new ecological and technical problems.

The human teacher must do what her genetic cousin Salomé does not have to. She must harness her own MTT ability in ways that Salomé will probably never have to. She must teach her pupils how to do this in ways that Salomé will probably never have to in Sartre's education. In that sense, her teaching, if primed with extrapolative tendencies, becomes far more vital for a healthy future of human species and that of the planet.

Synopsis 2A

- There is increasing evidence that advanced theory-of-mind ability is the underlying reason for higher cognitive abilities seen in humans, including direct teaching.
- The fact that children acquire theory-of-mind ability and MTT ability around four years of age raises a curious question about why this is a developmentally critical period – and by extension, about the role of socially-learned symbolic language in human development.
- Nonhuman animals do not need to engage in extensive MTT, nor require advanced theory-of-mind beyond what is necessary to maintain their socio-ecological niches. However, this is precisely why they are vulnerable. That is, they are unable to anticipate the harm and damage *Homo sapiens* have caused and will cause to their livelihood and survival. Only we are capable of anticipating such damage. Perhaps, here the crucial question for educationalist boils down to how to imbue this insight with student learning, particularly, through their science and environmental education curricula.

2.3. Section 2. Language, brain, and memory

2.3.1. *Limits of cognitive-neuroanatomical continuity*

Human brains are not just large ape brains, they are ape brains with some rather significant alterations of proportions and relationships between the parts.

Terry Deacon, 1997, p. 255

About eight years ago, Thomas Suddendorf and Michael Corballis (2007) published an impactful article on the evolution of foresight in *Behavioral and Brain Sciences*. This article attempted to establish that MTT is responsible for the evolution of future-oriented thought and action since “it allows us not only to go back in time, but also to foresee, plan, and shape virtually any specific future event” (Suddendorf & Corballis, 2007, p. 299). In the open peer commentary section of this article, the originator of the concept of episodic memory Endel Tulving and his colleague (2007) wrote:

despite the spectacular advances that science has made, we still do not know why the human brain is so much bigger than the chimp’s. Surely it has evolved to serve some adaptive functions that are not shared by our small-brained relatives, but apart from language it is not obvious what these functions might be. (p. 334)

It appears that it has not cogently occurred to either author that language *is* the reason why we have unusually enlarged brains, and why foresight ability evolved beyond what was normally needed for a technological species of our own stature, as an unintended consequence of language taking over virtually all aspects of human cognition and neurobiology (Deacon,

1997). It could be said that Darwin (1871/2004) too had remarked the importance of language evolution, seen in his noteworthy remarks scattered in *The Descent of Man*:

If it could be proved that certain high mental powers, such as the formation of general concepts, self-consciousness, &c., were absolutely peculiar to man, which seems extremely doubtful, it is not improbable that these qualities are merely the incidental results of other highly-advanced intellectual faculties; and these again mainly the result of the continued use of a perfect language. (p. 151)...without the use of some language, however imperfect, it appears doubtful whether man's intellect could have risen to the standard implied by his dominant position at an early period (p. 209)... the largeness of the brain in man relative to his body, compared with the lower animals, may be attributed in chief part to the early use of some simple form of language. (p. 679)

Ask also this way: Is it not an odd and curious fact that the only species with language and the only species with the ability to *spontaneously* and *voluntarily* engage in MTT is the same species? Since language evolution is considered to have radically changed an otherwise unremarkable primate inside-out (Christiansen & Kirby, 2003; Bickerton, 2009; Bickerton & Szathmary, 2009), a reasonable conjecture is that just as any other cognitive abilities accepted as uniquely human, MTT ability and foresightful/prudential reasoning also received a full update thanks to language.

A *full update* analogy rather than a total novelty offers a case in point; as part of their greater challenge to anthropocentric discourses, many behavioral and brain scientists disagree with the contention that MTT is a uniquely human cognitive capacity. There is currently limited yet somewhat compelling positive evidence for the existence of MTT in nonhuman animals,

including bonobos (Mulcahy & Call, 2006), rats (Eacott, Easton, & Zinkvickay, 2005), and scrub-jays (Clayton, Bussey, & Dickinson, 2003; Raby et al., 2007). As I examiner earlier, common chimps also demonstrate a rudimentary form of MTT evident in their remarkable mindreading abilities and, if perhaps to a limited extent, in their ability to contemplate complex tool use and using those tools to open up new socio-ecological niches in various parts of Western Africa (Boesch, 2012).

The possibility that MTT exists in nonhuman animals is also made compelling by virtue of evidence showing that it is the hippocampus, rather than forebrain structures, where the ability to construct past and future events and possibilities lie (Addis, Wong, & Schacter, 2007; Hassabis et al. 2007). Phylogenetically, the hippocampus is one of the oldest parts of mammalian brain whose cytoarchitectonic⁸ characteristics are largely preserved across species for millions of years (Carr & Viskontas, 2007; Manns & Eichenbaum, 2009). Therefore, it is reasonable to infer that many, if not most, animals possessing this part of the brain will be able to engage in some form of future-oriented thinking and behavior. Furthermore, the discovery of mirror neurons across species (Rizzolatti & Craighero, 2004; Gazzola et al., 2007) lends support to something of a “cognitive-neuroanatomical continuity” hypothesis. Analyses of functional magnetic resonance imaging (fMRI) show that when we engage in lip-reading, the same neurons in the same cortical structures are activated in nonhuman animals which take the form of lip-smacking (in monkeys) and barking (in dogs) (Buccino et al. 2004).

Indeed, why should we consider any cognitive ability that appears uniquely human as distinguishing us from rest of the animal kingdom, when different methodologies and

⁸ In biology, the term refers to the structural arrangement of cells in an organ.

disciplinary frames demonstrate otherwise? This is especially the case as the advent of comparative cognitive neuroscience makes it increasingly difficult to sustain anthropocentric arguments pertaining to the *Homo sapiens'* separate mental status from nonhuman animals. Likewise, it too is difficult to sustain that MTT is a hallmark of human cognitive evolution.

As Bickerton (2009) pointed out, it could be that it is *unlikeness* rather than uniqueness that is the issue here, since “for every other ‘unique’ thing that’s evolved, you can see what was there before it, what evolution had to work on in order to produce it” (p. 21). The fact that we constructed substantially different socio-ecological niches in considerably short evolutionary timespans (Laland et al., 2000) and that no other animal did suggest that language had some role in inducing new selection pressures on the performance and regulation of our pre-existing cognitive abilities. These selection pressures should also affect the pre-existing function of MTT ability. It is not that we are the only species that use MTT and engage in foresightful/prudential reasoning (if not behavior). The difference has never been “humans have these newly evolved α module in their brains that gave them language, foresight, creativity, mathematics, arts and so on” and that “nonhuman animals are stuck with their outmoded β module,” as though the α module has been implanted by a top-down agent – an idea that Noam Chomsky (1972) relished a few decades ago when he advanced a discourse on the origins of universal grammar. In technical terms, human brains did not outevolve nonhuman animal brains. The neural computational difference stems from our interactions with unprecedented socio-ecological niches of our own making that are made to house the symbolic language and culture, *with* the

help of the symbolic language and culture⁹. These niches in return demanded us to use our brains in hitherto *unlike* ways, with hitherto *unlike* ecological problems, and hitherto *unlike* (if not unprecedented) neural computational tasks. Why could not one of those ways be an *update* on MTT that is required to face those ecological problems and tasks?

2.3.2 Brain evolution economy

Engineering new socio-ecological niches suggests that our ancestors not only used their intellectual potentials and pre-existing problem-solving skills in different ways, or appropriated their psychophysical energies to enable alternatives to emerge, but also found ways to make significant alterations in their behavioral, cognitive, and learning ecologies. But does this mean that they also needed completely new physical structures in their brains?

The answer to this question appears to be a firm “no” at the moment. For one reason, a basic principle of natural selection suggests that the selection works towards *sufficiency*; in creating sufficiency, natural selection becomes efficient in preserving the traits that are working for individuals within a socio-ecological niche (Darwin, 1859/2009; Maynard Smith & Szathmary, 1997; Odling-Smee et al., 2003). By virtue of this principle, Dunbar (1998) pointed out that large brains do not evolve just because they can since “brains are exceedingly expensive both to evolve and maintain. The adult human brain weighs about 2% of body weight and consumes about 20% of total energy intake” (p. 180). By the same token, it could also be postulated that the evolution of new cognitive modules, just as the evolution of new brain structures, would be extremely costly.

⁹ It is as though we have used an old hammer to build a new hammer; or that we are housing a hammer in a hammer box that that hammer helped construct it.

For a second reason, comparative neuroanatomical examinations lend support to this sufficiency argument. Studies emerging from Deacon's (1997) comparative neuroscience lab showed that there are virtually no radical structural differences across chimp, macaque, and human brains – in fact, not even among other mammalian brains. Mammalian brains are architectonically and histochemically identical to one another (Deacon, 1990; Krubitzer, 1995). In layman's terms, they are identical in the organizations and placements of cortical structures and cell biochemistry. As examined by Krubitzer and Kaas (2005), the omnipresence of cortical areas such as "primary somatosensory area (S1), the primary visual area, and the primary auditory area (A1)" across mammals, as well as "their general geographic arrangement across species indicate that they were present in the last common ancestor and that they cannot be eliminated under most circumstances" (p. 445).

This examination points out that the enlargement of human brains did not mean the emergence of completely new cortical structures, lest a new kind of intelligence should be needed with, for example, the emergence and evolution of agricultural niches. The human brain has evolved without any radical structural alterations to the areas observed in a typical primate brain. As Donald (2002) also observed, "every structure we can describe in the human brain has an equivalent, or homologue, in the chimpanzee" (p. 111). We still possess the pre-existing primate cognitive modules; in fact, the hunt for new cognitive modules in the human brain in order to explain the alleged uniqueness of the human cognition has been in vain (Donald, 2002). Rather than evolving new structures or cognitive modules, the human brain has undergone radical renovations in pre-existing cortical structures and their neural computational associates, due in large part to the demands of symbolic language learning (Deacon, 1997).

Particularly, one of the most dramatic adaptations that brain structures had to undergo to accommodate symbolic language tokens were related to “cortical parcellations” (Deacon, 1990, p. 645). Deacon (1997) explained that these parcellations refer to functional subdivisions in the brain, and they occur when external selection pressures (e.g. symbol learning giving novel forms of semiotic structural frames to pre-existing socio-ecological complexity challenges) demand certain cortical and subcortical parts of the brain to grow disproportionately relative to its other parts. In that respect, Deacon (1997) argued that parcellation “is a zero-sum process in which enlargement of one structure only occurs at the expense of another” (p. 183), suggesting that “shifts in relative proportions will be translated into [cognitive] functional trade-off” (p. 222). A critical issue that most intelligence researchers in education have neglected is that one of the most dramatic parcellation effects that symbolic language occasioned in the human brain has been a decline of efficiency in information processing, sharing, and organization activities. Large brains such as those of humans are not necessarily energy-efficient or easily educable. Deacon (1990) elaborated:

In order to evolve significantly larger sizes brains must decrease connectivity. This trade-off undoubtedly has its costs. The most obvious costs of decreasing connectivity with increasing size are reduced integration of distributed functions and significantly increased transmission and processing times. Larger brains are not necessarily more efficient and more powerful than small brains. (p. 657)

Drawing on Deacon’s (1990) work, comparative neuroanatomist Lori Marino (1995) similarly observed that large brains’ inefficiency is linked not with “a *change* in function but simply a *maintenance* of function” (p. 125). If information-processing activities suddenly come

under greater demands, be it due to smaller socio-ecological challenges (i.e. relocation to new geography and climate and its unintended effects on human psychophysiology) or larger ones (i.e. having evolved as smaller group animals, now trying to adapt to a society whose population hit 7 billion), brains will need to match those demands by not evolving completely new structures, but instead either *expanding* or *contracting* certain cortical and subcortical areas relative to other brain regions¹⁰ (Deacon, 1997; Reader & Laland, 2002). This means specialization, especially when it comes to managing information and matching various learning strategies to establish a kind of domain-dependent information processing homeostasis – an issue that could be commonly observed among some engineering and medical professionals who tend to overspecialize within a single domain due to the sheer amount of technical topics need to be mastered. The energy costs of maintaining large brains vis-à-vis the demands of cultural niche construction in the present day could explain why especially in recent times, MTT too had to specialize in certain domains and grew considerably apart from the original function of theory-of-mind, compelling processed information, knowledge, and the resulting intellectual skills or cognitive processes to become increasingly divided, unrelated, or dissonant (cf. Gardner, 2006).

Consider the following example from an undergraduate student that took part in a study conducted by myself and the developmental psychologist colleague (Boyes & Parlar, 2013a; Parlar, 2014c). The student reported the following justifications when we asked her to reflect on her relationship with nature:

¹⁰ The very fact that the total mass of the brains of modern humans is much smaller relative to archaic humans provides some support to this contention (CARTA, 2015), suggesting that the information processing demands exerted on modern human brains are quite different than those exerted on archaic humans. For more information see <http://carta.anthropogeny.org/events/domestication-and-human-evolution>

[Moving to a place without nature] wouldn't be that difficult at all, because like I said, I'm not that attached to nature. I'd want to visit the mountains but that's about it...I don't have a very strong relationship with nature. I used to go out a lot to the park/biking/rollerblading but that's it...I'm really into rock climbing and going out to places like Banff or somewhere with a nice view of the mountains.

Note the discrepancy between the following three statements: (1) I'm not attached to nature; (2) I don't have a very strong relationship with nature; (3) I'm really into rock climbing and going out to places like Banff or somewhere with a nice view of mountains. The student is unable to recognize that the third statement contradicts the first two. The reason for this discrepancy in this student's cognitive process is more likely due to the effects of the specialization of human cognition to differentiated semantic-symbolic networks widely observed in our current cultural niches. In the case of this student, she is unable to relate her outdoor rock climbing activity to establishing a personal relationship with nature. It would be too costly for the individual brain to reconcile these two cognitive processes, when this discrepancy is deeply-seated and widely promoted by the current cultural niche. By the same token, specialization of MTT abilities in certain domains more than others make individuals unable to harness this ability when identifying and solving dynamic system problems in which many knowledge domains interact one another and coevolve.

2.3.3. The prefrontal cortex and the hippocampus

What are the underlying neuroanatomical and psychological factors that resulted in MTT ability to specialize in certain domains more than others? Was it a by-product of the total

enlargement of brain, or the enlargement of a specific part of the brain that cannot efficiently manage exponentially growing complex information networks in actively evolving symbolic cultures?

The prefrontal cortex appears to hold part of the answer here, as it has undergone significant changes in the past few hundreds of thousands of years. The prefrontal cortex is considered as one of the latest evolved parts in the hominid brain (Toga & Thompson, 2005). It is the powerhouse of symbolic thoughts where “prefrontal information processing will likely play a more dominating role in nearly every facet of sensory, motor, and arousal processes” (Deacon, 1997, p. 257). Equally important, the prefrontal cortex is not particularly associated with one type of activity; rather its several regions are connected with different brain structures (Bush & Allman, 2009; Deacon, 2009a). Therefore, prefrontal cortex cannot be treated as a “homogenous” entity (Deacon, 1997, p. 259). It could be better defined in terms of the kinds of complex relationships it has established with other brain subsystems, such as “more posterior brain regions” (Wheeler, Stuss, & Tulving, 1997, p. 334). The other part of the answer lies in the activity of the hippocampus. There is positive evidence showing that the hippocampus is responsible for the formation of episodic memory (Okuda et al., 2003) and is responsible for the formation of MTT activity in the human brain (Schacter & Addis, 2007b). However, neither part alone can be attributed as *the* part responsible for MTT. Rather, it is more helpful to think of MTT activity being co-regulated by both parts, and its flexibility and reach is dependent on the degree those parts function collaboratively.

Among the three structures that surround the hippocampus, the entorhinal cortex (EC) is determined as a key region that serves as the main boundary between the frontal lobe areas

and the hippocampal region (Insausti et al., 1995; Fyhn et al., 2008). Howard Eichenbaum and colleagues (2007) indicated that the EC, along with the parahippocampal cortex, also influences the formation of spatial reasoning process. In a way, it is helpful to think of the EC as the bridge responsible for creating temporal MTT corridors between the prefrontal cortex and the hippocampal region. It is in these temporal corridors where the conscious human agent is capable of warping spacetime mentally to access lived episodes of past and construct the episodes of future. In this corridor, the human agent deploys its symbolic ability to link semantic-procedural knowledge networks with lived or anticipated phenomenological experiences, enabling the formation of episodic memory as part of the declarative memory system, making recursive learning and learning by extrapolation possible. Tulving (2002) originally defined episodic memory as “a recently evolved, late developing, and early-deteriorating, past-oriented system” which “makes mental time travel through subjective time, from the present to the past, thus allowing one to re-experience, through auto-noetic¹¹ awareness, one’s own previous experience” (pp. 5-7). Tulving’s examinations demonstrated that episodic memory needs to be distinguished from semantic memory (i.e. fact memory) and procedural memory (i.e. skill memory), since retaining the particularities of *when, where, and what* (www) units are not always compatible with the impersonal facts that are being learned, for example, throughout our schooling career. Neither computing what 7 times 9 equals, nor reciting the function of iron in hemoglobin seem to require episodic recalling. Semantic memory would simply suffice for these tasks.

¹¹ In Tulving’s terminology, auto-noetic awareness (or auto-noesis) refers to the neurocognitive skill for experiencing time as recursive series of subjective events.

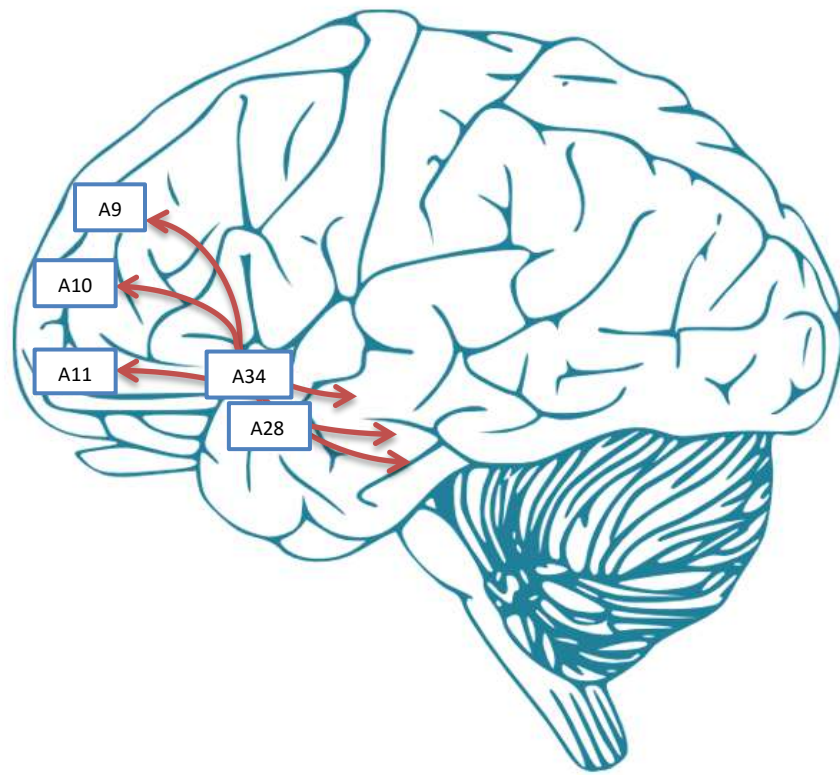


Figure 2.3. The hippocampus is surrounded by parahippocampal region, comprised of parahippocampal gyrus (enables memory encoding of particularly environmental scenes), perirhinal cortex (assists with processing of visual perception), and entorhinal cortex (the EC) (the chief “bridge” between the hippocampus and neocortex, influencing spatial reasoning). Brodmann Areas 34 and 28 comprise the EC, responsible for regulating information flow between the medial-temporal lobe, and prefrontal cortex areas including A11 (Orbitofrontal cortex), A10 (Anterior prefrontal cortex), and A9 (Dorsolateral prefrontal cortex)

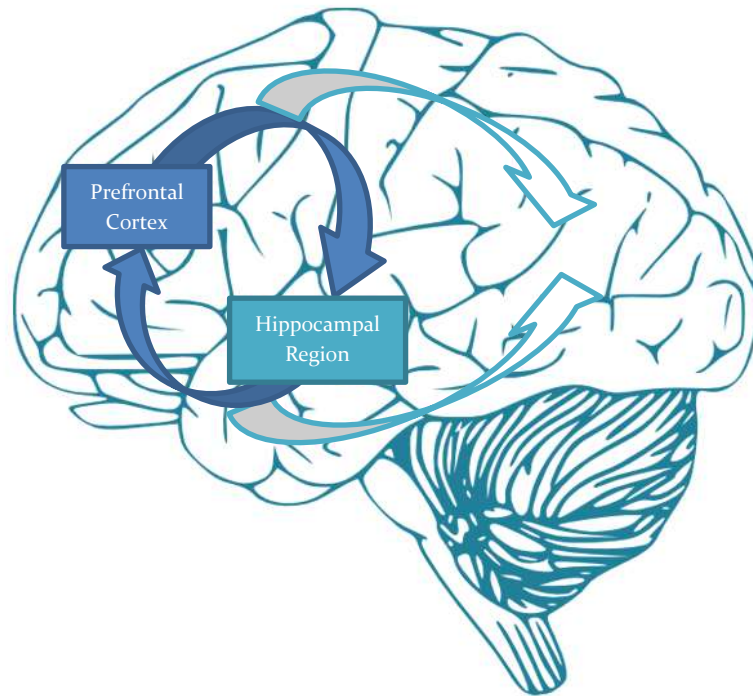


Figure 2.4. A depiction of a “front heavy” brain. Partly adapted from Deacon (1997).

Dark arrows represent the influence of the prefrontal cortex functions over the hippocampal region; whereas gray/white arrows depict the active influence of prefrontal cortex over other brain structures.

The real obscurity surrounding *which-memory-system-affects-another-in-what-ways* often shows itself in the case of patients with brain lesions. For instance, an experimental study that recruited three amnesiac children and administered various intelligence tests (such as Wechsler Memory Scale) showed that the damage that occurs in the medial-temporal lobe (where the hippocampus is located) results in “severe loss of episodic memory but leaves general cognitive development, based mainly on semantic memory functions, relatively intact” (Vargha-Khadem et al. 1997, p. 373). This experiment provided support for Tulving’s contention

that amnesia affects episodic and semantic memory discriminately. It later prompted Tulving and Markowitsch (1998) to conclude that “the hippocampus is necessary for remembering ongoing life’s experiences (episodic memory) but not necessary for the acquisition of factual knowledge (semantic memory)” (p. 198). However, Squire and Zola (1998) were generally unconvinced of the findings of Vargha-Khadem et al. experiment, instead, suggesting that it will be an amnesiac patient (i.e. complete hippocampal and parahippocampal damage) with additionally damaged prefrontal cortex area that will likely to establish whether or not episodic memory is affected separately from semantic memory.

Because of the complexity of the function of prefrontal cortex, the existing neuropsychological research on the separate and the intertwined functions of episodic and semantic memory systems tend to remain agnostic about the role of prefrontal cortex in increasing/decreasing the mnemonic activity associated with the hippocampus, and vice versa. What little focused ecological investigation done in this area pointed out that the executive functions dealt by the prefrontal cortex helps coordinate episodic projection into past events, including “anticipation, planning, monitoring, and structuring behavior toward future goals” (Wheeler et al. 1997, p. 335, drawing on Shallice, 1988). Since evidence is nebulous in regards to which parts of the prefrontal cortex is more strongly linked with which parts of the hippocampal and parahippocampal regions, it would be more prudent to use the analogy of temporal MTT corridors when understanding this complex link. For instance, if we agree that the prefrontal cortex enlargement has occasioned substantial connective alterations in between pre-existing frontal lobe areas and the hippocampus, we might be able to raise an argument against Clayton et al.’s (2003) conviction that Scrub-Jays have episodic-like memory;

indeed, they have. They have the hippocampus, and therefore, the ability to create basic forms of temporal MTT corridors. Natural selection allowed these temporal corridors to be formed adequately so that Scrub-Jays can remember the cached food and reap its long-term survival benefits. However, the formation of a true episodic memory is strongly linked with the presence of syntax-governed language in the species. The selection for MTT's flexibility and reach (read: its overall fitness) only makes sense if the traveller is able to explicitly communicate a past, present, and future episode or counterfactual situation in some syntax-governed form of communication. Only such form of communication can effectively specify, catalogue, or restore the particularities of when, where, or what events. It is more likely that subjective, lived experiences did not form a true episodic memory until symbolic language tokens allowed semantic-procedural networks to sample those experiences adequately and making them relevant to the species' socio-ecological niche construction pressures.

Scrub Jays do not possess forebrain areas that are as disproportionately enlarged as those seen in the hominid lineage whose cognitive evolution became definitively biased with the evolution of syntax-governed, autopoietic (i.e. self-organizing) protolinguistic forms (Bickerton, 2014). Their needs for MTT, including the ability to voluntarily sample learned lessons of past and learnable lessons of future is limited to the extent of their niche-building activities – which are extremely sufficient and conservative in comparison to actively evolving human socio-ecological niches. Therefore, Scrub-Jays do not need mindsharing cultures as we do. They have a kind of consciousness that is sufficient for them to become aware of where to gather food, to cache it, or to build a nest. In that regard, they need to be able to recall those “where” events. But they have never had to evolve a consciousness that is required to

anticipate the next moves of a niche-destructing hominid like us. Thus Scrub-Jays, although possessing a rudimentary form of MTT, do not possess the ability to spontaneously and voluntarily engage in mental representations of their own Scrub-Jayness, and become aware of *why* they exist in the first place, or what they could become in the future. On the other hand, we do, since we engage in mindsharing effortlessly; learning in our species walks in tandem with desperately seeking for validation of *what, where, and when* events that befell us from other members of our species.

Ultimately, it is because, as Deacon (1997) firmly put it, our brains (unlike the brains of Scrub-Jays) are “front heavy.” The prefrontal cortex “‘has more votes’ in whatever is going on in [other] regions of the brain to which it projects” (Deacon, 1997, p. 257). Thus it is not unlikely that the prefrontal cortex has more votes in the hippocampal area management as well. For instance, Deacon (1997) inferred that hypoactivity in the prefrontal cortex metabolism is often, if not always, associated with symptoms such as “schizophrenia, depression, Parkinsonism, and Alzheimer’s,” whereas, hyperactivity is associated with “manic states, panic states, and obsessive-compulsive disorders” (p. 422). If this inference is plausible, and the connection between the prefrontal cortex and the hippocampus is somewhat linear, then with decreased and increased metabolic activity, the unusually enlarged human forebrain is likely to respectively require limited and greater connective demands from the medial temporal lobe. Indeed, one experiment conducted by Williams and his colleagues (1996) lends some support to this inference, as they demonstrated that suicidally depressed individuals whose prefrontal cortex shows hypoactivity manifest episodic memory deficiencies. These deficiencies are marked with their reduced ability to reconstruct the particularities of past and future scenarios

they were exposed to. As Schacter and Addis (2007a) examined it, those deficiencies occurred when patients were “given word cues and instruction to recall an episode from the past or imagine a future episode” (p. 780). To what extent this prefrontal cortex hypoactivity (i.e. suicidal depression) could be linked with anomalies in the activity of the hippocampus, is currently anyone’s guess.

When examined individually, the hippocampus is similarly understood with respect to its connection with several other neighbouring or closely related cortical regions (Manns & Eichenbaum, 2009). The current research demonstrates that the hippocampus shows “increased activity when people construct and elaborate on both future and past events” (Schacter & Addis, 2007b, p. 332). In fact, during this event-construction process, right hippocampus is found to be more engaged than the left in the construction of future events (Addis et al. 2007). This led Schachter and Addis (2007b) to infer that “episodic simulation of future events involves an even more intense constructive process than does episodic remembering of past events” (p. 332). Indeed, Klein and his team’s (Veinott, Klein, & Wiggins, 2010) studies inferred that decision-makers, although having little struggle during retrospective risk assessments, appear to struggle more when they have to do a *project pre-mortem*, “the hypothetical opposite of post-mortem” which “comes at the beginning of a project rather than at the end, so the project can be improved rather than autopsied” (Klein, 2007, p.1). Future is harder to contemplate but not impossible – as Klein’s studies seem to show, this is an area that our computing inefficient large brains can do better if educated properly.

Further evidence for the formation of temporal MTT corridors between the prefrontal cortex and the hippocampus also emerges from the studies on insight problems. For instance,

Luo and Niki (2003) asked Japanese participants to complete a riddle task whilst being imaged with fMRI. Upon indicating that they could understand the presented question participants' hippocampi became activated. When participants were given the answer and indicated that they could understand the answer, hippocampal activity decreased from baseline. They offloaded neural control from episodic memory to semantic-procedural memory, decreasing hippocampal activity. This suggests that when forming novel associations (read: insight) the hippocampal area is engaged more than the other parts of the brain. It could be that this is because during the struggle to form novel associations, participants are engaged in MTT, laboring at the task of recalling the particularities of previous associations, and making them relevant to the construction of future events. If we recall Schacter and Addis's (2007b) evidence showing that the right hippocampus is more engaged in the construction of future episodes, it is possible that during an insight moment, participants formed novel associations in anticipation of its future outcome. This suggests that insight production is in principle a future-oriented, foresightful behavior.

From an evolutionary perspective, it is unsurprising that when participants make novel syntactic associations their hippocampal area is engaged. As Deacon (1997) argued, a resulting enlargement and hyperactivity in forebrain areas requires greater processing needs from areas such as the hippocampus, depending on the domains of external symbolic needs – a point that is also indirectly corroborated by Wheeler and his colleagues (1997). Indeed, as I mentioned previously, we engage in MTT in certain domains (e.g. running a small, private business, parents educating their children) more extensively than we do in other domains (e.g. managing our food, water, and natural resources; controlling population growth; prioritizing the preservation

of biodiversity for future generations of humans and nonhumans). Here the former domains are something we can exert some individual control over and do a better job; whereas, in the latter domain, because the individual control is often offloaded onto the memory of experts and their social institutions, they have (unfortunately) become domains where we scarcely engage in MTT – even less, when it comes to *behaving* foresightfully/prudentially. They are not the domains with which we engage actively during formal schooling or through lifespan, unless we are educated to do so in domains such as risk assessment, system design, engineering, and organizational planning.

2.3.4. The flexibility and the reach of mental time travel

The MTT corridor analogy could be the right term to explain how symbolic language made this ability increasingly flexible and domain-dependent. However, episodic memory is not the only memory system that MTT possible. The neuroarchitectonic corridor between the prefrontal cortex and the hippocampal region suggests that the ability to harness MTT when identifying and solving the practical problems of a species is contingent on the healthy combinatorial function of both semantic-procedural and episodic memory systems (see also Martin-Ordas, Atance, & Louw, 2012).

There are disagreements on whether or not episodic memory predates semantic memory as part of declarative memory suite (Donald, 1991; Tulving, 2002). But the fact that symbolic language and thought enabled human brains to rematerialize episodic images of past through words and syntax suggests that the formation of episodic memory system is contingent upon a priori symbol recognition. We needed to have the socially convened (read: symbolic)

images, icons, depictions, and words to be able to sample and retain the particularities of experienced episodes. The reason why none of us can remember *when* we started uttering the first words (e.g. childhood amnesia) is a clear sign of this chronological order of evolutionary sequence (Conway, 2005; Nelson, 1992; Perner & Ruffman, 1995). Moreover, Tulving is correct with his claim that episodic memory is an early deteriorating memory system. Studies have consistently reported participants' false memories pertaining to an event (Roediger & McDermott, 1995, in Suddendorf & Corballis, 2007). Where semantic memory/knowledge networks are constituted by virtue of cumulative linkages between word sounds and experiences, episodes occur only once and the semantic details embedded in those episodes can be easily forgotten (Deacon, 2013). Episodic memory is thus both evolutionarily and developmentally more fragile than semantic-procedural memory systems – a point that justifies why MTT tasks should be devised to strengthen student's episodic memories and enable them to use this memory system more efficiently in their ecological problem identification and solution tasks.

In terms of cultural evolution, the role of episodic memory similarly cannot be understated. Through inventing external symbolic storage (ESS) tools and technologies (Donald, 1991), we found ways of reliving, retaining, and learning from those episodes via its relations to symbolized cumulative cultural objects, including pictographs, paintings, photos, caricatures, videos, musical tunes, as well as various mnemonic devices frequently used in formal education. This must give us another clue to why in the modern world MTT ability has underdeveloped in certain domains of experience and had increasingly lesser impact in the formation of other types of cumulative symbolic culture. As an example, industrialized cultures

have grown increasingly sophisticated in financial forecasting, people management, and technological sophistication and pervasiveness. These items currently constitute a centripetal force where an individual's total amount of daily mental energy is inclined due to the selection pressures of industrial-urban niches on cultural evolution. In effect, individuals have not developed sufficient finesse, knowledge, or skill in the following areas:

- Foresightful/prudential management of natural resources,
- Protecting natural ecosystems for long-term psychological and cultural needs,
- Collaborative and adaptive problem identification and solution as applied to dynamic system problems (also known as complex adaptive systems).

This energy allocation problem could be quantified by educational researchers through new techniques in near future in order to understand how the mental energy devoted to learning could be directed to the abovementioned domains. However, even without quantification, it could be inferred by observation that the industrial societies have forsaken building cultures based around issues such as long-term environmental stewardship (Kidner, 2001). The underlying suggestion here is that MTT ability could be deliberately harnessed to enable stronger associative-recursive learning, semantic detail retention, and motivation cultivation in the examination of distinctly ecological problems with broader ramifications on human and nonhuman welfare. Picture the long-term psychological, physiological, technological, and cultural evolutionary corollaries of an education system that gravitates around training students to retain hundreds of subtle semantic and episodic details in the natural ecosystems! Such has been the way of hunter-gatherer societies where adults direct the young people's mental and physical energies towards mastering the details of their

surroundings due its long-term benefits for the group's survival. The result of this pedagogy was the cultural experience of greater periods of ecological sustainability.

Episodic memory appears to play the role of a catalyst in the human brain that enables individuals to identify complex ecological problems, as it helps them remember the details and particularities of the problem being identified and solved. Without episodic memory, no MTT occurs; no MTT, no problem identification and solution in dynamic events where topography/geography and time specificities play a key role in the culmination of problems. Due to its immense flexibility potential, MTT, as it turns out, is one of the most vital cognitive traits required to produce simple and yet compelling insights into dynamic system problems, whether it is a social, political, or an environmental one.

Although a working relationship between semantic and procedural memory does not necessarily call for language to be present, episodic memory does. The ability to recall and retain the particular details of past episodes and conceive future episodes by virtue of projection, prospection, ramification thinking is an *a priori* requirement for engaging in offline thinking. Nonhuman animals that do not use vocal communication are evolutionarily unprepared to harness episodic memory to make an effect in their lives as we do with our technologies, precisely because they do not have vocal communication units – words and syntax – to plot them into a plan or blueprint. They need not learn from past mistakes and plan for interventions to prevent ecological collapse. They have never needed it.

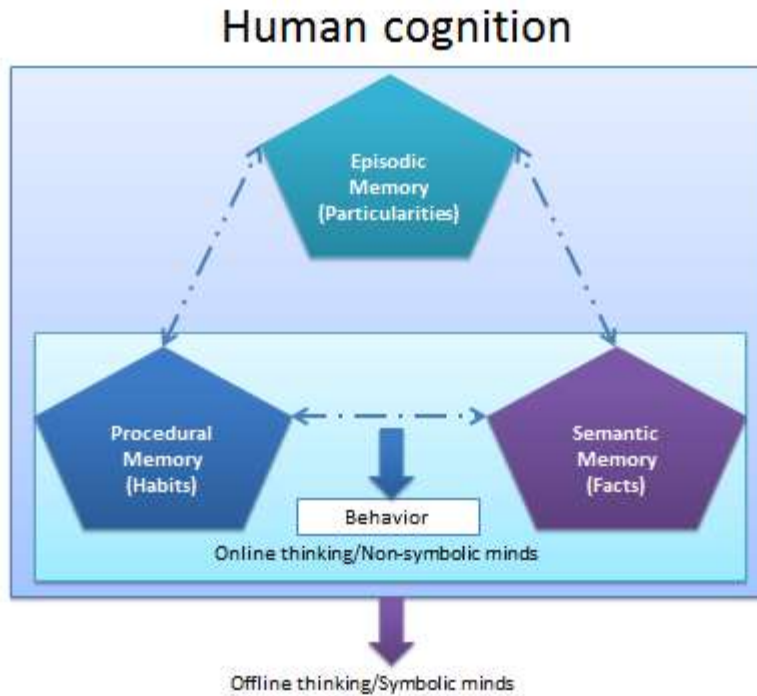


Figure 2.5. An imagined model of offline and online thinking and their effects on human memory systems.

A strong argument can be made that language had a definitive impact on allowing MTT to extend its reach and flexibility in *Homo sapiens*. It is more plausible that episodic memory was not a memory system until the emergence of symbolic language ability, which allowed our ancestors to self-trigger their past experiences, bring them to *here-and-now*, and make those experiences interact with their regular procedural/semantic memory networks. It was thanks to language that by merging these two memory systems, we were able to tap into a *conceptual* space where most of our novelties have their beginnings, and continued to change our behavioral, cognitive, and learning ecologies at a pace that would be considered unusual from an evolutionary perspective. The advent of material culture beyond our basic needs was thanks to this conceptual space. The capacity to engage in mimetic rehearsals, thinking outside here-

and-now, and effectively detach thinking from behavior is an unpredictable consequence of symbolic language taking over all aspects of human cognition which Deacon (1997) captured as “leveraged takeover.” In taking over, symbolic language virtually *plugged* episodic memory into semantic/procedural memory networks, allowing its human users to freely extend their MTT abilities in both directions of the spacetime continuum.

Suddendorf and Corballis (2007) wrote that “mental time travel is evident in voluntary behavior that solves a problem that the organism will encounter a future point in time, where ‘future’ entails that the problem is not already manifest (as when acting to satisfy hunger)” (p. 302). The reverse is also true: MTT is also evident in both voluntary and involuntary behavior that solves a problem that the organism *has* encountered in the past, where “past” entails the problem is either manifest, or diffuse, buried under layers of succeeding knowledge and information. This is what constitutes a basis for foresightful/prudential thought. Symbolic language, for all its drastic changes in the human brain, has only recently begun to strengthen our episodic memory recall. The emergence of external symbolic storage systems (ESS) such as books and computer hard drives was therefore not a coincidence, as they were invented to bolster our insufficient episodic event recall. But we still have a tendency to remember things differently; we routinely suffer from false memories. We routinely encounter false information, knowledge, and falsely scaffolded or constructed understandings throughout our schooling career. An unfortunate ramification of this effect is *environmental generational amnesia* which refers to the phenomenon that

with each ensuing generation, the amount of environmental degradation can and usually does increase, but each generation tends to take that degraded condition as the nondegraded condition, as the normal experience. (Kahn, 2011, p. 165)

According to developmental scientist Kahn (2011), environmental generational amnesia occurs because “we plain construct mistaken understandings of what counts as a healthy, vibrant, life-sustaining natural world, and we do not receive enough discrepant information to make it easy to correct our mistaken understandings” (p. 175). But it could also be interpreted as a failure to engage young people with limited MTT tasks in regards to long-term environmental stewardship or long-term ramifications of anthropogenic environmental change. In that sense, Kahn’s hypothesis essentially points out a problem endemic to episodic memory, which only formal education could systematically address.

The upshot of this situation is that because of symbolic language, MTT ability can be made more flexible just as its reach can be extended in the appropriate knowledge domains. Indeed, the suggestion here is that this ability could be harnessed to cultivate a foresightful/prudential application of general intelligence in ecological problem identification and solution. This requires training students for a special form of consciousness that MTT allows us to cultivate and advance – a topic that will be examined in the next chapter.

SYNOPSIS 2B

- Cognitive neuroanatomical continuity hypothesis (if it could be stated) suggests that there are no structural differences among mammalian brains. Human brains are primate brains whose *ecology* was substantially altered with the complex evolution of symbolic language and culture. Due to the preservation of a conservative hippocampal region across species, our MTT ability is functionally the same as those experienced by a chimp and Scrub-Jay – the only difference is that these nonhuman animals do not *need* to perform this ability beyond what is necessary for them. Human beings, as the species governed by the effects of autopoietic socio-ecological niches, became increasingly more dependent on harnessing MTT. These niches are inherently unstable and unpredictable, having occasioned unintended consequences for the future of the planet and biodiversity. The lesson deriving from this point is that although the brain is unlikely to evolve to correspond to these needs, education *can* and *must* evolve to engage human brains to perform robust forms of foresightful/prudential reasoning in pressing domains of inquiry such as long-term environmental stewardship.
- As in Donald's (2013) terms, the human brain is born ready to be plugged into the symbolic network we constructed over the past few hundred thousands of years. However, could this tendency be societies' Achilles Heel, as seen in their inability to combat climate change, anthropogenic environmental change, or succumbing to psychologically and physically oppressive political systems and religious doctrines? What is, then, the role of education in combating this evolutionary weakness?

Chapter 3: Foresightful/prudential intellect: Conditions and markers

Intelligence is not only the ability to reason; it is also the ability to find relevant material in memory and to deploy attention when needed.

Daniel Kahneman, 2011, p. 46

3.1. Introduction

Intelligence is one of the most tortured subjects in education and is often strongly associated with testing and measurement. For most of the 20th century, advances in this area have conservatively expanded on Alfred Binet's intelligence quotient (IQ) psychometric tests. Only in the last few decades psychological scientists began to reconsider the criteria for defining and measuring this construct in ways that do not restrict it to psychometrics. As it is well known to educationalists, a prominent researcher in this treacherous field is Howard Gardner (1983, 1999) who proposed the theory of multiple intelligences (MI) as an alternative to the psychometric measurement trend. More recently, notable attention has also been given to the application of evolutionary psychology and comparative psychology in redefining intelligence (Sternberg, 2002). Although these theoretical investigations captured the necessity to study and support the development of intelligence from a thoroughly Darwinian perspective, the role of MTT in the formation of a foresightful/prudential general intelligence remains an empirically and conceptually underexplored territory.

The previous chapter established that future-oriented reasoning and behavior inevitably utilizes MTT as the chief cognitive faculty, with episodic and semantic-procedural memory

systems, the prefrontal cortex, and the hippocampus as the chief neuropsychological actors. Informed with these components, this chapter constructs a new type of educational frame that could be called *mental time travel based learning* (MTT-based learning). The goal of this frame is to harness the MTT ability from early stages of childhood as a measure of enhancing capacities for foresightful/prudential reasoning and action. This frame could be utilized when students engage with their science, technology, engineering, and mathematics (STEM) curriculum topics – with science and environmental education being the most prominent domains of application.

Although we use our MTT abilities when identifying various problems in the complex domains of the world of adults, the true potential underlying this cognitive faculty can be cultivated if curriculum topics draw students' attention to how, where, and when to think evolutionarily and pragmatically about the long-term sustainability of natural ecosystems and resources, or the planetary consequences of the current human decision-making and behavior, or the direction of human cultural evolution on those phenomena.

With these broadly intertwined goals running in the background, we must necessarily open a conversation on the development of a different type of intellect, along with educating or training students for a special form of consciousness that MTT-based learning can allow them to cultivate and advance. Before dealing with this area specifically, we must first examine the existing issues in the educational study of intelligence and determine the place of foresightful/prudential intellect among them.

3.2. Current definitions of intelligence

The emergence of intelligence as a construct for educational measurement dates back to the early 20th century. Although the history of how this measurement system developed is complex and nuanced, two well-known concepts generally drove the literature: the intelligence quotient (IQ) (Binet & Simon, 1909/1976; Stern, 1914) and general cognitive ability factor (*g*) (Spearman, 1927). Over time with the movement away from Gestalt psychology towards the information-processing view of cognition, the foci of intelligence tests turned their attention to understanding how fast and efficiently learners process and organize information. Accordingly, *g* is defined as “the capacity to rapidly and fluidly acquire, process, and apply information,” involving “the performance of higher mental processes including reasoning, remembering, understanding, and problem-solving” (Gully & Chen, 2010, p.9). Other intelligence researchers reported that *g* is a succinct benchmark of working memory that underscores the information processing activities in the prefrontal cortex and positively correlates with a species’ total brain size (Reader & Laland, 2002; Toga & Thompson, 2005).

In educational psychology, Robert Sternberg (2002) argued that psychometric tests of intelligence, such as the IQ tests, are developed on a basis of measurement without a priori formulation of an empirically demonstrable theory of intelligence. Atran (2015) critically examined that the construct of IQ

thoroughly confounds domain-specific abilities – distinct mental capacities for...
geometrical and spatial reasoning about shapes and positions, mechanical reasoning
about mass and motion, taxonomic reasoning about biological kinds, social reasoning

about other people's beliefs and desires – which are the only sorts of cognitive abilities for which an evolutionary account seems plausible in terms of natural selection for task-specific competencies. (p. 15)

Where IQ tests offer quick results and supposedly authoritative analyses for pragmatically-driven educational agendas, the absence of a scientific theory of intelligence underlying this testing and measurement attitude inevitably makes it difficult to sustain those tests as reliable tools for assessing students' learning and developmental potential. Against this backdrop, Sternberg frequently employed the biological adaptationist view and defined intelligence as an individual's psychological ability to adapt to the environments they find. More recently, Bickerton (2009) expanded upon this view and argued that the development and specialization of intellectual abilities co-vary with constructed socio-ecological niches. Human symbolic language and culture-based niches often determine the types of cognitive skills and levels of information processing abilities required to do tasks or invent or adopt technologies that are well-suited for cultures and geographies where those individuals grow up.

In cognitive psychology, intelligence has recently been linked with the metacognitive ability, especially, with self-regulation and increased attention. Metacognition refers to the ability to self-control and self-monitor one's cognitive processes and learning progress (Brown et al. 1983). It is also associated with planning for goal achievement (Ford et al., 1998). In addition, Veenman and Spans (2005) observed that metacognitive skill is more prognostic of successful learning retention than traditional intelligence measures. A multi-methodological study conducted by Rueda and colleagues (2005) also lends some support to the association between metacognitive skill and general cognitive ability. In this study, researchers trained

children of four to six years of age for attention and emotional control and administered the Kaufman Brief Intelligence Test (KBIT)¹² (Kaufman & Kaufman, 1990) before and after the intervention. The results of the study showed enhancement in children's nonverbal intelligence scores, establishing a positive correlation between executive attention and general intelligence. Educationally, the results of this study suggests that there may be more benefit in training students for self-regulatory knowledge (Bell & Kozlowski, 2008), namely, "the ability to reflect, monitor, and control one's own behavior" (Gegenfurtner, 2011, p. 154). Seen from this perspective, it could be that foresightful/prudential intellect is in part linked with the ability to exert cognitive control and self-regulate or restrain one's behavior.

3.3. Gardner's Multiple Intelligences

In education, there has recently been a surge of interest in Gardner's theory of multiple intelligences (MI theory). As opposed to psychometric tests favoring the measurement of cognitive performance, MI theory reframed intelligence with respect to various psycholinguistic and psychophysical adaptation domains, having been subsequently introduced as a developmental goal of formal schooling (Gardner, 2004; Gardner & Hatch, 1989). In its core lies an account of intelligence not as a testable cognitive performance, but "a biopsychological potential to process information that can be activated in a cultural setting to solve problems or create products that are of value in a culture" (Gardner & Moran, 2006, p. 229). Although MI theory also relies on an information processing view of cognition and a biological adaptationist view of intelligence, Gardner devoted more attention to addressing the insolvent problems

¹² Researchers administered the non-verbal section of the KBIT.

occasioned by the testing and ranking cultures of formal education by construing his theory as an educational theory.

Gardner initially introduced seven intelligences: (1) logical-mathematical; (2) linguistic; (3) musical; (4) spatial; (5) bodily-kinesthetic; (6) intrapersonal; and (7) interpersonal. Later on, he (1999) added the naturalistic intelligence, pointing Charles Darwin and E. O. Wilson as exemplars of this category, since they “are keenly aware of how to distinguish the diverse plants, animals, mountains, or cloud configurations in their ecological niche” (Gardner, 2006, pp. 18-19). In some popular sources, naturalistic intelligence has been associated with Wilson’s (1993) biophilia (e.g. Louv, 2008), and with the ability to contemplate human-nature relationships holistically (Morris, 2004). However, naturalistic intelligence does not necessarily refer to Wilson’s biophilia, the partly genetic, partly culturally-modified propensity to preserve protracted contact with natural ecosystems. Gardner (2006) argued that naturalistic intelligence refers to an ability to catalogue objects as a way of producing transferrable knowledge of object diversity. In the modern world, this ability is extrapolated in the selection and categorization of the semantic details of organic and synthetic objects or abstract phenomenon based on their colors, magnitude, symbolic image, quantity, vector, and so on. Finally, Gardner (2009) also considered the possibility of *existential intelligence*, “the intelligence that generates and attempts to clarify the biggest questions about human nature and human concerns” (p. 6).

Educational researchers reported success stories upon a degree of systematic implementation of Gardner’s frame (e.g. Weller, 1999; Hoerr, 2003; Shearer, 2004; Chen, Moran, & Gardner, 2009), or were at least willing to consider the relative merits of strategizing

formal education via MI theory (Armstrong, 1994; Chen, 2004; Weber, 2005). However, MI theory has not received sufficient attention and support from psychological scientists prone to using controlled experiments, neuroimaging, psychometric tests, and rigorous theoretical and conceptual models. Lynn Waterhouse (2006) is notable with her criticism that MI theory fails to delineate an account of human intellectual development that is consistent with the theories, methods, and established empirical evidence on the evolution and function of human cognition known from evolutionary psychology and cognitive neuroscience. In response to Waterhouse, Gardner and his colleague Moran (2006) sustained that MI theory flags a different entry point to intelligence that confronts the negative psychosocial ramifications of the educational testing culture, thus requiring different methodologies and theoretical sensibilities.

The exchange between Gardner and Waterhouse epitomizes why intelligence is a sensitive topic in education. In addition, this exchange has also resurfaced several conceptual and empirical problems that were routinely papered over due to the complacency and lack of evidence-based research endemic to the 20th century educational research (see again, Wolfe & Poynor, 2001; Slavin, 2002). It is therefore important to examine this exchange here before developing a new way of understanding intellectual development induced by MTT-based learning.

Waterhouse's critical examination of the MI theory could be illustrated by way of three key domains: Philosophy of science, methodology, and applicability.

3.3.1. Problem 1: Philosophy of science

According to Karl Popper (1963), strong scientific theories need to establish validity by virtue of withstanding falsifications that attempt to compromise its “confirming instances everywhere” (pp. 34–35). It is the underlying rationale behind ‘hypothesis testing’ that many factual investigations regularly employ; whereas for historicist Thomas Kuhn (1962), a strong scientific theory makes itself evident when it threatens to overthrow the dominant settlements in pre-existing ways of understanding, interpreting, and practicing scientific knowledge. In Kuhn’s terms, this meant *paradigm change*.

Although Popper and Kuhn are often thought as counterpointing one another in how scientific investigations need to be done, they diverge on the grounds of *which* part of epistemic element must take priority. For Popper, it was hypothesis testing, and thus empirical/factual investigations; for Kuhn, it was conceptual (grammatical) investigations of pre-existing theories and empirical findings, through which scientific researcher is responsible in creating a noise in the practice of normal, status-quo science.

Waterhouse’s approach is part Popperian, part Kuhnian. For instance she (2006) argued that MI theory does not satisfy the criteria set forth by Popper, due in large part to the absence of the empirical validation issue. Because intelligence is understood as a construct in psychological science, Waterhouse (2006) argued that, just as any other psychological construct, multiple intelligences must be subjected to empirical examination using controlled experiments. In that sense, multiple intelligences should be substantiated via further research, especially “if they have clearly specified testable components” (p. 209). Drawing on Allix’s (2000) previous criticism to Gardner, Waterhouse (2006) furthered that “even if Gardner were

to generate testable components, the validity of individual intelligences still could not be explored because Gardner has not specified the functional links he has theorized to exist between the intelligences” (p. 209). Finally, Waterhouse argued against Gardner’s claim that MI theory is much better in accounting cognitive profiles of students, gifted individuals, and those who work in special professions than how IQ subtest scores portray them. She maintained that there is no empirical evidence that shows otherwise. MI theory should not be compared with IQ subtests, since doing so would be similar to taking two different approaches to the study of intelligence and reaching radically different conclusions about the very construct.

3.3.2. Problem 2: Methodology

The second line of criticism seen in Waterhouse’s conceptual examination of MI theory is the lack of support emerging from neuroimaging methods and evolutionary psychology’s adaptationist framework for MI theory (see also Tooby & Cosmides, 1992). Gardner is well-known with his opposition of the IQ test factor (Spearman’s *g*) in quantifying an individual’s general cognitive ability; whereas, Waterhouse (2006) showed that there may virtually be no difference between *g* and Gardner’s (1999) “Central Intelligences Agency” as the base of an individual’s intelligence since both factors are associated with activities in the prefrontal cortex. Therefore it is imprudent to claim that MI theory is not necessarily compatible with *g*, or those intelligences cannot be tested via psychometric methods gravitating around the measurement of *g*. Furthermore, as Waterhouse (2006) pointed out, cognitive neurosciences do not show a picture of divided brain or intelligences as Gardner (1999) routinely suggested. Drawing on evolutionary psychology, Waterhouse (2006) additionally argued that the theory of adaptive

cognitive modules lend support to why the human brain's problem-solving skills has undergone significant changes in the modern world, but did not structurally differentiate from those of archaic human beings, therefore concluding that the "human brain is unlikely to function via Gardner's MI" (p. 213).

3.3.3. Problem 3: Applicability

According to Sternberg and Grigorenko (2004), one reason why many children do less than jobbing average at a developmental level where others can do fine (and sometimes above average) is linked with teaching and assessment not enabling those less adept children "to learn and perform in an optimal way" (p. 274). This problem is noticed by Gardner (2006), epitomized in his argument that the cultures of education need to move from sophisticating ranking and testing measures towards sophisticating sensible and democratic ways of assessing a student's varying degrees of accomplishments. This shift from ranking-testing towards assessment sophistication is a cornerstone of MI theory's application decree. On the other hand, Waterhouse (2006) insisted that without setting up control groups that can help justify whether or not intelligence can develop in a fashion that Gardner suggests, it is likely that

some MI applications have been successful by serendipity, that is, they have induced improved learning because, coincidentally, some aspect of that method was effective independent of the MI framework of the applications. (p. 209)

Waterhouse argued that the application of MI theory is driven by initial excitement and enthusiasm to make positive changes in education, not by positive evidence in intelligence research that illustrates variations among the intellectual abilities due to the diversity of human

genetic heritage (Kovas, Harlaar, Petrill, & Plomin, 2005) and the total brain volumes (McDaniel, 2005). Furthermore, Waterhouse (2006) considered that there are three chief reasons why MI theory is excessively fashionable and remains scientifically uncredited. Drawing on Shermer's (1997) work, Waterhouse (2006) detects three core social cognition challenges prevalent in education that deny investigations on MI theory:

[C]redo consolans, an unproven idea may be comforting if it predicts a good outcome, makes us feel powerful, or makes us feel in control; *immediate gratification*, an unproven idea may be attractive if it offers instant solutions for difficult problems; and *easy explanations*, an unproven idea may be accepted if it offers a simple story about something that is difficult to understand. (p. 219)

Waterhouse argued that MI theory in fact “provide[s] a *credo consolans* for educators because each offers the promise of control over a complex and invisible process – the act of learning – and each predicts a good outcome for students if applied in educational practice.” (p. 219). Secondly, MI theory “also suggests the possibility of the immediate gratification of a quick solution for a difficult problem” (p. 291). Indeed, says, Waterhouse (2006), MI theory appears to suggest that “if we each have eight different intelligences, just teach all the eight intelligences and students’ varied learning problems will be addressed” (p. 209). Thirdly, Waterhouse finds MI theory unreasonably popular since it “offers the easy-to-understand explanation that cognitive processes are divided into separate intelligences, each defined simply by the content that it learns and processes. Thus, MI theory adherents can believe that they understand the way cognitive functioning is organized in the brain” (p. 219). The ultimate

promised reward of MI theory is thus “more effective teaching” as well as “an easy-to-understand model of cognition” (Waterhouse, 2006, p. 220).

Based upon these assessments, Waterhouse concluded that MI theory’s application may in fact be more harmful to education in the long run despite its short-term benefits, especially if it is being taught to pre-service teachers whose “beliefs about how students learn are strongly influenced by their educational training” (p. 221, drawing on Hofer, 2002). She cautions that teaching MI as a universal fact or scientifically-attested theory would “damage teachers’ epistemologies of the learning process itself” (p. 221) since they then will not be acquiring an empirical picture showing the complexity of how human cognition evolves and develops.

3.4. Other ways of assessing intelligence

An examination of the previous and current applied research on intelligence shows that there are large numbers of constructs, abbreviated processes, and phenomena that attempt to explain motivational, attentional, and neurological processes underlying human cognition. These constructs and processes offered are often motivated by a search for a constant individual difference variable that could successfully establish the intellectual differences between two people, or by a search for a measurement that captures an individual’s potential to learn new competencies. Especially, due to growing discontent and concern with psychometric testing (Kozulin, 2005), learning potential researchers offered more than one way to study individual differences, such as Vygotskian dynamic assessment model that intertwined assessment with mediation and intervention (Lidz, 1987; Sternberg & Grigorenko, 2001a, b, 2002; Lidz & Gindis, 2003). On the other hand, for the majority of 20th century, psychometric

intelligence testing (and similar devices for testing cognitive performance) remained intelligence researchers' favorite methodological choice. One chief reason for this choice is that they are easier to administer, economically viable, and make conclusive statements about human intelligence, thus facilitating the ranking and slotting of students throughout their schooling careers. In that sense, these tests are utilized as a crowd-control measure. However, the scientific rationale underlying these tests and methodological correlates are substantially diluted primarily because they eschew the dynamic evolutionary ingredients underlying the differentiation of intellectual abilities with respect to culture, language, geography, and climate. Equally clearly, psychometric tests are not prescriptive of general intelligence, nor are they able to measure the changing morphology of human intellectual abilities due to cultural evolutionary selection pressures occasioned by technological advances, globalization, and anthropogenic environmental change.

A visible trend developing since the last quarter of 20th century is that anyone who scientifically investigates intelligence needs to remain agnostic about advocating for a universal measure so as to avoid unwarranted socio-political repercussions. Naturally, the attention instead has turned to measuring individual differences via piecemeal empirical approaches, which led to the formulation and interpretation of various constructs and abbreviations that spotlight contextual learning as determined largely by cultural-linguistic factors. On the other side, although MI theory is a promising route to rethinking how intelligence develops due to gene-culture coevolution processes, it sacrifices theoretical rigor in favor of remaining pragmatic and accessible to lay person. If we consider MI theory as an attempt at reculturing education towards assessing learning and enfranchising those who did not particularly excel at

mathematical problem solving, then it may be considered valid and necessary in its own right. But some educational psychologists' main problem with MI theory appears to be linked with calling those eight constructs *intelligences*. For instance, Messick's (1992) analysis of Gardner's work showed that multiple intelligences are hierarchical prioritization of cognitive tasks that are associated with working memory, and therefore the constructs formulated by Gardner are multifarious aspects of the general intelligence factor, not separate intelligences. This point coincides with the Neo-Piagetian perspective of intelligence where working memory competences, information processing vis-à-vis domain specialization, metacognition, and cognitive governance walk in tandem under the rubric of general cognitive potential (Demetriou & Raftopoulos, 2005; Demetriou, Mouyi, & Spanoudis, 2008). Although Gardner (2006) frequently argued that his intelligences interact with one another (or inform one another), the Neo-Piagetian perspective, including those studies that illustrate the human brain evolution, suggest that the MI characterization of intellectual development does not warrant a status of distinction. Equally clearly, one must wonder to what extent the root-cause of MI theory's disputed scientific premise among psychologists of intelligence is a "semantic" one.

There are a number of reasons why Gardner's multiple intelligences do not receive enough attention from the psychologists of cognition, learning, and motivation. MI theory compartmentalizes intelligence into eight domain-specific competencies (and even more domains are found according to Gardner's recent advances) that can be fostered by curriculum and instruction. This perspective has a tantalizing effect among intelligence researchers in that it blurs the conventionally accepted differentiations between intelligence, ability, and skill. As a result, multiple intelligences are rendered incapable for assessment via the traditional research

methods of psychological science, especially, the experimental design. Indeed, Gardner and his colleagues bolstered the defence for MI theory by suggesting that it will require a distinctly interdisciplinary empirical research framework (Davis, Christodoulou, Seider, & Gardner, 2011).

As Gardner and Moran (2006) also emphasized:

An MI approach demands a change of minds among researchers and educators: it requires an interdisciplinary perspective, cultural sensitivity, and an interactionist-dynamic research methodology... The advantage of this approach is that it better explains the wide variety of “intelligent” performances among children and adults depending on the level of training, context, culture, and innate predisposition. An MI approach better addresses the incongruities and imbalances of intelligent behavior not only between individuals but also within individuals. (p. 228)

In my analysis, there are two things to consider in regards to MI theory. First, although, Gardner (2009) pointed out that one criterion for intelligence should be that it needs to have an “evolutionary history and evolutionary plausibility” (p. 5), it does not devote sufficient attention to the role of language in the shaping of human cognition, brain, and memory systems.

Reference to the distinction between declarative (verbalized) and non-declarative memory recall and prospection efficiency and their respective effects in intellectual development is currently virtually absent in the framework of MI theory and needs to be developed.

Furthermore, as I demonstrated in Chapter 2, the evolution of symbolic language was a key turning point in human niche construction activities to an extent that it radically altered the neural-computational architecture of the human brain. Remembering Deacon’s (1997) earlier remark, the human prefrontal cortex – responsible for working memory – is significantly

inefficient in information processing capacity due to the total enlargement of the forebrain areas by symbolic language learning pressures. The predominant role of language in the shaping of human intellect brings us to the second consideration, that is, symbolic language and thought is integrated into every aspect of human cognition and working memory, including the processes that influence musical ability, spatial reasoning, and kinaesthetic competence as soon as children spontaneously manifest symbol recognition, theory-of-mind competence, and indeed, mental time travel. From this perspective, to say that there could be something called linguistic intelligence is a prima facie contradiction to the co-evolutionary and co-developmental ratchet effect between symbol learning and prefrontal cortical enlargement. One could thus argue that symbolic language and thought is what intelligence is all about in *Homo sapiens*.

But even though Gardner's MI theory withstands so much criticism and passes many roadblocks three decades after he first proposed MI theory, it needs to be able to work well within the extended evolutionary framework that is niche construction theory. The connection between the formation of multiple intelligences and the evolutionary-developmental effects of ecological inheritance mechanism (of niche construction) on the active formation of intellectual capacities are yet to be explored. Equally clearly, MI theory, or any theory of intelligence currently on offer, does not take into account the compounding unpredictable associations between continuously growing human cultural needs, technological sophistication and pervasiveness, and their overall impact on the shaping of intelligence. From this perspective, it is more likely that multiple intelligences are culturally groomed manifestations of human psychophysical adaptation to local and global industrial-urban niche construction effects, and

do not necessarily possess a verifiable genetic and standalone neural basis (cf. Davis et al., 2011). The intellectual competences of experts, exceptional individuals with brain damage, and mathematical savants are currently more explainable within the framework of gene-cultural coevolution than with multiple intelligences.

Finally, where Gardner's theories are only applicable to modern *Homo sapiens*, an extended evolutionary framework insists that any measure of intelligence should be observable *across* multiple species – or at least, in mammals – given the cognitive-neuroanatomical continuity hypothesis put forward in the last chapter. Only a few of Gardner's intelligences are observable across equally complex social species such as chimps (Boesch, 2012) and orcas (Rendell & Whitehead, 2001) – interpersonal, bodily/kinaesthetic, and spatial-navigational intelligences. But as far as the rest are concerned, they do not quite qualify. For instance, the evolution of biosonar (i.e. echolocation) in odontoceti, particularly its extended use forms among sperm whales (Whitehead, 2003; Whitehead & Rendell, 2014), or how sperm whales developed the rosette formation as a way of *socially* defending their vulnerable members against transient orca hunters (Pitman et al., 2001) are manifestations of adapting to and actively shaping group behavior in marine habitat corridors, offering a more robust pathway to understanding how species vary with respect to their individual, social, or ecological intelligences. On the other hand, multiple intelligences and psychometric testing of intelligent quotient are distinct with their lack of differentiations of the variance of intelligence with respect to the aforementioned evolutionary categorizations. They are anthropocentric and their applicability and assessability have been demonstrated among industrialized human geographies around the world (e.g. Chen, Moran, & Gardner, 2009). Unless it can be

demonstrated that the established criteria for IQ and eight (or nine) multiple intelligences can be found among non-industrialized, hunting, gathering, and herding communities such as the Inuit, San Bushmen, and Sami people, the very criteria for defining what intelligence is falls short. Indeed, there is currently no compelling evidence illustrating that natural selection favored the formation of eight intelligence modules, or the ecological inheritance mechanism (as articulated by NCT) promoted those intelligences in individuals so that they can be better adapted to their socio-ecological niches. In that sense, one suggestion is that a strand of research in multiple intelligences should be devoted to identifying specific levels of cultural and ecological niche construction effects on intellectual development, skill development, or competence.

Waterhouse's contention holds merit in the sense that pre-service teachers acquire an easy-to-understand version of human cognition that skims through the crucial biopsychosocial components of intellectual development, such as theory-of-mind and MTT, including niche construction effects on intellectual maturation, adaptation, copying, imitation, and assimilation (Rendell et al., 2011 a, b). These components are not over-the-top details of intellectual development that can be skimmed with summarized, one sentence explanations of how human cognition develops; they are essential to the contemporary study of intelligence and for understanding, for instance, why individuals who grew up in different geographies and cultural niches are more adept at mindreading and offer more decentralized thinking in classrooms or workplaces. They need to be part and parcel of the discourse driving teacher education programs or human resources departments.

In my judgment, the current accounts of intelligence in educational space tend to sidestep a number of other crucial entryways that inform how intelligence develops: (1) geographical-climatic differences, (2) naturalistic insight problems, and (3) System 1 and System 2 thinking.

3.4.1. Entryway 1: Geographical-climatic differences

The examination of the existing intelligence literature suggests that there is a dearth of empirical studies that took into account geography and climatic conditions as determinants of human intellectual performance and potential. In educational research proceedings, one is less likely to report an empirical study or compose a conceptual paper that examined the link between individual's adaptedness to its physical and social environment and that individual's intellectual abilities. The chief reason for this could be the late emergence of Darwinian accounts of human cognition in educational psychology, where predominant approaches insufficiently differentiated the concept of intelligence from a perspective that draws on biopsycholinguistic variations occasioned by cultural niche construction processes (see also Bickerton, 2009, 2014). Persons who grew up in mountainous regions and learned to use their intellects in the stalking, ambushing, and hunting of a caribou, finding freshwater, and ways of staying warm will develop intellectual skills that are demonstrably different from those who grew up in congested cities and learned to solve abstract algorithmic problems in digital platforms. Unfortunately, the existing literatures on intelligence measurement and assessments tend to paper over cross-cultural, cross-geographical, and cross-climatic developmental differences in favor of statistically-supported accounts of intelligence that uphold addressing

the selection pressures of industrial-urban niche construction processes on learning (Kidner, 1999).

Prevalent theories of human development routinely suffered from the same shortcoming. As an example, neither Piaget's nor Kohlberg's ambitious models of cognitive development took into account the distinct developmental processes observed among hunter-gatherer children of the Inuit, San Kalahari Bushmen, Yakut, or Mongolian tribes. Instead, these processes are widely observed by social and biological anthropologists. Both Brody (2002) and Konner (2012) avidly reported that hunter-gatherer childhood is unequivocally shaped by growing up in close proximity to diverse and healthy natural environments, which induce noticeable different developmental effects on epistemic certainty, decision-making, judgment, and ecological problem identification and solution. Whereas, it is unequivocally clear from Darwinian perspective that the study of intellectual development needs to be inclusive of topological variations as well as cultural niche construction variations. Along with geographical and climatic differences, the development of intellectual abilities needs to be simultaneously understood with respect to changing shapes of knowing, teaching, and learning (see Davis & Sumara, 2000). When geography, and by extension ecology, is not understood well, the role of natural selection/adaptation effects on cultural variation, intellectual skills (especially ecological problem identification and solution) remains unarticulated. Given educational psychology's current emphasis on studying individual differences and strengths, this appears to be either an oversight or neglect on the part of intelligence researchers, since a Darwinian account of intelligence unequivocally draws attention to geographical and climatic differences as the

primary moderators underlying intellectual skills, especially, ecological problem solving and technological innovation (Boesch, 2012; Parlar & Davis, 2013).

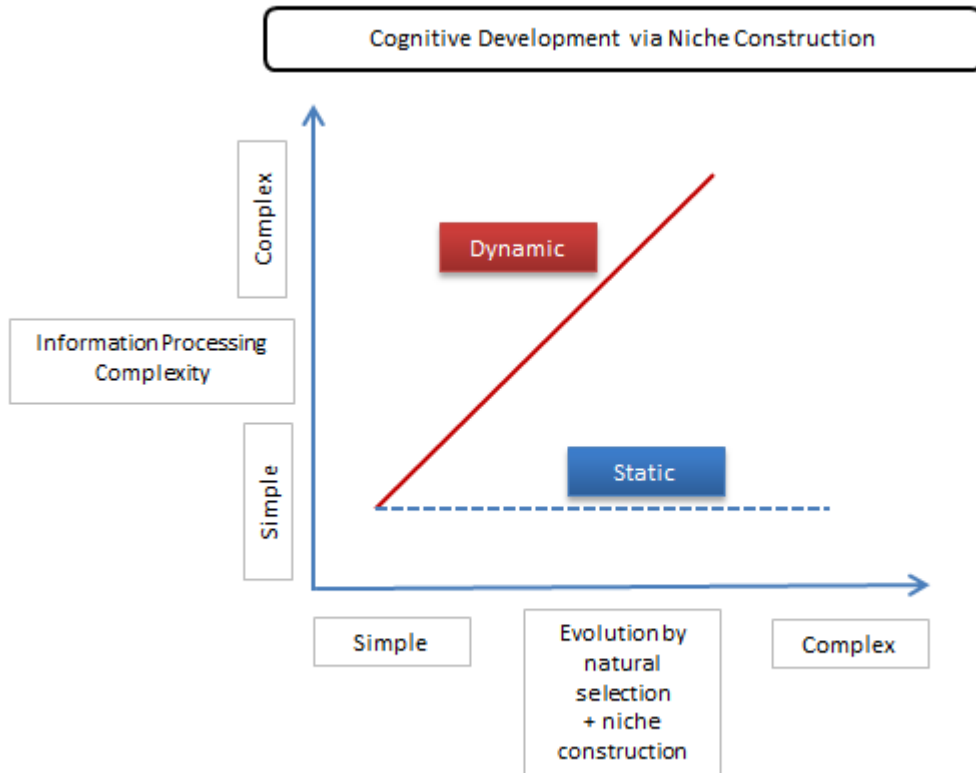


Figure 3.1. Cognitive development via niche construction. Based on Boesch’s (2012, p. 193) model. In the extended evolutionary framework, information processing complexity co-varies with the complexity of constructed socio-ecological niches.

Furthermore, geographic and climatic differences are often conflated with the cross-cultural differences in the measurements of g (e.g. Lynn, 2003). In diversity-inclusive, cross-cultural classrooms, where attention has been drawn to learning and motivation differences sourced by competency in English as a second language, as well as cultural and subcultural habits shaping family environments, we produce little educationally relevant knowledge on the impact of quantitative and qualitative fluctuations in temperature, weather cycles, soil, water,

and air conditions, biological diversity and wildlife corridors, the impact of anthropogenic environmental change on the development of intellectual abilities. Methodologies that are required to understand these effects on intellectual development have not yet been sufficiently developed. What little is known in these quarters has visibly emerged from the studies of cognitive-developmental research in folkbiology. A notable study conducted by Ross, Medin, Coley, and Atran (2003) who recruited 6, 8, and 10 year olds across urban and rural American populations, and a rural Menominee population (an indigenous culture) showed that Menominee children's folkbiological knowledge of plants and animals were impressive, only to be matched by older children in rural American populations, and scantily among urban populations. The research team further articulated that "Menominee children often made inferences in terms of ecological relations" (p. 39) and that both young and older Menominee children "showed a propensity for generalizing from bees to bears and they often mentioned that a bee might sting a bear or that a bear would eat honey" (p. 39). In that sense, "the inductive reasoning of [Menominee and rural majority children] is not based on biological similarity but on a relation the two species entertain" (p. 42). Because ecological understanding, or simply, "relationships thinking" (Ingold, 2004) allows one to assess the ramifications of what happens to another species, for example, when honeybees face decline in their numbers, the inference would be that Menominee children and rural children and the symbolic cultural context that supports their cognitive development would be better equipped in recognizing the consequences of environmental degradation for their own societies. Thus one can observe the development of more foresightful/prudential general intelligence in the preservation of those ecological relationships (see also Wolff, Medin, & Pankratz, 1999).

Because intelligence has been traditionally associated with psychometric measurement in controlled, carefully manicured environments, more ecologically oriented studies demonstrating the prognostic impact of geographical and climatic factors on learning, motivation, problem-solving, self-regulation, and cognitive control have not made sufficient inroads in the broader corpus of intelligence literatures or into teacher education programs. In particular, the impact of natural environments on the general cognitive ability has only recently been taken into consideration. This knowledge stems from disparate fields with more or less identical goals of enabling individuals to articulate the human place in nature (e.g. Ingold, 1989, 2000, 2006; Shepard, 1997; Kellert, 2002; Gruenewald, 2003; Louv, 2008; Boesch, 2012). The implicit suggestion emerging from these accounts is that this articulatory ability is necessary for sophisticating human judgment and decision-making ability in relation to long-term environmental stewardship. A thoroughly Darwinian account of intellectual development necessitates that further conceptual work and more sophisticated educational designs are required to examine the individual learning and motivation differences sourced by inhabiting particular climatic regions and geographies. These designs could prove particularly fruitful in multicultural populations that are endemic in the Canadian classrooms. In that respect, stronger curricular convergences need to be forged between environmental education and evolutionary sciences as informed by psychology, anthropology, and biology.

3.4.2. Entryway 2: Naturalistic insight problems

Although intelligence-measurement efforts generally subsume problem-solving and creativity, the link between intelligence and insight-based problem solving has not been

sufficiently explored. Most research on insight problems has been conducted in the laboratories of experimental psychologists and informed by Gestalt psychology (Wertheimer, 1945/1959) as opposed to Darwinian evolutionary theory. The Gestalt view holds that insights are sudden transformations of thought patterns (Mayer, 1995). In order to assess these processes, researchers formed gridlock tasks that intentionally led participants to dead-ends or stalemates. Researchers then expected their participants to overcome these obstacles through “aha” moments. A classic example is the 9 dots problem (MacGregor, Ormerod, & Chronicle, 2001). Here participants try to connect 9 dots on a paper without raising a pencil. A participant who can solve this problem without resorting to painstaking analyses would then experience an “aha” moment, grows confident, invokes a sense of certainty, and attempts at overcoming the obstacle through a novel way of solving the task. In that regard, information processing view defines insight as restructuring of information (Ohlsson, 1984; Miller & Cohen, 2001; Weisberg, 1995). Once the problem is solved through novel associations, there is no turning back (Weisberg, 2006) – the problem solver is expected to experience conceptual change.

More recently, Klein (2013) demonstrated that insights that solve problems in the real world do not occur in a fashion predicted and groomed in laboratory settings by what he calls as the “impasse paradigm” (p. 178). Klein argued that one reason why naturalistic studies are not incorporated into cognition and creativity research is because naturalistic methodology does not attempt to control conditions and test rigorous hypotheses, and thus they are considered as possessing lesser scientific value. Against the mainstream’s conviction, Klein and Jarosz (2011) investigated 120 cases where insights emerged and either directly or indirectly contributed to the reasonable identification and solution of various real world problems. Based

upon a grounded theory methodology yielding the categorization of insights, they discovered that insights often identify and solve problems by virtue of 3 pathways: (1) Connections, (2) Contradictions, (3) Creative Desperation. To exemplify *connections* path, Klein referred to Martin Chalfie's application of green fluorescent protein (GFP) to worms that eventually yielded a new standard biological technique. To exemplify *contradictions* path, Klein used Harry Markopolos's recognition that Bernard Madoff's unyielding financial success was fraudulent – which was done simply by looking at the Wall Street mogul's financial chart and realizing that Madoff was running a Ponzi Scheme. To exemplify *creative desperation* path, Klein used Wagner Dodge who managed to escape a life-threatening wildfire by employing a counterintuitive solution: “to escape the fire, he started a fire” (Klein, 2013, p. 84). In most of his cases, Klein found that tacit knowledge¹³ (i.e. expert knowledge) played an important role in the generation of insights, arguing against the impasse paradigm's contention that experience bias is an obstacle to see problems in a novel way. However, in other insight cases, Klein (2013) demonstrated that sometimes tacit knowledge can get in the way of insight generation – such as when a young, inexperienced police officer recognized a crime being committed in a situation where the older officer did not (Klein, 2013, pp.3-4). This example lends further support to the hypothesis that the insight moments do not necessarily correlate with developmental-experiential readiness that underlie the formation of expert knowledge; instead they are contingent upon place, time, and the problems that are endemic in those contexts. This is consistent with the Darwinian model of intellectual development that takes into account niche construction variations on culture and learning.

¹³ Klein's examples involve individuals who are considered experts in their fields. Martin Chalfie is a chemist; Markopolos is a financial analyst; Dodge was a wildland firefighter.

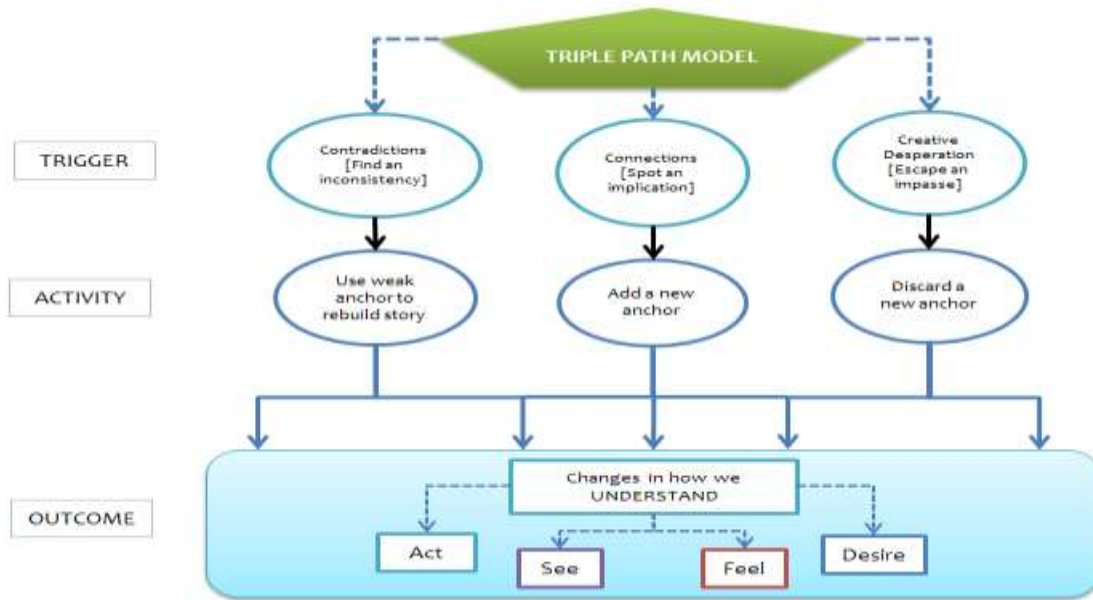


Figure 3.2. The triple path model (Sourced from Klein, 2013, p. 104).

Klein’s triple path model on how insights identify or solve problems in the real world should be considered another entryway in assessing the development of human intelligence. This is especially because the identification and solution of problems via insights are inevitably linked with the problem-solvers’ biopsychosocial upbringing and takes into account niche construction effects. According to the Darwinian evolution, insight problems should have selective advantages in that it must benefit the development of future-oriented behavior and thinking. Equally clearly, the problem-solving that occurs in laboratory settings are of recent phenomenon; throughout our evolutionary history, human beings have created, perpetuated, framed-reframed, identified, and solved most practical problems from general survival, mating, and foraging to particular engineering challenges via naturalistic insights, such as when they had to find new ways of building shelters so as to become resilient in changing environments or new ways of framing and overcoming a food security problem.

The basic concern is that the assessment of the development of human intellectual capacity for identifying and solving problems cannot be taken off from the naturalistic environments where they organically develop and evolve, nor should they be. Accordingly, it could be argued that any study on intelligence that is conducted within artificial settings has little educational yield in the sense that it prepares individuals for complex and unpredictable problems of human-engineered systems. Rather, formal education should provide opportunities for students to explore measures of freedom and attain means for identifying and solving problems, learning from those problems, and retaining the particularities of how those problems are solved. This approach signals an educational strategy focused on strengthening episodic memory and understanding the link between episodic memory strength and intellectual flexibility. In that sense, Klein's triple path model offers a viable assessment criterion for educationalists to support, assess, and shape intellectual development.

3.4.3. Entryway 3: System 1 and System 2 thinking

Other ways of assessing intelligence have also been offered. As an example, seeing some factual limitations of IQ-based measurements, Kahneman (2011) argued that more could be learned about the nature and function of the human intellect by studying the hypothetical System 1 and System 2 thinking. Based on his five decades of collaborative experimental research in cognitive psychology with mathematician Amos Tversky (e.g. Kahneman & Tversky, 1973, 1979; Tversky & Kahneman, 1992), Kahneman extensively demonstrated that System 1 heavy brains respond or behave "automatically and quickly, with little or no effort and no sense of voluntary control" (p. 20). System 1 thinking patterns are often impulsive, easily influenced

by insufficient information, less motivated to think long-term, and less prone to using scientific theory, method, and knowledge to logically contemplate, understand, or conceptualize problems and their solutions from particular vantage points. System 1 reasoning is a quick cognitive operation yielding uncritical thinking, which uses tacit shorthands to make sense of events (e.g. an omnipresent god). In Kahneman's account, System 1 prone users often jump into conclusions about a piece of information or knowledge that is either substantially incomplete or insufficiently supported. Since System 1 heavy brains have little voluntary control (read: metacognitive checks-and-balances) over their judgments, assumptions, and ideas, it could be that they are more inclined to sample past episodes and construct future episodes impulsively as well. When they encounter incidents, perturbations, upheavals, choices, decisions, uncertainties, novelties, and complexities, System 1 heavy brains are inclined to resort to reactionary solutions, and thus more inclined to see direct/immediate causes of those events, and prefer and demand their treatment through unsophisticated solutions.

Over the past decade, the examples of near-institutionalized System 1 thinking I encountered include shooting grizzly bears for harassing the cattle, laying off employees due to declining commodity prices, and innovating new technologies to solve the problems created by older designs (i.e. techno-fix, see Huesemann & Huesemann, 2011). The basic issue here is that these are not merely poor decision-making problems; they are problems rooted in the education of human mind from very early stages through formal schooling. They are often encountered because empirically supported theories of human cognition are not only in their infancy, but also have insufficiently informed formal curricula and teacher education programs. Consequently, formal education has put disproportional emphasis to semantic (i.e. facts) and

procedural (i.e. ways of doing) knowledge training, and gave little attention to tasks and tools that teach self-regulation, metacognitive control, collaborative problem identification and solution, long-term/foresightful/prudential reasoning – indeed, the theory-of-mind and MTT tasks that are at the kernel of those activities.

On the other side, System 2 heavy brains are more prone to responding and behaving in a manner that they assign “attention to the effortful mental activities that demand it, including complex computations” (Kahneman, 2011, p. 21). They may be more prudent than most, since they are not easily influenced by evident and available information, less prone to succumbing to various types of bandwagon effects, more prone to using analytical methods, if able and accessible, to logically assess, conceptualize, and identify problems and their solutions from non-cursory vantage points. Since System 2 prone brains exert more attention, it could be inferred that the symbolic thought patterns underlying System 2 brains make heavier use of declarative (i.e. voluntary) memory. They use words and syntax (i.e. semantic memory tokens) to sample lived, imagined, or vicariously experienced episodes of past and future as comprehensively and reasonably fit as their information processing capacities allow. System 2 heavy brains reconstruct episodes more prudently and deliberately, often by reviewing relevant evidence and insisting on establishing logical coherence. They pour more attention and concentration into the task at hand. When they encounter incidents, accidents, perturbations, upheavals, uncertainties, novelties, and complexities, System 2 users tend to be more inclined to investigate the underlying causes of those items, and prefer or demand their treatment via systematic, designed, and often unconventional interventions.

Based on the System 1-System 2 model of characterizing human cognition, Kahneman (2011) recognizes that a prominent marker of what counts as intelligent thought and behavior is more linked with the ability to deploy metacognitive checks-and-balances. As outlined earlier in this chapter, this evidence-based perspective argues that self-decentralization and cognitive control tasks are more predictive of general intelligence and its educability than psychometric tests. These tasks are necessary to restrain System 1 thinking patterns and their devastating ramifications, such as when individuals and collectives overestimate their problem-solving, management, and planning capacities (Buehler, Griffin, & Ross, 1994). Indeed, the current global environmental, health, safety, human personality, administration, governance, and technological decision-making crises are largely the results of System 1 using stakeholders, decision-makers, and collectives overestimating that the planet-earth could easily carry 7 billion agriculturally-dependent *Homo sapiens* without inflicting severe long-term damage to its self-regulating ecosystem services, biological diversity, and the species' overall psychophysical health and wellness itself.

3.5. Where does foresightful/prudential intellect fit in?

Perhaps the most difficult challenge in the study of intelligence is figuring out the criteria for labeling a thought process or a behavior “intelligent.”

How does one decide?

Robert Sternberg, 2002, p.1

As indicated in the beginning of this chapter, although the research on intelligence has gradually moved into a more Darwinian territory, psychometric tests remain as the intelligence researcher’s favorite methodology. However, there is increasing convergence in human sciences that intelligence tests have very little meaningful educational yield, and they are not helpful in producing evidence-based theories and models of intellectual development which formal education requires. As opposed to this backdrop, I introduced three other ways of assessing intellectual development that situates extended evolutionary framework of human cognition at the core of the effort. This framework argues that intelligence has a topological and morphodynamical quality – meaning that, intellectual skills cannot be measured according to a single factor such as *g*, although can be informed by it. Equally clearly, intelligence cannot be compartmentalized in ways that MI theory portrays. Instead, the extended evolutionary framework argues that intelligence can be refashioned or redirected according to the changing needs and adaptational dynamics of cultures due to socio-ecological niche construction effects on human learning (Laland et al., 2000). Without doubt, the most acute need of the currently globalized societies is supporting the development of an intellectual capacity that is more foresightful/prudential in matters concerning the human interactions with natural and

technological systems. On the pragmatic domain, this goal suggests various types of interventions such as the use of a more dynamic vocabulary, making school curricula more relevant to evolutionary trends, and the invention of theoretically-informed tools and technologies that will assist the development of this intellectual capacity.

As Ehrlich (2011) examined, existing educational cultures and curricular models not only put “too little systematic thought to the ever-changing needs of responsible citizens,” but also are “insufficient to simply become aware of the environmental consequences of what we do” (p. 6). Intelligence tests – or intelligence testing on that matter – are offshoots of standardized education and standardized education provides little valuable input on ways of allowing students to cultivate foresightful/prudential reasoning. Many students going through the conventional standardized education package are often rendered *disengaged* from the most acute socio-ecologically complex issues threatening the prospect of a healthy planet, and by extension, health human cognitive, behavioral, and learning ecologies, since standardized education has little consideration on the long-term virtues of a dynamic science and environmental education. Indeed, terms such as biophilia or environmental sustainability were not part of teachers’ vocabulary until recent times. Recent inclusion of these terms in formal curricula suggest that we have at least begun to conceptualize what may be more important for the developmental goal of education; but we are still lacking appropriate tools and technologies required to incorporate these terms into formal learning.

With foresightful/prudential intellect, a question emerges in regards to whether or not this type of intellect could be construed as one of Gardner’s multiple intelligences. In his original text, Gardner (1983) identified multiple criteria for defining a multiple intelligence in

order to prevent arbitrary formulations. In many ways, if considered as a multiple intelligence, foresightful/prudential intellect frame corresponds well particularly to a number of Gardner's criteria, such as evolutionary history and operational logic (i.e. mental time travel), manifestation among exceptional individuals (e.g. Albert Einstein, as an exceptional mental time traveller), and support from experimental psychological tasks (e.g. Fischhoff, 1975; Mitchell, Russo, & Pennington, 1989). However, my concern in regards to how foresightful/prudential intellect develops, not as a standalone intelligence defined by Gardner's criteria, but rather as a developing reasoning competence sourced by MTT also brought me to the following analysis: in all of Gardner's multiple intelligence constructs, we can see foresightful/prudence induced by MTT. When playing impromptu style variations involving *tempo rubato*¹⁴, a pianist anticipates the next passage and where to direct the tune in his head; he plans ahead before heading to that stage, and can additionally plan ways of preventing the harmony going off-track. Here, MTT and foresightful/prudential reasoning is applied to Gardner's musical intelligence. Based upon years of experience and tactical training, the captain of an aircraft could think ahead, calculate the approach vector, anticipate potential mishaps sourced by atmospheric pressures, and safely land the vehicle on an unconventional terrain in an emergency. He could develop strategies for avoiding loss of personality and equipment. Here MTT and foresightful/prudential reasoning is applied to Gardner's spatial-navigational as well as logical-mathematical intelligences simultaneously. When a ballerina anticipates the next moves of her choreography in her head, she engages in mimesis/offline thinking, and

¹⁴ *Tempo rubato* refers to a musical tempo where a performer can accelerate or decelerate the pace of a musical track's tempo at his/her discretion, without violating the overarching structure and time frame of that musical track. The performer can slow down the pacing at one bar, and compensate for that loss in the succeeding bars, giving a natural feeling to the performance, as opposed to a mechanical, computer-generated music. The act of planning for the compensation at what particular stage requires the performer to engage in MTT.

anticipates what to do and what not to do in order to perform, her ballet successfully. She becomes foresightful/prudential momentarily. Here MTT is applied to Gardner's bodily-kinaesthetic intelligence. When striking a conversation with a woman, a man could engage in MTT and strategize his conversation in ways that he can secure a second date with that woman – men consider themselves lucky if they manage it! Here we see MTT being applied to Gardner's interpersonal intelligence. When an ecologist encounters evidence showing that human-induced ecological engineering activities, such as horizontal drilling and hydraulic fracturing, will result in the contamination and loss of groundwater volumes in near future in the province, he can engage in MTT, plot and categorically demonstrate the kinds of plant and animal species and minerals will become compromised by that engineering activity for the future human and nonhuman members inhabiting the province. Here we see MTT applied to Gardner's naturalistic intelligence.

With all things being equal, I have at least laid out some of my justifications for why foresightful/prudential intellect might not be a multiple intelligence candidate or why it cannot be subjected to traditional intelligence testing. Unexpectedly, the conceptual examination done so far in this thesis has shown that foresightful/prudential intellect gains more votes than MI, for being considered as part of a species general intelligence. When contextualized from the perspective of (neuro)psychological research on human memory systems and their distinct evolution due to socio-ecologically driven language learning pressures, foresightful/prudential intellect, with the supporting frame of MTT and its evolution, differentiates itself from MI theory's main vocabulary, and offers a subtle entry point to the cognitive-developmental foundations of human abilities and skills.

As argued in the last section, foresight production relies mostly on episodic memory, using MTT as a general cognitive faculty; because of this cognitive generalization, foresightful/prudential thought and action can manifest itself in any domain – more in some domains (e.g. financial risk assessment in corporate business world) and considerably less in others (e.g. protecting biodiversity for future generations). Clearly, not engaging in foresightful/prudential reasoning in the latter domain could be one of the leading causes of developmental psychological issues such as Kahn’s (1999, 2011) environmental generational amnesia.

Among the existing definitions of intelligence, foresightful/prudential intellect appears to be more associated with cognitive governance. As mentioned in the first chapter, the word prudence refers to the capacity to have forethought that comes with practical knowledge. In Kahneman’s terminology, the equivalent of this capacity would be matured heuristics and biases (i.e. System 2 functions) that allow individuals to engage in prudential decision-making and judgment. According to a more contemporary dictionary, intelligence is also referred as “the ability to govern and discipline oneself by using reason, sagacity or shrewdness in the management of affairs, skill and good judgment in the use of resources, as well, caution or circumspection as to danger and risk” (Merriam-Webster Online Dictionary, 2014). Notice that the third and fourth definitions of intelligence here are particularly about prudential behavior, or even a rarer form, *providence*. From this viewpoint, it may strike us that intelligence is rudimentarily associated with prudential reasoning, and therefore, logically more aligned with the ability to synthesize learning into foresightful behavior. This understanding by default builds on Kahneman’s distinction that the development of general intelligence is more closely

associated with cognitive governance, motivation, self-decentralization, and learning to restrain impulsive judgments in situations where more deliberate thinking is required.

3.6. Critoeconoesis

Mental time travel, as an evolved, generalized cognitive faculty, is responsible for driving future-oriented thinking and action in *Homo sapiens* (Suddendorf & Corballis, 2007). Just as other generalized cognitive faculties that had to specialize due to symbolic language-based niche construction demands (Deacon, 1997), MTT too had to specialize based on domain-specific abilities. Our task right now is to build a bridge from this point to the development of foresightful/prudential intellect.

This bridge could be built in the form of a reasonable educational hypothesis – that, students who actively learn their topics by virtue of MTT tasks become more foresightful/prudential thinkers in those domains. This should also be supplemented with a secondary hypothesis that the development of foresightful/prudential intellect is also contingent on the types of MTT tasks students are engaged with; that is, those MTT tasks must prompt students to construct future episodes, or facilitate constructing those future episodes by teaching them how to extrapolate those episodes based on pre-existing facts or previously experienced episodes. Merely engaging in cognitive search to retain semantic information does not suffice. Simple mnemonic devices that traditionally assisted rote-learning tasks such as memorization of facts and procedures do not necessarily engage episodic memory, but rather result in its further vulnerability to deterioration. As Suddendorf and Corballis (2007) also pointed out, “[e]pisodic memory may decline as a consequence of the increase in the extraction

of facts and rules, or what some would call crystallized intelligence” (p. 311). This suggests that training students for semantic and procedural knowledge would be insufficient to make their cognitive processes prudential or foresightful in regards to a place, a situation, a system, or a possibility. In addition to these, they need to become adept at cultivating a special type of consciousness associated with episodic memory.

The working definition for this special type of consciousness, which is produced as a consequence of deliberately done MTT (whether done individually or collaboratively) could be called *critoeconoesis*. This definition of consciousness should be contrasted with Tulving’s (2002) correlate terms for episodic memory, *autonoesis* or *autonoetic consciousness*. In Tulving’s account, autonoesis refers to an individual’s ability to cast episodes of oneself in past, future, or counterfactual scenarios. From this perspective, autonoesis focuses entirely on autobiographies and does not necessarily indicate that individual decentralizes its thought processes or engages in ecological thinking. In Chapter 2, I attempted to demonstrate that most empirical studies on MTT and episodic memory function tend to focus precisely on the self, as opposed to ecological problem identification and solution. Accordingly, the neglected inquiry among those who research episodic memory is what happens when an individual becomes adept at mentally placing a situation, a place, a group, or a system in the past, future, or counterfactual scenario and assess its consequences. To capture this cognitive phenomenon, a new word could be introduced. The term *critoeconoesis* provides a semantically suitable conception. In this term, *crit* – refers to critical, *oeco*- refers to ecology or the environment, and *noesis* referring to concept, understanding, or comprehension. In that respect, *critoeconoesis* intends to capture the phenomenon where individual is able to deploy its MTT ability and focus

not on self and the ramifications of past, future, or counterfactual situations for the self, but on past, future, and counterfactual situations of environments and systems, and critically assess their ramifications for human and non-human systems.

With the association of future-oriented thinking and action with episodic memory, Tulving's account can now be extended towards an ecological trajectory, and argued that it is critoeconoesis, rather than autoeconoesis, that may be more responsible for the kind of development of foresightful/prudential intellect argued in this thesis. However, it is equally clear that critoeconoesis should build on autoeconoesis. Nelson's (2001) work on children's autobiographical accounts sufficiently showed that autoeconoetic capacity develops early on effortlessly, facilitating the growth of our symbolic narratives that we articulate throughout our entire lives. This point additionally aligns with one of central tenets in Piaget's (1983) theory that as infants we are less apt in decentralizing and devote less mental energy to understanding the viewpoint of others. With gradual socialization and education, the normal expectation has been that egocentrism should gradually decline and more advanced theory-of-mind skills should develop. On the other hand, developmental research also regularly demonstrated that egocentrism persists through lifespan, often manifesting itself in different forms based on the emerging needs of different stages (Elkind, 1967; Enright, Lapsley, & Shukla, 1979) as encountered in different environments (Schwartz, Maynard, & Uzelac, 2008). An evolutionary explanation of this situation could be that focusing on self, and therefore engaging in autoeconoesis, regardless of one's age, is a mechanism selected to facilitate individuals to mentally contemplate themselves in different contexts and ease their adaptation to those contexts.

On the other hand, critoeconoesis refers to a cognitive process where individuals can go beyond auto-noesis and become foresightful/prudential *for* another situation, such as the future of a nonhuman animal species, an ecosystem, or a group. Accordingly, when we educate an individual for critoeconoesis, we train them to become more adept at reconstructing past and future episodes, enhance their ability to decentralize their thinking, and assess its ramifications for not the self, but for other actors involved in those episodes. Due to the development of early infant cognition, this back-and-forth reconstruction process should necessarily subsume auto-noesis. Subsequently, what could now be called critoeconoetic consciousness is deployed in the identification, examination, and solution of a problem. It is required when making prudential societal decisions, creating prudential engineering designs, or when constructing prudential scientific understandings, all of which concerns larger actors other than the self.

In essence, both auto-noesis and critoeconoesis, driven by episodic memory, differ from a consciousness generated by the use of semantic and procedural knowledge in that they do not make conclusive statements; instead, they point out *emergent* phenomena or possibilities. When those phenomena or possibilities are considered with respect to other actors as opposed to self, episodic memory enables the cognition to gradually decentralize. The knowledge that a new technology could give more power to administrators and subsequently could reduce civil liberties is an example of critoeconoesis is deployed. For instance, Schneier (2014) examined that unlike the popular assumption that internet has empowered those who did not have voice and were underprivileged in the past it empowered also those who are already in privileged positions and can exert greater control on individual freedoms. The knowledge that humanity could achieve more by concentrating its mental energies on the conservation and restoration of

biological diversity as opposed to religion and sports is also inferred by deploying critoeconoesis. Paul Ehrlich (2011) is a particular champion of this thought, more than once demonstrating that creating more jobs in environmental protection and conservation sectors will route human behavior towards a more sustainable behavior in the long-run. The knowledge that protecting the hunter-gatherer economic livelihood models could be beneficial in routing humanity to a more sustainable course is another example of how critoeconoesis can be deployed, often observable in the work of Jared Diamond (2006).

Critoeconoesis harnesses the MTT ability in the sense that it promotes a form of evolutionary thinking – that individuals can spontaneously or deliberately assess the consequences of past and future events, or meaningfully bridge them and incorporate into their analysis or decision-making. Since flexible MTT ability is required to engage in evolutionary thinking, critoeconoesis appears to be instrumental to the further flexibility of MTT and cultivation of foresightful/prudential general intelligence towards new layers of understandings. More specifically, critoeconoesis is produced when complex cognitive processes enable previous learning to be retained, synthesized, and articulated in the solution of new ecological problems. In that respect, critoeconoesis could be understood as an underlying mechanism of ecological problem identification and solution via insights.

Critoeconoetic consciousness could also be produced as a result of collaborative MTT efforts. When an extrapolative learning process is activated by more than one or two individuals who simultaneously retain, synthesize, and articulate an ecological problem or its solution, the control of episodic memory is temporarily offloaded onto another individual. This is more or less defined as “if you complete my memories, I’ll complete yours,” building on our

species' evolved tendency to engage in reciprocally altruistic behavior. Collaborative MTT helps producing knowledge which then could be imbued in a design, a process, or a technology. Educationally, this means bringing those individuals to the same problem-solution headspace and reducing the educational culture gap among them, while retaining their individual characteristics in the produced knowledge or designed product. In that sense, what is being promoted is not standardization or uniformity; it is harnessing the reciprocal altruistic tendencies of individuals and enabling them to become collaborative learners.

Critoeconoesis is part and parcel of scientific thinking, reasoning, and contemplation; therefore, there is no reason why individuals cannot be educated for deploying this consciousness to enhance their learning of dynamic systems. In that sense, educating for critoeconoesis could be construed as a major goal of science education. This suggestion can also be bolstered by the idea that educating someone for critoeconoesis by default means training that person to reason or act not only foresightfully, but also evolutionarily. Educating students in multifarious ways of deploying critoeconoesis suggests that educationalists should design learning experiences that turn students' attention to studying and understanding dynamic systems as opposed to solving artificial puzzles in the classrooms. It is in those dynamic systems where episodes are more robustly experienced.

I am aware of no pre-post educational assessment or longitudinal design intervention that has systematically attempted to understand or demonstrate the formation of critoeconoesis, and how this cognitive skill may be contributing to the formation of prudential/foresightful reasoning patterns – whether or not a course taker becomes a prudent individual, capable of forethought, aware of complex adaptive systems, work transdisciplinarily,

and able to make judgements, identifies and solves problems in this very crucial domain is not educational knowledge. As an example, in Alberta Education's (2014) Biology 20-30 curricula where I examined the place of evolution education and evolutionary thinking, I was surprised to see that foresight, prudence, or providence are not the terms you will find as part of a unit's four foundational learning outcomes in attitude, knowledge, skill, and STS (Science, Technology, Society). Apart from early childhood cognition studies restricted to artificial settings and tasks, there also is no visible developmental psychological study that investigated whether or not children demonstrate foresightful/prudential judgements when examining a dynamic system problem. The development of foresightful/prudential reasoning and action is not a domain we have yet systematically investigated in the educational study of human intellect.

Clearly, a reliable critoeconoetic capacity develops over decades, after much life experience, and an education helping us maturing our heuristics and biases. But it is also important to realize that currently no education system is equipped with sufficient imagination, attitude, and practical tools to understand the implications of this capacity for educating the long-term sustainability of biological communities. Our best bet as educationalists has often been to provide learners what we know earnestly, leave it to time, and discontinue the assessment of cognitive development over time. However, the "things will turn out all right" approach is a logical extension of standardized curricula that uses *preparation* and *training for job market* concepts when justifying the role of education and academic achievement. Seen from democratic citizenship and sustainability education perspectives, this approach is at best a questionable cognitive engineering attempt that achieved more ecosystemic failure than success. It created minds that are not prudent. By extension, it is unable to justify itself as a

foresightful/prudential educational model at the face of anthropogenic environmental changes. Standardized education occasioned more ecological theory-of-mind failure than success – especially given that (1) we scarcely make sure that (2) students know that (3) previous generations are actually in the process of squandering their futures. It could be that Kahn’s environmental generational amnesia is an epiphenomenon of not having this form of curricular outcome goal.

In that regard, we are arriving at the reasonable conjecture that the development of foresightful/prudential intellectual capacity, of which critoeconoesis is a vital part, requires that we engage students with not a problem-based or inquiry-based learning per se, but rather a type of learning which involves MTT tasks. MTT tasks could be deliberately embedded within problem-based or inquiry-based learning; but the success of these tasks also depends on the nature of problems students are engaged with. In my judgement artificial, static puzzles, although stimulating MTT, are not capable of building a foresightful/prudential intellect in the sense it is proposed in this thesis. They have very limited applicability and replicability outside of the laboratory. As Klein (2013) argued, artificial tasks such as

the nine-dot puzzle, the box-candle puzzle, and the pendulum puzzle....are all *domesticated* insight tasks. The researchers using these tasks aren’t doing any hunting or exploring. They are harvesting a predictable crop, one that has emerged from decades of pruning and modifications. (p. 175)

Instead, the problems that we give to students should have *emergent possibilities* or *alternatives* embedded within them so that students’ emerging critoeconoetic competencies are thoroughly engaged. Foresightfulness demands that individuals become aware of the

ramifications of a particular course of action that did happen in the past or could happen in the real world. Artificial puzzles that are manicured and impervious to change cannot sufficiently assist with the development of foresightful/prudential intellect, or efficient deployment of critoeconoesis. They possess limited educational value in the sense that puzzle-solving by itself has limited applicability outside the school where human-made systems created complexity, unpredictability, and instability. Therefore, the problems we need to engage learners with need to be dynamic system problems where agents' behaviors change with respect to other agents.

SYNOPSIS 3

- It is important to notice that Howard Gardner did not originally intend his MI theory to be utilized by educators. He formulated his theory within the field of cognitive-developmental science. With growing interest in his theory by educationalists, Gardner has gradually come to construe his theory as an educational theory, building a stronger link between developmental science and education. Foresightful/prudential intellect takes a similar scholarly stance – where it is formulated within cognitive-developmental science informed by behavioral ecology and cognitive sciences, and it is also construed as an emerging developmental goal of science and environmental education. The question is then, what types of curricular designs and educational interventions can achieve more success in promoting foresightful/prudential reasoning in learners?
- Although foresightful/prudential intellect fits many of Gardner’s criteria for intelligence, it does not necessarily refer to an emerging multiple intelligence. Rather, it can manifest itself within any one of Gardner’s intelligences. This position bolsters the justification for a non-divisive approach to cognitive development, akin to Neo-Piagetian perspectives.
- Critoeconoesis provides an assessable construct exemplar of how foresightful/prudential reasoning patterns emerge and develop in classrooms and other learning settings. The important question concerns how educators can identify and support critoeconoetic thinking via naturalistic methods of assessment, as opposed to artificial methods of assessment.

Chapter 4: Developmental readiness of the ability to retain critical episodes and synthesize foresightful/prudential solutions

4.1. Introduction: Empirical research in mental time travel

Empirical research efforts that make use of MTT have currently limited track record in science and environmental education. The most notable research to the date is conducted by Louis Chawla (1998a, b) whose research program on significant life experiences could be considered an exemplar of MTT research. Chawla asked her participants to recall their childhood experiences of natural environments. She then correlated these stories with their adult activities. Her findings revealed that these experiences are often predictive of the development of pro-environmental behavior during adulthood and support the pursuit of professions in the areas of environmental science, policy, conservation, and activism. Chawla's research is widely cited by many environmental educators to bolster the goals of the field (Louv, 2008; Sobel, 2008; Kellert, 2013). However, this research program does not focus on the benefits of harnessing MTT ability in the identification and solution of dynamic system problems.

More psychologically driven studies on MTT capacity have emerged from developmental science. The findings build a reliable trend, suggesting that the ability to remember past and project ideas towards future spontaneously emerges around 3–4 years of age (Nelson, 1992; Atance & Meltzoff, 2005; Atance & O'Neill, 2001, 2005; Busby & Suddendorf, 2005; Conway, 2005; Suddendorf & Busby, 2005). More recently, a non-verbal test conducted by Suddendorf and colleagues (2011) identified that young children are able to identify novel problems and

ensure their future solutions. This study strengthens the connection between MTT and foresight, and lends additional support to the claim that episodic memory is instrumental in solving novel problems and securing their future solutions (Raby & Clayton, 2012). These empirical studies also corroborate that MTT and theory-of-mind are indeed developmentally (and perhaps evolutionarily) linked. They also provide circumstantial support to an emerging claim that insight-based problem solving, which largely uses the same neuroanatomical resource (i.e. the hippocampus) as episodic memory, could be examined and promoted within the perennial frame of MTT (Parlar, in preparation). However, a main shortcoming endemic in these developmental studies is that they are conducted in artificial settings prompting young children to engage with artificial puzzles; or what could be called “domesticated” mental time travel tasks (cf. Klein, 2013). Apart from early childhood education, it is doubtful to what extent they can inform formal curricula or the frame of foresightful/prudential intellectual development over lifespan.

The study I present in this chapter set out to developmentally explore how students use their MTT abilities when evaluating a complex environmental stewardship problem. An additional purpose of this exploration was also to observe the types of solution clusters students gravitate towards, and to understand what types of responses emerging in those clusters include analytical or insight-based solutions that could be considered foresightful/prudential. The problem introduced as the treatment/intervention measure was not a puzzle or a static phenomenon. Instead, it was a dynamic, event-based problem encountered in the real world. It should also be considered a novel problem especially for Grade 5 and 7 students in that the problem was not something they routinely engage within

their curricula. Finally, I wanted to understand at what grade level students would be ready to engage with MTT-based learning using complex environmental problems.

4.2. Content of the treatment measure

In year 2001, a juvenile, orphaned killer whale (*Orcinus orca*) nicknamed Luna appeared in Nootka Sound, British Columbia. Upon his appearance, the orca proactively sought social contact with human beings, to the surprise of the local communities that had never seen a wild killer whale attempting to communicate in that fashion. Luna's appearance immediately attracted the attention of the communities in the area, including Mowachat Muchalat First Nations, marine biologists, tourists, as well as the Canadian Department of Fisheries and Oceans (DFO)¹⁵. Soon after, an event that seemed low-key turned into a complex problem that opened up the ancient flood gates: Indigenous epistemologies versus Western epistemology, nature versus nurture, humans versus animals, lawmaking versus letting things be, remaining objective versus taking action, among many a theme. The resulting momentum was an instance of self-organizing interactive complexity, occasioning uncertainty and defying pre-existing ways of handling things if everything was to be done by following procedures. In the middle of this complexity, a killer whale swam, proactively seeking for social contact from human beings, and eventually died in such pursuit after spending 5 years in the area. It was an accident.

The Nootka Sound accident appeared as an ideal intervention tool to see the developmental differences among students' reasoning-strategies. Previous research had made use of similar interventions, such as when Kahn (1997) engaged a group of school-aged children with Prince William Sound Oil Spill accident and other environmentally problematic scenarios.

¹⁵ Today, the agency is also known as Fisheries and Oceans Canada.

Kahn collected children's narratives from different cultural settings¹⁶ through Piagetian semi-structured interviews and categorized their justifications under the rubric of two overarching constructs, namely biocentric moral reasoning – the appeal to consider humans as greater part of the ecological community - and anthropocentric moral reasoning – the appeal to consider human interests before those of the ecological community.

In this study, I followed similar sensibilities, particularly in regards to the significance of targeting populations that involve diverse cultural identities. However, my approach focused more on understanding the mechanism of MTT that allowed children and young adults to use their moral judgements and arrive at different solution syntheses to the presented environmental problem. Suddendorf and Corballis (2007) indicated that MTT could be a more robust evolved cognitive faculty underlying human beings' moral and ethical judgements, since autoeogenesis enables individuals to retain cognitively and socioemotionally relevant details and assist in the formation of worldviews and identity.

Due to my exploration of MTT ability as applied to dynamic systems problems, I took advantage of a documentary film that had sufficiently captured most complexities of the accident by virtue of a reliable chronology. It involved a killer whale, which I thought would be an immediate appeal to all age groups. It was also a local matter (i.e. it took place in Western Canada) that involved a species conservation and public safety issue – a hot topic encountered in environmental policy making in all Canadian provinces. In addition, engaging Calgary children with an issue that took place in West Coast provided an interesting contrast: that many

¹⁶ Kahn's participants were from African-American communities in Houston, Portugal, and Brazil.

of these children who have multicultural backgrounds have not even been in West Coast of Vancouver Island or even seen a killer whale.

4.3. Dynamic system problems research

Although the present study includes the characteristics of other research into social cognition that has looked into problem identification and solution differences across different age/grade levels (e.g. Harter, 1975; Battistich et al., 1989), there is one difference: the nature of the problem introduced via treatment measure was an exemplar of dynamic system problem. Dynamic systems (sometimes also associated with complex adaptive systems) involve organic or synthetic agents whose behaviors adapt or evolve with respect to other agents. Their behaviors and cognitive inclinations differentiate over time as a way of preserving the anticipatory regulation of future outcomes (i.e. socio-ecological allostasis)¹⁷ (see also Juarrero, 2002; Deacon, 2006). The agents involved in this system are *compelled* to learn by virtue of compounding associations between agents' experiences with other agents, as a way of bringing temporal order to a disorder (Deacon, 2011). Where the underlying behavior observed in this system has a logically deductible outcome (e.g. the culmination in the form of accident), the agents come out from this system with their cognitive processes and behaviors altered or modified.

Psychological science has a substantial historical track record in using experimental design techniques whose treatment contents involved static, artificial, object-based puzzles when assessing children's intellectual capabilities and motivational levels. Equally clearly, the designs that gave frame to data collection have been equally rigid in order to reduce internal

¹⁷ See the second chapter for the definition of this term.

validity threats and enhance the study's replicability in future attempts (see Machado et al. 2000; Shadish et al., 2002). However, particularly after the inception and growing popularity of Gardner's MI theory, educational researchers began to notice the importance of engaging students with tasks that assist the development of other skills, as opposed to focusing disproportionately on problem solving in mathematical tasks. Especially in recent years, the learning sciences community has welcomed publications that promote novelties in the content of taught science curriculum, such as designs that enable students to directly engage with problems that portray the workings of dynamic systems or phenomena including emergence and self-organization (Hmelo-Silver & Azevedo, 2006) and evolution by natural selection (Jacobson & Wilensky, 2006). The focus on teaching science through dynamic systems or complex adaptive systems can be contrasted with the traditional science education content where students are taught to memorize facts, names, and procedures associated with places, time, and observed phenomena (see also Hart, 2010; Blumstein & Saylan, 2007, 2011).

By this token, it could be argued that children's capacity for identifying and solving dynamic system problems (or complex adaptive systems) is a relatively new territory. Based on this emerging alignment, one of the present study's goals has been to explore how students engage with a complex problem, which could then inform designs and teaching efforts that more deliberately focus on enhancing foresightful/prudential problem identification and solution capacity. However, educational researchers have not sufficiently examined the role of MTT as a cognitive faculty responsible for the ability to understand the workings of complex adaptive systems. In that sense, the present study aims to illustrate how students use MTT to

make sense of the introduced problem, whether or not they deploy critoeconoosis and arrive at different solutions that can prevent the problem from reoccurring.

4.4. Methods

4.4.1. Recruitment

Over a period of 12 months, 346 students responded to the study: 71 undergraduate students (*M age*= 23), 188 Grade 5 students (10–11 year olds), and 87 Grade 7 students (12–13 year olds). They comprised 54% Grade 5 (*M age*= 10), 25% Grade 7 (*M age*= 12), and 21% undergraduate students (*M age*= 23). Of this population, 262 student responses were coded in the preventative action questions, yielding a total codable response rate of 76%. In this study, the sample includes 56% from Grade 5, 26% Grade 7, and 18% undergraduate students; therefore, there is no significant difference between the total population and the sample population. In the government authority question, 205 response samples were coded for analysis, yielding a total response rate of 59%. In the initial impressions questions, 227 responses were received from Grade 5 and Grade 7 out of 275, yielding a total response rate of 83%. Finally, in the Mars-Oceans justifications which only Grade 5 students were engaged, I received a total response rate of 138, yielding 73%.

The study was informed by a recent proceeding in *Behavioral and Brain Sciences* that critiqued the psychological science's focus on recruiting undergraduate students from industrialized and developed nations, which broadcasts misleading and often biased portrayals of how humans learn, develop, or behave (Henrich, Heine, & Noranzayan, 2010). Henrich and colleagues' critical examination provides additional support and justification for why niche construction theory (which subsumes cross-cultural psychology) needs to be considered in

contemporary research in human sciences (see also Bennis & Medin, 2010). Taking Henrich and his colleagues' caution into account, both undergraduate students and school-aged children were recruited from diversity-inclusive environments. The undergraduate students were recruited via University of Calgary's Department of Psychology research participation pool via the assistance of Michael Boyes, from introductory classes that tend to involve students from different ethnicities and educational leaning. All undergraduate students participating read and signed informed consent forms. Nearly a half of these students originated from non-English speaking countries including Kenya, Persia, Egypt, Philippines, China, Brazil, and Chile. Therefore, the undergraduate populations were from diverse ethnic backgrounds, representing a typical Canadian multicultural standing.

The school-aged children were recruited from four Calgary Board of Education (CBE) schools, upon acquiring police information check and two levels of extensive ethics clearance from Conjoint Faculties Research Ethics Committee and CBE ethics resource office respectively. Two schools that participated in the study were from economically less developed communities relative to the other two schools. Similarly, children from all four schools were from diverse ethnic and economic backgrounds. Child participants with no parental consent form returned were excluded from the study. Subsequently, their homeroom teachers engaged them with different activities during regular classroom hours. As many children encountered in classrooms spoke English as their second language (ESL), throughout the study, we consulted with the homeroom teachers who provided assistance.

4.4.2. Design

As this project began as a theory-generating study rather than a hypothesis-testing study, the research design involved an open-format questionnaire. Given the fact that both school-aged children and undergraduate students are invited, basic questionnaire methodology was used to keep the data collection process consistent and yield developmental trends analysis. As well, Suddendorf and colleagues (2011) argued that because future-oriented thought is embedded in our everyday life, basic questionnaire method is sufficient and useful in understanding the extent of MTT in children.

We developed a first draft of post-study questionnaire for undergraduate students on the basis of the literature on the biophilia hypothesis (Kellert & Wilson, 1993; Kahn, 1999, 2011). Initial studies done with undergraduates gave us further insight on the kinds of questions that undergraduate students find more engaging and responded with more variety (i.e. preventative actions), and the kinds of questions that appeared highly redundant¹⁸ (e.g. importance of nature for children). With feedback from these studies, some of the questions for children were either modified or omitted with respect to their reading levels. A bulk of these studies has been reported elsewhere (Boyes & Parlar, 2013a, b; Parlar & Boyes, 2013; Parlar, 2014, c). Here, I only introduce a portion of the data that are relevant to the task at hand.

Upon deriving feedback from undergraduate students, the following design sequence was kept constant for children:

¹⁸ Nearly a hundred percent of undergraduate students stated that contact with nature is important for child development.

Documentary → Open Episodic Recall → 1st preventative action question → Right/Not Right Question → 2nd preventative action question

Each question attempted to focus participants' attention on the generalities and particularities of the accident. Although our attempt was exploratory and our intent was not to measure the impact of right/not right questions, we always sequenced the second preventative action questions as the final question in all groups. Right/not-right questions were essentially about students' moral/ethical justifications in regards to the decisions and actions of the involvement of government authority in the incident. We asked the questions right/not-right as a stimulus and scaffold rather than treatment.

Two preventative action questions were asked, the first iteration being "what if anything should have been done differently?" and the second one being "should anything have been done differently involving Luna's situation?," prompting participants to consider ways of preventing similar accidents, incidents, or events from reoccurring. The rationale for introducing two iterations of this theme was to increase the likelihood of getting a response to this theme, e.g. if a child participant does not respond to the first one due to neglect, distraction, or another problem, it can always respond to the second one. By the time this study was conducted, the foresightful/prudential intellect frame did not fully present. Therefore, the formulation of these questions was primarily informed by a related frame, namely, environmental psychologist Kidner's (1998, 2001) work on the formulation of long-term preventative environmental ethic, which is contrasted with palliative problem solving and decision-making. Upon analyzing data and coding responses, Kidner's frame became naturally articulated under the rubric of foresightful/prudential intellect. With the new theoretical frame

of MTT in mind, the preventative action questions can be contemplated as episodic memory stimulus tasks aimed at prompting participants to synthesize their episodes based on the experienced event and producing a foresightful/prudential solution to the problem. As we did not have a hypothesis prior to the study in regards to any potential difference between the first and second iteration of the preventative action questions, we did not expect to see any difference between them. The responses to both iterations of the preventative action theme were therefore coded separately (cf. Kahn, 1999).

In addition to these questions, for further exploration purposes, we also presented a few additional MTT tasks to Grade 5 and Grade 7 students, where they were engaged with the following topics: (a) their initial impressions; (b) a choice regarding colonizing Mars and settling on the planet,¹⁹ or exploring Earth's oceans and communicating with orcas; and (c) their perceptions on cohabiting with the wild. I first introduce these in order to portray children's overall cognitive profile, and then move to the analysis of preventative action justifications.

4.4.3. First data analysis: The process of coding

Qualitative analysis techniques were employed in the developmental analysis of preventative action questions, combining both thematic analysis (Braun & Clarke, 2006) and the five-stage constant comparative technique of grounded theory (Glaser & Strauss, 1967). This process involved (1) identifying and coding each preventative action categories from qualitative responses; (2) comparing responses as applicable to each category; (3) merging categories and their characteristics; (4) redefining and recoding them; and then (5) generating hypotheses and inferences for further analysis. Finally, I illustrated each preventative action category

¹⁹ Grade 5 only.

qualitatively, especially when two categories were interacting with one another, and in places where educationally significant justifications (e.g. the deployment of critoeconoesis) were not demonstrable through quantitative analysis.

Towards the end of this process, inter-rater coding was undertaken by randomly sampling 30% of responses from each grade level (e.g. Kahn, 1997, 1999). I trained a second coder in the use of an initial coding manual, defining how to use the manual as questions arise. The second coder was not informed about my assumptions, inferences, and then-emerging hypotheses. During the first round, each coder identified a set of thematic categories. During the second round, coders compared each other's categories. I also framed the discussions about categories by drawing on the etymology and semantics of constructs. We then reworked the categories, discarded those that are not of use, and settled on a final draft. During the third round, each coder independently rated all the items in the selected sample one last time. Finally, Cohen's Kappa is used to measure the inter-reliability of the coding. In each preventative action response coding, 89% and 81% of agreement was respectively achieved.

4.4.4. Second data analysis: Descriptive and inferential statistics

Where descriptive statistics were used to calculate percentages in all frequency data, nonparametric statistics were used to make inferences about category use across different developmental stages (Agresti, 2007). In each preventative action stimulus questions, to test the association of independence among grade level and category, chi-squared tests were used. Differences across Grade 5, Grade 7, and undergraduates were found as reported. To test whether or not proportions of students' categorical preferences varied, Cochran's Q was used.

Statistically significant Cochran Q tests were followed up with the McNemar change test (Kraska-Miller, 2014), comparing students' categorical preferences. The McNemar change test is also employed to account the changes that occurred in the second stimulus question. No gender and educational discipline differences were found among undergraduate students in their right/not-right justifications questions. In addition, no significant gender and school differences were found among grade-age children in any question, and thus both the child gender data and school data were collapsed.

4.5. Results I: Children's environmental profile

4.5.1. Open episodic recall

Initial impressions are likely to be the first clue to children's thought processes and to what their auto-noetic consciousness captured and retained. Quantitative analysis of children's open episodic recalls showed that 44% of Grade 5 and Grade 7 students recalled Luna's behavior as the most important or interesting thing they learned from the treatment measure. This was followed up by Welfare of Wildlife (12%), DFO's Behavior (11%), First Nations' Activism via Canoeing and Singing (8%), Pod Failure (6%), Human-Nature Interactions (6%), Luna's Death (5%), and Community's Behavior (4%). Pod failure – that Luna's killer whale pod had abandoned him – did not emerge among Grade 7 students as an important episode.

A potentially positive educational impact of the treatment measure was the conceptual change pertaining to killer whales, stemming from Luna's unique interactions with human beings. Consider the following participants:

G-127: ...I never knew that killer whales will every try to communicate with humans. I thought they were all mean and they eat people.

G-134:...when the humans interacted with the [whale]....I thought it was amazing how a deadly animal can become a piece of human nature.

Another child thought that it was Luna's death that became instrumental in her learning:

G-198:at the end when the orca dies. I find it interesting because the orca has [gone] through so much with the human[s] and then when he was swimming next to a boat, he got hit by the motor and was injured. Then that was the last time everyone [saw] Luna....it teaches us just how orcas are like humans. They are young and they like to play a lot like humans and they deserve to get just as much attention as us. Orcas aren't that different compared to humans.

Isomorphic/anthropomorphic accounts such as the above response were prevalent among most Grade 5 and Grade 7 students. In addition, I also observed theory-of-mind failure.

Consider the following 10 year old's response:

G-119: I think the most important thing was when Luna was communicating with the people so that she has a better chance of finding her family. I guess it wouldn't help too much but if the people saw other whales they could lead their boat in that direction so she could find the whales then ask them because they speak whale language.

Dylan thought that Luna's communication with humans was a way of asking help from them to reunite him with his pod. But was that really the case? For many adults that got involved in the event, it was clear that the whale was not searching for his pod, and even other marine mammals, but proactively *creating* opportunities to socialize with human beings. Moreover, when Dylan mentioned the whale language I was immediately reminded of Deacon's (1997) eight-year-old interrogator who asked him, "why animals don't even have simple languages?" But for many concrete operational children that use inductive logic (Rips, 1975;

Carey, 1985; Inagaki & Hatano, 2002; Keil & Newman, 2008), the human-like qualities, including language-like behavior, are immediately extrapolated to the rest of the nonhuman world (Piaget, 1929). As it has been obvious to many researchers, anthropomorphism is a matured evolutionary heuristics that enables the symbol using hominids such as us to make sense of the complexity of the world and reduce uncertainty (Epley, Waltz, & Cacioppo, 2007; Waytz, Epley, & Cacioppo, 2010). By extension, this includes nonhuman animals having their own species-specific language.

4.5.2. Mars versus oceans

What other themes have emerged? For example, Grade 5 children were engaged with a dilemma pertaining to either colonizing Mars or sending humans to oceans to communicate with orcas. Of the responses, 83% preferred communicating with orcas and 17% of responses preferred Mars. Undoubtedly this result was facilitated through the treatment measure. Among children who thought communicating with orcas would be more important pursuit for humanity, responders often provided both anthropocentric and biocentric moral reasoning, including responses such as, “to help us with science; to discover our planet and to learn more about the species that share our planet,” as well as responses such as, “Mars does not need our help and wildlife does need our help.”

Perhaps the most unexpected result emerging from this question came from children who justified that colonizing Mars would be a more important trajectory for humanity; here I encountered more qualitative variability. For example, Mars being a “cool” objective or a scientifically curious target was one of the most dominant anthropocentric justification

categories. A second subcategory involved a concern for human welfare, with children arguing that Mars is dangerous to humans, and that we must explore oceans or orcas since they are safer or friendlier alternatives to humans. However, one child justified that

G-128: We should go to Mars because in a while people don't keep care of the earth and that means that the whales would die anyway....

Although this response may seem to reflect an anthropocentric concern for human welfare, its logic is different than avoiding harm in unknown territories; rather it reflects a sense of resignation, suggesting that the human predicament is a foregone conclusion and nonhuman species such as whales may not be even worth protecting. In relation to this particular response, three other children provided anthropocentric reasoning focusing on a concern regarding overpopulation:

W-254: Sending people to Mars [is more important]...because we are going to get more people, we need more homes.

W-264: I think sending people to Mars to colonize is very important because the amount of people on the world means more cars, more factories, more houses.

D-296: Mars....because the earth is getting bigger but Mars is small so we send people to make life.

Notice that children here are combining both auto-noesis and crito-econo-esis. Where auto-noesis is evident in the subjective experience of Mars and its representation in their cognitions, crito-econo-etic assessment in regards to future *emerges out* from their subjective experience of human population growth (including the child whose answer *earth is getting bigger* in fact referring to *human population is getting bigger*). But how curious is it that a 10-year-old is capable of recalling that population growth is one of the most acute environmental

problems? Granted that it is somehow embedded in their episodic memory networks; but where do these impressions originate from? Environmental topics such as population growth, Malthusian forecasting, and resource scarcity are not part of a Grade 5 classroom's science curriculum, nor have we developed educational tools to assess whether children grasp the non-linear relationship between population growth and environmental impact (Harte, 2007).

One possible answer is that these concrete operational children, in developmental terms, possess pre-existing ways of thinking logically about the connection between population growth and the need to expand, which they may have been acquired in other, non-formal educational contexts via observation and social learning. Considering that many children were originally from different countries, an even more likely answer is that they were born and initially grew up in places where population growth and its socio-ecological ramifications are more acute than one would observe in Canada (where population is lower and growth is relatively stabilized by virtue of creating a culture of hard work, gender equalities, and pursuit of higher education). That initial exposure may have profound impacts on their current cognitive ecology in regards to the question. In addition, the anthropocentric reasoning underlying these responses is robust to a degree that it overrides a concern and interest for communicating with orcas even after the treatment measure. These children revealed themselves to be in the "me and humanity" consciousness stage, where they are able to recognize the needs of other humans, but not yet willing to prioritize the needs of nonhuman animals.

Perhaps more surprisingly, of those children who opted for Mars, three children provided biocentric reasoning, arguing that

G-124: We should [send people] to Mars, so the animals can have peace in the world by themselves and us not destroying their house.

G-181: I think Mars because if people communicate orcas too much the orcas can get harmed.

G-201: Sending people to Mars...if we went under water we might disrupt the underwater creature natural habitat.

As could be observed, here we encounter a completely different critoeconoetic assessment that promotes an equally different problem-solving headspace. It is known that the patterns of relativistic thought are more endemic among post-formal operational individuals (i.e. young adults) (e.g. Chandler, Boyes, & Ball, 1992). Indeed, these concrete operational children do not show it, by resorting to ‘this’ or ‘that.’ Not having relativistic headspaces might be enabling them to deploy critoeconoesis more decisively. It is particularly curious to observe that in these children’s responses, sending human beings to Mars equates with disabling harm to biological diversity of the earth. They are in the “me and nonhuman world headspace,” where we encounter critoeconoesis deployed to produce a differentiated foresightful/prudential reasoning. Whether or not this is a robust headspace remains to be seen.

4.5.3. Cohabiting with the wild

Cohabitation with the wild has recently become an emerging educational theme among environmental educators and developmental psychologists. A recent volume published by Kahn and Hasbaach (2013) particularly focused on this issue, urging the community that wild nature still exists but not in abundance; it would be our effort to rediscover it and understand its vital role in regulating our lifelong psychophysical health.

When I asked Grade 5 students about whether or not humans can successfully live together with the wild species, I once again encountered great variability in their responses.

There were isomorphic responses such as the following:

D-314: Because we are all alive we all sleep eat and live so the question is WHY NOT.

D-307: Because we all have brains.

G-141: We can because wild animals are just like us. We're scared of them and they are scared of us but maybe one day that all will change maybe we can live together because we breathe the same air they do.

Responses invoking hindsight and co-evolutionary logic such as:

D-303: Because we have been doing it for millions of years.

W-262: Yes we have been doing it for millions of years, why stop now?

D-329: I think they can because people have always lived with animals on this planet and people should interact with them more so we have a better life together.

D-279: Yes I think they can because primates like chimpanzees are really smart already and they are already interacting with humans and they could help each other survive if they needed to.

G-149: Because animals help us survive.

G-163: I think they can live together because they have been together for all their lives.

Responses invoking reciprocal altruistic reasoning such as:

G-140: Because they give us lots of resources and we give them what they need to.

Responses invoking essentialist-teleological reasoning such as:

G-142: Yes we and them are both put on here for a reason.

W-271: I feel that we and animals, we're created to be together and help each other

As well as many conditional responses avoiding harm that made up of majority of all responses:

G-144: Depends on the animal. If it is a friendly animal, then yes.

G-162: It's hard to say but I will say maybe because we kill animals and hit them just for skin and we kill them with our cars and we pollute the world. But sometimes we are nice and we clean up.

On the other side, some children did not think cohabitation would be viable:

G-121: No matter what happens, one will hurt the other at some point.

G-132: Because humans keep building these structures and kill animals and their homes and soon all animals might die out.

G-177: I don't think that would work well because humans need an artificial home and artificial thing while wild animals need wild things.

Other children went to greater lengths and found the question a source of deeper engagement. For example one child who had a conditional response argued that

G-194: They could, if humans didn't use so much technology and weren't so stupid about nature. We destroy the planet and don't take good ideas. If humans would be willing to depend more on earth and less on all our fancy gizmos and keep making buildings where we don't need buildings we would. However, I don't think that is going to happen. We've already made so many animals endangered, it's a miracle we still have so many animals. We interfere way too much.

As it could be seen, in this child's response we once again encounter the deployment of critoeconoesis where there is concern for future and the need to make prudential decisions. In a similar way, another child also justified that,

G-122: I don't know maybe if humans can open up instead of being the self-concerned race that looks down on everything and thinks it's the highest race in the world, maybe if we stop killing

and scaring animals for pure enjoyment and maybe think how they feel once in a while, and don't choose the animal's future and maybe let them be independent and not cooped up in freaking cages all the time! Then just maybe... we can live together like neighbors and not like predator and prey.

For the majority of children I observed, cohabitation involved conditional responses with many children discerning some species as dangerous and unsafe and therefore not suitable for cohabitation; it could be said that their headspace was limited to “me and my immediate concerns”; but for a small segment of children, it meant other things insofar as they evaluate the issue from a broader ecosystemic perspective, such as children who invoked co-evolutionary logic and the two children above who applied their prudential thoughts and invoked more extensive justifications. They were able to decentralize and offload more control to their cognitive processes than their peers, manifesting an observable developmental difference in their organizations of thoughts and perceptions.

4.6. Results II: Developmental readiness analysis

4.6.1. Authority position and involvement

The coding of right/not-right responses proved particularly painstaking because often times, I encountered responses such as the following (this one from a 10-year-old):

G-137: I thought it was right that [the government agency] wanted to protect [Luna] where he wouldn't get hurt and I totally thought that was right. But imprisoning the poor creature would be extremely wrong and bad for the whale.

I observed that some children used discretionary judgments when evaluating this incident. They did not think the government agency was obligated to let others interact with

the whale, but did specify in which cases the agency was right or wrong. Indeed, Kahn's (1992) previous studies on children's obligatory and discretionary judgements also found that, developmentally, children as young as Grade 2 are able to make discretionary judgements in regards to whether or not an agent's act is morally right. It is therefore not surprising that we encounter the same situation among Grade 5'ers. Another developmental take on this could be in terms of authority. As an example, the existing literature on children's perception on authority suggests that, although children's decisions are significantly impacted by parental authority insofar as it overrides their decision-making, the situation may be largely dependent on the complexity of the event where they need to make decisions (Tisak, 1986). In our case, it is reasonable to consider that the complexity of Nootka Sound incident provided sufficient stimulus for children to consider what is particularly right or wrong about the authorities' decision-making.

The analysis revealed that when children associate being right or wrong with the Luna's captivity option in particular, they tend to extrapolate their judgments to the government agency's entire behavior. As such, for statistical analysis, we coded responses that more comprehensively evaluated parties' involvement in the incident, allowing us to choose the dominant category more decisively. The results showed difference in the proportions of student responses to each situation $\chi^2(2, N = 205) = 32.96, p < 0.0001$. Overall, 70% of students considered the DFO's position or authority as not all right. However, within each individual grade level, the results showed 79% of Grade 5, 80% of Grade 7, and 45% of undergraduates evaluated the agency's involvement as not all right. Across grades, the results showed a statistically significant dependency between use of justifications and age level

$\chi^2(2, N = 205) = 23.57, p < 0.0001$. Where most school-aged children were adamant about the DFO's involvement in the incident as being wrong, nearly a half of undergraduate students justified the agency's involvement and position as necessary.

Qualitatively, I once again encountered variability in children's responses. Consider the following response from a 10 year old:

G-235: What I thought was wrong with that, was because Luna didn't have a decision of anything and that he wasn't able to do what he wanted to do. But I thought that position was kind of a good choice, because he would be patrolled and the department would make sure nothing bad would happen to him. Luna would also be able to play with the group that patrolled him.

Notice that in this child's response, although he laments that the killer whale was not able to make a choice, he contended that the DFO's involvement was necessary because it provided protection to the whale. On the other hand, a Grade 7 participant had a different idea:

EP-68: They were right in the way that they needed to protect Luna and the people, but they could have done so in a less harsh way. Completely cutting off contact will most likely have a psychological and negative effect on Luna. The intent was alright but the delivery was slightly over the top.

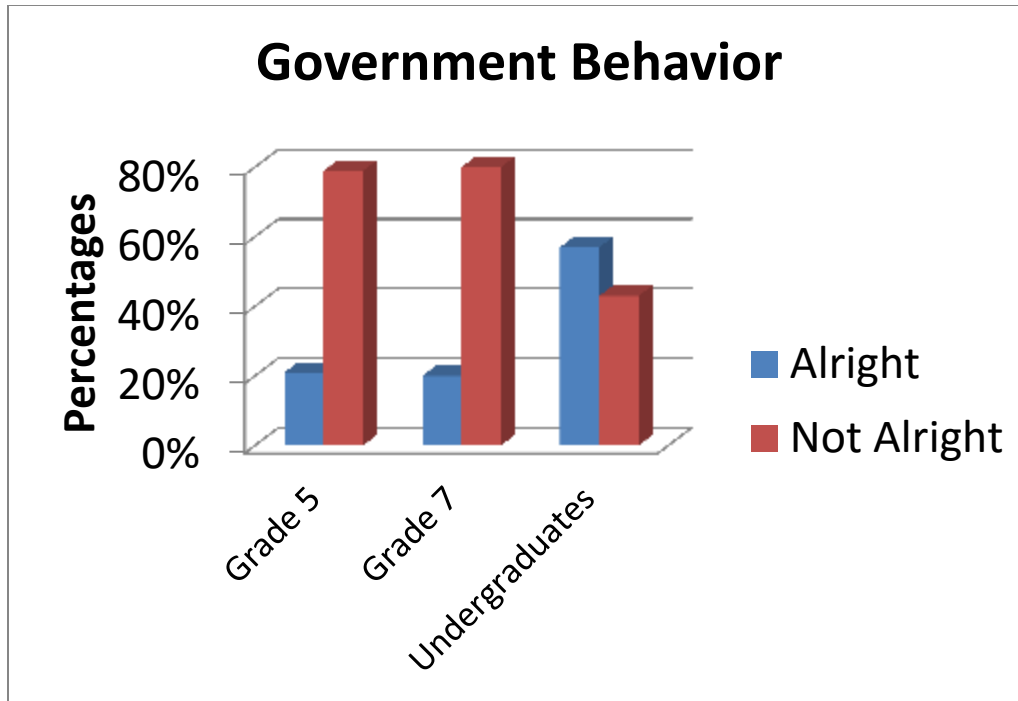


Figure 4.1. Percentage of justifications for the government agency’s behavior.

These responses show that some children as young as 10 to 12 year olds are able to discern what was right or wrong about a complex incident such as this. This means that unlike what the common-sense dictates, children do not necessarily use impulsive System 1 thinking, or think ‘childishly,’ but able to bring thoughtful observations into the issue. Especially in the latter participant’s response, we see an attempt to mentally place the complex situation between Luna and DFO in a future scenario (“completely cutting off will most likely have a psychological and negative effect on Luna) and assess the ramifications of this anticipated episode. Once again, such response could be considered an evidence for the capacity to deploy critoeconoesis and engage in foresightful/prudential reasoning.

4.6.2. Preventative actions

Application of a grounded-theory method using constant comparative technique led to the emergence of five main categories across three developmental groups (see Table 4.1.). Preventative actions and the general failure factors (GFF) that correspond to the former were principally determined based on the two iterations of the theme. For convenience, they will be referred as Stimulus 1 and Stimulus 2 from this point onwards. In addition, during the interreliability coding process, my second rater and I enhanced the rigor and reliability of each code, by tracking and evaluating participant's initial impressions, as well as, their right/not-right responses for the DFO's involvement.

Two kinds of analyses pathways emerged: (1) How categories are distributed across grades, and (2) which categories are prioritized over others. As I had no a priori hypothesis or expectations regarding whether Stimulus 1 would differ from Stimulus 2, I remained agnostic about them until the differences were statistically tested.

TABLE 4.1. SUMMARY OF CAUSAL FACTOR/PREVENTATIVE ACTION CATEGORIES		
GENERAL FAILURE FACTORS (Errors/Faults)	PREVENTATIVE ACTIONS (Insights/Improvements)	DEFINITIONS
Interspecies Communication Failure	Interaction Preservation	Appeal to identify/solve the problem by sustaining socio-ecological interaction between humans and Luna, including reciprocating Luna's social needs by virtue of petting, playing, and making eye contact, providing care for Luna, or monitoring for his safety and well-being.
Incompatible Goals	Relocation	Appeal to identify/solve the problem by relocating the whale to open ocean, aquarium, zoo; as well, reuniting him with his pod.
Community's/Luna's Behavior	Behavioral Management	Appeal to identify/solve the problem by managing either human behavior or the whale's behavior.
Organizational Problem-Solving Failure	Organizational Innovation	Appeal to identify/solve the problem by prompting the DFO to change its policies, organizational behavior, and mandate
Design/Engineering Failure	Technological Regulation	Appeal to identify/solve the problem by regulating motorboat activity, including engineering ecologically benevolent technology, and using non-motorized transportation to occasion sustainable and healthy human-nature interactions.

Based upon a sampled response rate, Pearson's chi-square test-of-independence indicated statistically significant associations between developmental stage and choice of preventative action categories in both the first preventative action stimulus $\chi^2(8, N = 232) = 37.28, p < 0.0001$ and the second one $\chi^2(8, N = 178) = 20.43, p < 0.009$. The fact that these associations were significant in both instances particularly indicated age-related differentiated appeals to general failure factors and preventative actions. For instance, in the first stimulus question, the results showed two statistically significant developmental trends in the use of categories. In Organizational Innovation, 36% of Grade 5, 24% of Grade 7, and 4% of undergraduate students showed appeal, reflecting a downward trend $\chi^2(2, N = 262) = 18.82, p < 0.0001$. In Relocation, 14% of Grade 5, 24% of Grade 7, and 40% of undergraduate students showed appeal, reflecting an upward trend $\chi^2(2, N = 262) = 15.80, p < .001$.

On the other hand, in the second iteration of the preventative action question, the results showed two significant developmental trends in the use of categories. In Relocation, 14% of Grade 5, 29% of Grade 7, and 40% of undergraduate students used this category, replicating the same observed effect in stimulus 1 $\chi^2(2, N = 262) = 15.99, p < .0001$. In Interaction Preservation, 10% of Grade 5, 19% of Grade 7, and 21% of undergraduate students used this category, producing a marginally significant upward trend $\chi^2(2, N = 262) = 5.95, p < .051$. Across categories, in stimulus 1, four kinds of significant categorical interactions were detected and reported under Figure 4.2; whereas in stimulus 2, three kinds of significant categorical interactions were detected and reported under Figure 4.3.

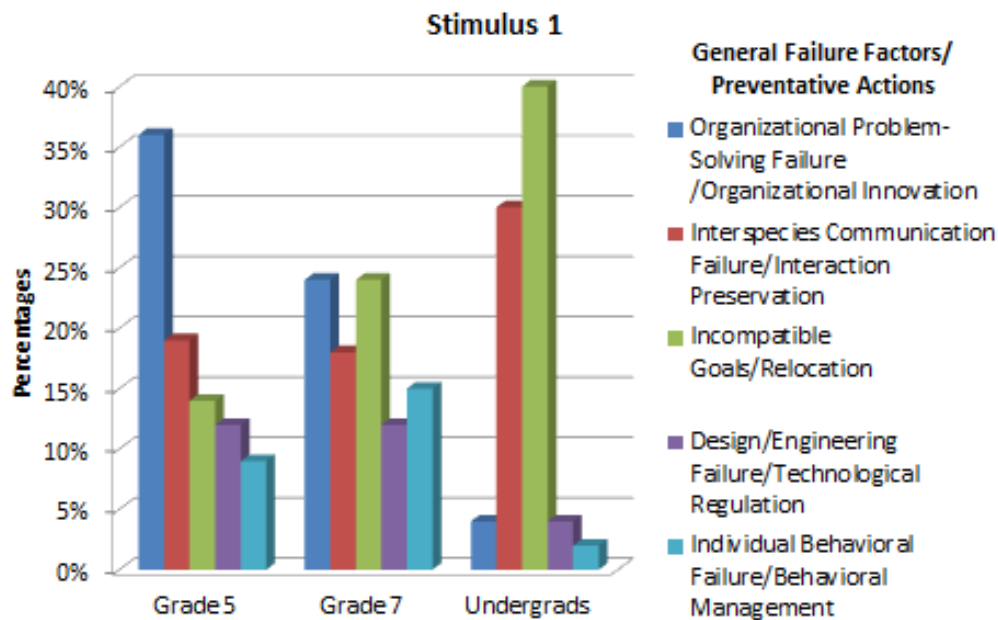


Figure 4.2. Interactions among category use in Stimulus 1

- Interaction Preservation * Relocation: Where Grade 7 (18% → 24%) and undergraduate (30% → 40%) response patterns do not differ from each other, they both differ from that shown by Grade 5 (19% → 14%).
- Interaction Preservation * Organizational Innovation: Where Grade 5 (19% → 36%) and Grade 7 (18% → 24%) response patterns do not differ from each other, they both differ from that shown by undergraduate students (30% → 4%).
- Relocation * Organizational Innovation: Where Grade 7 response patterns remain equal (24%), both Grade 5 (14% → 36%) and undergraduate (40% → 4%) response patterns differ significantly from one another.

- Behavioral Management * Technological Regulation: Where undergraduate (4% → 4%) response patterns remain equal, both Grade 5 (9% → 12%) and Grade 7 (15% → 12%) response patterns differ from one another.

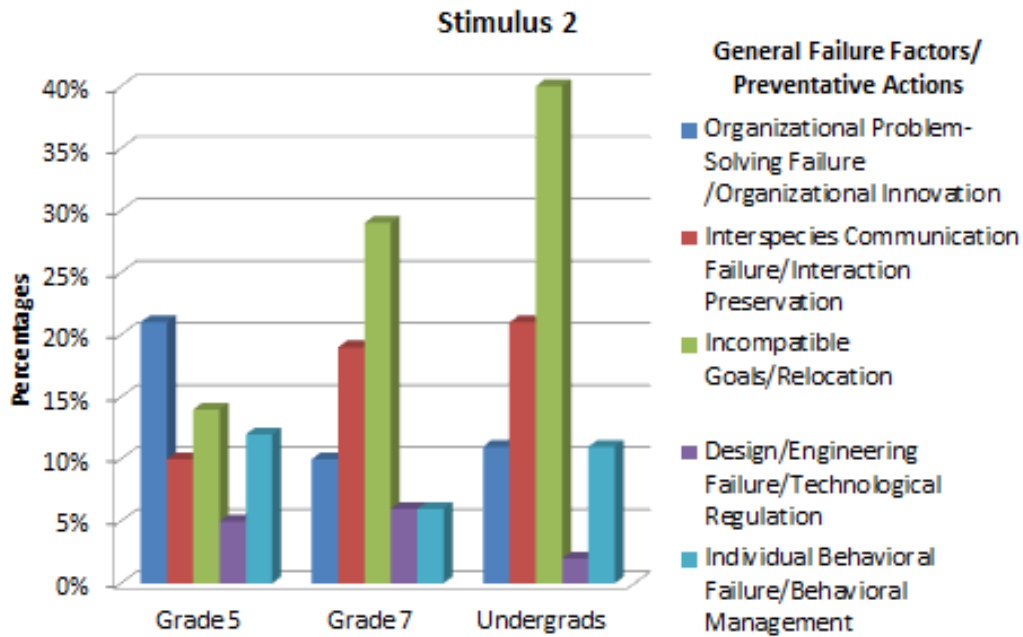


Figure 4.3. Interactions among category use in Stimulus 2

- Interaction Preservation * Behavioral Management: Where Grade 7 (19% → 6%) and undergraduate (21% → 11%) response patterns do not differ from one another, they both differ from that shown by Grade 5 (10% → 12%) students.
- Interaction Preservation * Organizational Innovation: Where Grade 7 (19% → 10%) and undergraduate (21% → 11%) response patterns do not differ from each other, they both differ from that of Grade 5 (10% → 21%) students.

- Relocation * Organizational Innovation: Where Grade 7 (29% → 10%) and undergraduate (40% → 11%) response patterns do not differ from each other, they both differ from that shown by Grade 5 (14% → 21%) students.

Furthermore, I specifically wanted to see which categorical interactions were significant within individual stimulus questions and across both. To find out whether or not there are significant changes in students' response to preventative action stimulus questions, McNemar's Change and Cochran's Q were employed. The data were transformed into binary distribution and the assumptions for the tests were met (Agresti, 2007). McNemar's test assessing the change between stimulus 1 and stimulus 2 responses revealed statistically significant results. Overall, students were more likely to justify Organizational Innovation $\chi^2(4, N = 262) = 10.41, p = .001$, Technological Regulation $\chi^2(4, N = 262) = 8.04, p = .004$, and to a lesser degree, Interaction Preservation $\chi^2(4, N = 262) = 3.94, p = .046$, as preventative actions in the first stimulus question than in the second question.

The results additionally showed that proportions of categorical use differ among students in both stimulus 1, $\chi^2(4, N = 262) = 34.14, p < .001$ and stimulus 2 $\chi^2(4, N = 262) = 36.55, p < .001$. Due to the significance of Cochran's Q in both situations involving multiple categories, they were individually followed up with pairwise comparisons using McNemar's Test (Kruskal-Miller, 2014) in order to pinpoint the differences in students' specific preventative action choices. Results revealed statistically significant comparisons in both stimuli, where students demonstrated higher-tier preferences for certain preventative action categories over others (Table 4.2.).

TABLE 4.2. SUMMARY OF THE TEST OF PAIRWISE COMPARISONS FOR PREVENTATIVE ACTION JUSTIFICATIONS				
		<i>Stimulus 1</i> ($\chi^2, df = 1$)		
Hierarchical Category Use		Behavioral Management	Technological Regulation	
Tier 1	Organizational Innovation	22.7***	17.82***	
Tier 2	Relocation	11.39**	8.15**	
Tier 3	Interaction Preservation	10.78**	7.81**	
		<i>Stimulus 2</i> ($\chi^2, df = 1$)		
Hierarchical Category Use		Technological Regulation	Behavioral Management	Interaction Preservation
Tier 1	Relocation	30.66***	12.66**	4.99*
Tier 2	Organizational Innovation	16.36***	3.71 ^a	.313
Tier 3	Interaction Preservation	11.76**	1.59	–
Tier 4	Behavioral Management	4.45*	–	–

NOTE - χ^2 = Values obtained via McNemar's test
^ap= 0.53
* $p \leq 0.5$
** $p \leq 0.001$
*** $p < 0.0001$

I will talk more about what these mean in the discussions. In the meantime, let us have a look at the qualitative responses and see how the identified categories subtly differ from one another.

4.6.2.1. Category 1: Interaction preservation

This category highlights a way of causal reasoning – specifically, that the accident could have been prevented if Luna’s interaction with human beings was kept in a state of equilibrium by virtue of the efforts of both humans and the whale. This category thus more robustly shows students’ ecological relationships thinking potential. Many children picked up on this when constituting their problem-solution headspace. As such, I encountered responses that were along the lines of providing care for Luna by touching him and making eye contact, as well, by creating a safer place for him, monitoring his safety and welfare, including giving him a human pod, and keeping off fisherman who intended to harm him because he was getting too close to their motorboats. Consider the following:

D-288: Something that should have been done differently is that they should [have given Luna] a human pod to take care of him. Maybe he would not have died and so he would have been with people who want him there.

Whereas for another preserving human interaction with the wild animal meant specifically attending to the whale’s safety:

D-315: I think the Orca (Luna) should have been touched or petted by humans since if we tried to avoid her she would still make contact with us so may as well keep her safe by us.

Notice that this 10 year old is able to anticipate that the “no touch” or “no eye” contact policy with the whale enforced by DFO’s stewardship group would be in vain, as he recognizes that the whale had been proactively interacting with human beings and nothing would stop it from doing that.

Undergraduates who appealed to this reasoning clearly provided more sophisticated responses. For the most part, I observed that participants' solution headspace of this category were inconsistent throughout both stimulus questions. As an example, when engaged with the second iteration of the preventative action question (i.e. should anything have been done differently involving Luna's situation), the following undergraduate participant argued:

PA-3: A policy of social contact with Luna might have shown success, but never tried. After all other ideas had failed, it seems foolish for no one to have tried the whale's option.

However, when engaged with the first stimulus question he justified:

PA-3: Luna should have been safely transported earlier, before further attachments had a chance to form.

There appears to be a dramatic change; that is, on one hand, arguing for preservation of human-nature interactions by virtue of a "policy of social contact," and on the other hand, arguing for a top-down relocation strategy to prevent "attachments" from developing. These two responses are the exact opposite of another. Indeed responses like these show that each question pulled participants into a different solution headspace, and generates a potential hypothesis that different ways of asking similar themes could lead to synthesizing experienced episodes in different ways. In what ways these different outcome arrivals could be related to a knowledge transfer problem (e.g. Schwartz, Varma, & Martin, 2008) or the fleeting, swayable nature of episodic memory recall and prospection remains to be seen.

4.6.2.2. Category 2: Relocation

The category of relocation can be divided into two types of appeals: top-down and bottom-up. Top-down relocation refers to a causal reasoning that the accident could have been

prevented if Luna was relocated somewhere other than Nootka Sound. Most justifications in this sub-category appealed to the captivity option as the best possible solution. Other justifications involved reasoning that Luna was not in his natural habitat. Consider the following example:

U-63: I feel Luna should have been taken back to the ocean, his natural habitat. You see, the problem is this: The animal had gotten too close to humans and humans close to him. It is an amazing thing to witness, the relationship between the whale and humans. But at some point or another, we have to realize that with all of our similarities in terms of compassion, we have to face the inevitable and that is, we have to [stay] in our own natural habitats. Just as humans would not relocate their lives to the ocean just to be with Luna.

On the other side, bottom-up relocation refers to reuniting the whale with its pod. Once again, this category has been determined by coding responses that do not demand change in government's overall management mandate, but evaluate reunification as a more separate solution attempt:

G-12: They should have taken Luna back to her family, when they saw her first, so her family would accept her easily.

EP-78: I think that they should have brought Luna back to her family to swim in the ocean were its safe again. I think they should have done this right when Luna came.

4.6.2.3. Category 3: Behavioral Management

This category refers to a causal reasoning that the accident could have been prevented if the local community or Luna made modifications in their behaviors. For example, one undergraduate participant argued:

PA-8: Perhaps it's humans such as the islanders that needed to adjust to accommodate for their new resident, Luna, and be more aware of other species, not just ourselves. Those whose equipment was damaged may not understand Luna's intentions of simply playing and wanting to communicate and judged by it as we would a human which is not fair.

On another take, in one Grade 7 student's response to both iterations of the preventative action theme, behavioral management meant something else:

EP-16 (S-1): No one should have interacted with Luna in the beginning, because then he might have not gotten used to humans and gone back to his pod.

EP-16 (S-2): I think people never should have interacted with Luna in the first place, because that's how he died.

4.6.2.4. Category 4: Organizational Innovation

Organizational Innovation refers to a causal reasoning that the accident could have been prevented if Department of Fisheries and Oceans had changed its overall attitude and mandate towards the community in the handling of Luna's situation. As an example, one child argued:

G-194: The government should have let Adam, or whatever the guy who was in the First Nations keep Luna company, so that he wouldn't have to go play with other boats and dangerous things. That would have been the best strategy.

The same child, in stimulus 2, also argued:

G-194: The government should have taken good suggestions, and not gone behind the people's backs. They [should] have someone stay with Luna so he wouldn't get into trouble.

This category has been particularly popular with the majority of Grade 5 students. On the other side, although nearly half of undergraduate students justified that DFOs position and

involvement was not alright, this particular reasoning seemingly did not translate in the preventative action questions.

4.6.2.5. Category 5: Technological regulation

Technological regulation refers to a causal reasoning that the accident could have been prevented had motorboat activity been regulated, either by suspension, redesign or alternative technologies such as using canoes and kayaks. The odd thing about this category has been that although the dangers of the killer whale's interaction with motor boats were emphasized and stressed in many other categories, the suggestion that technology should have been regulated to prevent the accident turned out to be a category that stood out from the other four.

What is special about this category? Let us have a look at it, with one undergraduate student I pseudonymed Langshaw, whose justifications stood out from the rest of his peers. In his engagement with DFO right or not right question, he argued:

PA-4: [The government agency was] right to attempt to isolate the whale from human technological dangers, but they took a passive approach of discouraging actions where they should have encouraged alternative responses to ensure the safety of the whale without attempting to control the interactions with the whale.

From the very beginning, Langshaw argued that the DFOs policy was sound, but he found shortcoming in their proceduralized safety culture which in his words discouraged "alternative responses" to address the safety, while at the same time preserving the human-nature interactions. For Langshaw, that alternative solution was obvious; where other students who resorted into more predictable solution headspaces, he was drawn into a radically different one:

PA-4: Design a prop shield to protect the whale from the blades on all local boats, or something of the sort so there wasn't the danger of harming the whale.

In Langshaw's headspace, the solution lies in not attending to the political matter or issues stemming from the social side of the story, such as preserving interactions, relocating the whale to 'end' the problem, restraining human behavior, or suggesting changes in government's stewardship behavior, but of the physical, engineering side of the story. This is epitomized in his response that the solution to the problem lies in designing a shrouded propeller – not to protect the propeller from wear and tear and preventing damage to humans, but to protect the marine mammals!

Langshaw was the only undergraduate student who looked at one of the chief root-causes of the accident with an empathic engineering headspace. He was the only student that came up with the prop shield idea as preventative action. A likely explanation is that his empathic engineering headspace enabled him to deploy critoeconoetic assessment which produced a long-term solution to the problem. The insight occurred to him as crystal clear safety management solution, addressing the basic (read: root) cause of the accident. He recognized this by sufficiently sampling his episodes, noticing that all other kinds of solutions had been tried by community, experts, environmental managers, marine biologists, as well as First Nations, and could not prevent the accident from happening. Where majority of students demanded preventative action in one of these domains and could possess conflicted views about what should have been done, Langshaw saw the root-cause through his "laser-like" intelligence profile (Gardner, 2006), deployed critoeconoetic assessment, and subsequently laid out an engineering solution that meets with a moral obligation of not harming the whale.

Is Langshaw's solution a foresightful/prudential one? Let us take a further look at his cognitive ecology before settling on an assessment. When he engaged with the second stimulus question, he remained consistent and expanded upon his conviction through analytical justifications that demonstrate a very keen ability to deploy critoeconoosis:

PA-4: The intervention at the level of the whale's interaction with technology would have gone farther than the interaction with man...They should have spent less time on trying to prevent human/whale interaction and done more to facilitate and study it. If they would have modified and improved upon the human technology in the lake to attempt to prevent any dangers towards Luna like the exposed engine props and threat of float planes they may have been able to create a more symbiotic relationship, instead of waiting until an accident were to occur. This would have possibly prevented the death of the creature and helped further the important goal of humans learning to live more within nature and less manipulating it.

In this response, we see a student who engaged in lateral thinking induced by MTT, synthesizing his episodic experience in creating a different solution headspace. Not only did Langshaw argue that regulating – or in his words “improving” – human engineered technology is necessary, but also a moral obligation (“learning to live more within nature and less manipulating it”), and a foresightful/prudential act (“create a more symbiotic relationship”). In Langshaw's solution headspace, moral obligation, foresightful/prudential act, and engineering design innovation walk in tandem; they are inseparable from one another. His argument more broadly points out that *Homo sapiens* are failing to co-evolve with other species, just as all other nonhuman animals do, but choosing to co-evolve with their own technologies, and when this choice has been challenged, failing to attend to the root-cause of the issue.

On the other side, technological regulation turned out to be a slightly more robust category among less articulate but to-the-point grade-aged children who had similar as well as slightly different ideas to Langshaw's, such as:

G-155: They should have taken canoes out instead of boats with propellers because if they did do that, Luna might still be alive today.

G-165: Maybe they should have used paddle boat if they wanted to see Luna, so he wouldn't have been scraped by the propeller.

G-170: I think the instead of using a tugboat, they should use a canoe or kayak.

EP-45: Allowing people to touch Luna but not on the motor. They would go on the canoes because it would be safer for Luna.

E-71: They should have been able to have contact with Luna but made a rule of [using] only paddle boats around to keep her safe.

As it could be seen, child participants who appeal to regulating technology do not particularly criticize the government agency's behavior for not being innovative, but rather focusing more specifically on the problem as occasioned by the mode of technology. They suggest an ecological problem-solving trick, namely *downgrading* technology. It is a solution headspace that did not emerge among undergraduate students. The fact that we did not encounter *downgrading* technology among undergrads but *upgrading* it (in Langshaw's response), in my judgment, is a developmentally curious question that must be explored.

4.7. Discussion

4.7.1. Children's Environmental Profile

The children's overall environmental profile shows something important: That environmental education has begun making inroads in the formal school curricula. When they responded to various questions in regards to the human interactions with nature, many children responded with diverse viewpoints. As an example, 44% of children marked Luna's behavior as the most important and interesting thing they learned. It is clear that young students find the so-called soft sciences such as animal behavioral ecology and human ecological interactions with nonhuman animals more appealing. They would be more successful entryways, for example, when enabling them to think more foresightfully/prudentially in the topics of evolution, biodiversity, or ecosystem interactions. As Dunbar (1995) also bolstered, behavioral ecology, animal cognition, or psychological science in general

are areas of science that are intuitively easier to understand because we can relate to their subject-matter more easily....The advantage of this lies precisely in the fact that these disciplines deal predominantly with social behavior, and would thus capitalize on children's natural facility for understanding the social world. (p. 183)

There is also reason for education to be optimistic about the impact of environmental education in the sense that children are noticing that the planet is in danger and humans must learn to cohabit with nonhuman animals; they also do not evaluate incidents as complex as Nootka Sound impulsively as "it's government's fault," but instead use discretionary judgements.

These findings suggest that it may be now time for science and environmental educators to consolidate the environmental learning of recent years by concentrating on creating foresightful/prudential reasoning supporting curriculum topics. For example, science teachers could provision opportunities for students to engage in deliberate MTT with respect to problems and dilemmas similar to colonizing Mars to *versus* sending humans to oceans to communicate with orcas. They can then use these science topics to scaffold children's learning and encourage for the deployment of critoeconoosis, or more broadly, promote critoeconoetic consciousness in the classrooms. These topics could easily harness children's MTT abilities and direct their cognitive energies towards the practical problems of the planet-wide environmental stewardship. More could be gained in science and environmental education by re-envisioning curriculum topics through sophisticating children's overall MTT abilities than simply teaching facts, constructs, respect, or care in an indiscriminating manner (Blumstein & Saylan, 2007, 2011).

4.7.2. Age Differences

The results of this exploratory study showed that children's and undergraduates' uses of preventative action categories change with respect to their developmental level. In addition, the results showed that with increasing age, the tendency to fault authority is decreasing, which affirms an expected developmental trend that post-formal operational individuals are able to engage in relativist thought patterns (Chandler, Boyes, & Ball, 1990), evaluate complex events far less impulsively than 10 year olds and 12 year olds. On the other side, the results also showed that children as young as concrete operational level recognize the complexity

underlying the Nootka Sound accident, and able to provide multiple justifications in their evaluations. Some children engage with the issue deeply, and do not simply shut out or provide impulsive System 1 responses. The question here ultimately boils down to whether or not science teachers could provide sufficient opportunities for students to lean more on their System 2 reasoning patterns when encountering ecological problems, so that those students who underperform based on their developmental stage could become more engaged.

It could be that 10 years of age is the bottom developmental threshold where science teachers could provision more MTT-based learning opportunities by engaging students with dynamic system problems similar to the Nootka Sound accident. In my judgement, the results of this study show that some children are capable of solving ecological problems through producing insights. Further studies requiring similar and other interventions using complex event-frames are required to understand whether or not 10 years of age is the developmental threshold for sufficiently negotiating with socio-ecological problems. Considering the Darwinian view of intelligence based on socio-ecological niche differentiations, these studies could specifically target other Canadian provinces, as well, could be conducted cross-culturally in other regions of the world.

4.7.3. The popular “three” and the marginal “two”

There are very subtle differences when it comes to how students synthesize their episodic experiences into preventative actions. According to Klein (1999, 2013), this is a typically encountered situation in real world contexts where subtle differences (or fluctuations) in individual’s experiences could lead them to profoundly different solution headspaces.

Perhaps the same could be said for our young participants. McNemar's test showed that student problem solving headspace clustered around three categories more robustly: organizational innovation, preserving interactions, and relocation *over* regulating technology and behavioral management. Although at this stage I tend to remain somewhat skeptical, it could be that the marginal two highlight the root-causes of the accident (i.e. human behavior error and insufficient technological regulation), and therefore the results suggest that only a small segment of students demanded those root-causes to be taken care of, rather than more visible, immediate causes of the incidents, such as the first three. This could also help explain why 70% of students thought the government's involvement and position was not all right, focusing their attention and motivation to addressing the DFO's institutional behavior in a reactionary way rather than other areas for growth, such as regulating technology.

Hierarchically, Organizational Innovation stood out as the most robust solution category and was particularly popular with Grade 5 students. For these children, the DFO stood out as the source of problem insofar as they wanted it to *go away*. In an odd sense, the government agency's attitude appeared to have resulted in eclipsing more foresightful/prudential courses of action by insisting on administering rules and policy as opposed to education and research. Similarly, relocating the whale also appeared to be a solution that focused on getting rid of problem – although what this meant showed much variability across different grades, such as when Grade 5 students appealed more to Luna's welfare by pointing that his pod abandoned him and he needed to be reunited with the pod. Finally, preservation of interactions often times pointed to “letting nature take its course” as understood and invoked by Mowachat-

Muchalat First Nations, eliciting an understanding that may run counter to western educational thought: sometimes the best solution to a problem is bringing no solution to it.

Indeed, some children recognized that the stewardship team's failed effort to use operant conditioning²⁰ on the killer whale (Staddon & Cerutti, 2003) was the underlying factual cause of the accident, and subsequently suggested that *leaving-things-be* could have been the optimal way of handling the problem – indeed, the results showed that students tend to prefer preserving interactions over managing behaviors of the community and Luna. This suggests that students think it is in everyone's best interest to preserve human–nature interactions rather than attempting to manage human or animal behavior. In my judgement, this domain, which was spotlighted succinctly in the documentary, could be capitalized on when teaching indigenous epistemologies to students in the Canadian classrooms.

One insight emerging from this study is that more could be gained in science and environmental education by providing opportunities for students to think about the root-causes (or basic/underlying causes) embedded in dynamic system problems – that it could be human behavior, organizational behavior, or human technologies that resulted in the demise of a killer whale, or more perennially, in the demise of biological diversity worldwide. If teachers decide to engage students with similar scenarios, dynamic system problems is one of the areas where they need to scaffold children's thinking and prevent them straying to impulsive System 1 thinking patterns, and cultivate more engaged, motivated, and prudent System 2 thinking patterns. By deliberately providing opportunities for students to tap into this headspace, more

²⁰ Originally coined by B. F. Skinner, operant conditioning refers to controlling the outcome of an agent's behavior by virtue of reinforcement and punishment.

could be gained in science and environmental education than simply letting students to discover their own lessons.

In that regard, we finally come to a full circle with our argument in the second chapter: that, it is *us* humans who need to be foresightful/prudent about the preservation of other species, precisely because it is us who possess an incredibly flexible MTT ability that helps us plot alternative courses of actions to prevent problems becoming infinitely insolvent. This insight must at least suggest a developmental goal orientation to an otherwise narrowly framed STEM career-based education, enabling us to recognize the basic cause of sustainability predicament: human cognition and human organizational behavior. No engineering, technology, or medical education program is adequately equipped to address the compounding problems of human cognition and its ramifications in the organizational scenery. Thus the suggestion here is that psychological science *needs* to be a more robust part of STEM-based school curricula (American Psychological Association, 2013).

4.7.4. Differences between Stimulus 1 and Stimulus 2 Questions

The analysis showed that with stimulus 2, students began focusing on the more immediate causes of the incident. Indeed, in focusing more on relocating Luna, either with the purpose of reuniting him with its pod, and to a marginal degree, to send him to a captivity in order to keep him safe and prevent from dying, students' previous solution headspace potentially undermined their pre-existing headspace. With this turn, we observed statistically significant changes that decreased their previously more robust appeals in organizational innovation($\chi^2(4, N = 262) = 10.41, df = 1 p = .001$), regulate technology($\chi^2(4, N =$

262) = 8.04, $df = 1$ $p = .004$), and to a smaller degree, in preservation of interactions ($\chi^2 = 3.94$, $df = 1$ $p = 0.46$).

With Stimulus 1, the more general, unstructured question, I now hypothesize that students became driven to more ecosystemic thought patterns. I believe this is because general, unstructured inquiry points compel them to decentralize and use their episodic memories to search for the most critical detail of the problem. They used System 2 thinking, using their episodic memories more proactively. Perhaps this effect was facilitated in the fact that this question was the first stimulus. The significance of this facilitation is both a theoretical and an empirical question, and it needs to be clarified in future studies. On the other side, with the structured question that got them focus on the situation of the whale, students appealed more to their emotional side, engaging in System 1 thinking, and therefore the immediate cause of the treatment that was sufficiently emphasized in the treatment measure.

Educationally, this psychological issue may be suggestive in the following sense: it could be that teachers not only need to engage their students with complex socio-ecological problem of similar calibre, but also they may first need to engage them with more general, unstructured inquiries in order to get students think broadly about dynamic systems. If curriculum continues to draw on single cause incidents, students will get very little opportunity to use their episodic memories as a significant cognitive resource. If curriculum draws on inquiries into multi-cause incidents, students will have more opportunity to engage in MTT. Indeed students get little opportunities when curriculum and teaching begins imparting that “humans cause the extinction of biological diversity.” A child who is naturally more prone to System 1 thinking and induction, this translates as, “It’s humans’ fault.”

Such pedagogical discourse is insufficient for the child to decentralize and tap into broader ecosystemic patterns of reasoning (as also pointed out by Parlar & Davis, 2013). We know from evolutionary anthropological studies that it is not humans per se, but the current human niche-construction activity that manifests itself as *one of the* leading causes of the decline of biological diversity (Laland et al., 2000). The more dynamic (not difficult!), multileveled, and scientifically fleshed-out the problem gets, the more opportunities students will find to harness their MTT abilities. Whether or not this could enhance student motivation to engage in further scientific inquiry is currently anyone's guess; future studies need to be designed with a side-goal of identifying this effect as well. In any case, the intended effect of this scheme is that students engaging with dynamic system problems could provide further opportunities to their teachers to aid their scaffolding through less direct and occasionally more diffuse forms of inquiry.

Developmentally speaking, there is also a rather counterintuitive inference here. Perhaps this less direct inquiry approach is necessary because it deliberately creates a disorder in the child, by pushing her conscious thinking into deliberation, towards a state of disequilibrium where she cannot think impulsively as she would if the word "Luna" were present in it; and the child then begins seeking for solutions by engaging her episodic memory more proactively, appealing to System 2 thinking patterns, to re-equilibrate his internal and external ecological state. This in itself was the method of Piaget. As Kahn (2011) noted by drawing on Piaget (1983),

a child brings to new situations an existing ways of understanding them, and in this sense seeks to assimilate the new to the old. But that process never works completely,

so the child also needs to accommodate to the new. Sometimes, the accommodations are not successful. At that junction, the child is disequilibrated, recognizing the problem but not the solution. Thus, according to Piaget, toward seeking equilibration, and through interaction, the child reorganizes existing structures of knowledge to take account of the new and previously discrepant information....in this account of the equilibration of cognitive structures the psychological system does not seek homeostasis in terms of an original state...but in terms of new and more comprehensive and adequate psychological structures. (p. 191)

Perhaps this is where one of the potential answers to our predicament lies. Categories such as organizational innovation, relocation, and preserve interactions had more robust appeal to students in stimulus 1 question, because they had to deal with a relatively more challenging inquiry that prompted them to more heavily lean on to their episodic memory systems. But they lost their appeal in statistically significant ways in stimulus 2 when question focused their attention to the killer whale. Indeed, the response rate to second question was generally much lower and more along the known patterns of thinking.

I cannot speculate further on this issue as only future studies could determine whether or not how significant this subtle effect is. My general understanding is that more studies are required to understand how resourceful episodic memory can get in environmental problem-solving, which could promote new ways of thinking about how to measure, assess, or foster foresightful/prudential thought and behavior.

4.7.5. Is prudential problem-solving declining with age? An observation of a retrograde developmental trend

In my judgment, technological regulation stands out as a distinct category, pointing out to a causal analysis and problem-solving headspace that was not prevalent among the students who participated in this study. When I encountered Langshaw's response, the curious question for me was why he was the only undergraduate student who evaluated the incident from a critical-empathic engineering headspace. In fact, why did not anyone who physically got involved in the Nootka Sound incident see the solution in a similar way?

But perhaps even more curious, why was the solution of using kayaks and canoes – just as First Nations did – not considered by any adult, but conceived by the unsophisticated mind of a 10 year old? I believe this is a developmentally important question.

As I hinted at in Chapter 3, Klein introduced a novel model (i.e. the triple path model) of naturalistic insights for the identification and solution of real-world problems; the chapter argued that this model could be used as a way of assessing intellectual development. The triple path model shows three critical dimensions to naturalistic insights (i.e. connections, contradictions, creative desperation) which could be also applied to how dynamic system problems are identified or solved. Unlike Kahneman (2011) who sees heuristics and biases as impediment to learning and problem solving in novel situations, Klein considers them an asset. As he put it, "when we put too much energy into eliminating mistakes, we're less likely to gain insights" (Klein, 2013, p.2). Seen from this perspective, we should be able to generate an explanation to the questions above.

Statistically speaking, technological regulation was not a significant category. It was marginal across all age groups, and it did not seem to significantly depend on the responses of one age group. However, the surprising aspect of this category is found in the qualitative responses. In Langshaw's response we saw a problem solving headspace that took the first path in Klein's (2013) model, *seeing connections*. He spotted an implication in the problem that others did not see, namely, the path to *upgrading* technology with an empathic engineering headspace to "help further the important goal of humans learning to live more within nature and less manipulating it." He added a whole "new anchor" (Klein, 2013, p.104) that changed our understanding of the accident, urging us to be foresightful/prudential in a different way.

But I believe there is an even more important stack of developmental discovery, that the majority of children who used technological regulation category mentioned using canoes and kayaks, and/or no boats with propellers. This reasoning for downgrading technology to prevent the problem did not appear among undergraduate students. However, it took the same path in Klein's model, *seeing connections*. It was a critical insight that most adults had either patently failed to see or failed to act upon, but did not escape from 10-year-olds' attention, by virtue of which they urged us adults to be foresightful/prudent in a much different way. Where most adult minds that took part in Nootka Sound accident were in the business of how to handle the complexity by a process of eliminating what is working and what was not, they overlooked this simplest solution that was only recognizable by 10 and 12 year olds.

I believe there is much to learn from this issue. Both Baldwin and Piaget traditionally urged their audiences not to underestimate a child's intelligence; the abovementioned analyses are consistent with their original insights into child development. In addition, one explanation

here should draw on children's biophilic tendencies, which, if Wilson's (1993) theory is correct, could be considered as partly congenital and partly cultural heuristics-and-biases. Far from being an impediment, in the case of Nootka Sound accident analysis, they became an asset in helping students recognize one of the potential root-causes of the incident (i.e. technological regulation failure). But the congenital part of biophilia here could have more votes, since the other explanation shows that we are living in a culture that embraces technology as a value-free enterprise that cannot be touched or critiqued (Huesemann & Huesemann, 2012). The suggestion of *downgrading* technology by using canoes and kayaks as opposed to *upgrading* it by designing a new prop shield, modifying and improving human technology served the same ends, but with profoundly different trajectories. It could be that where *downgrading* represents System 1 use, typically seen among 10-year-olds, and *upgrading* represents System 2 use, which should be expected among young adults such as Langshaw. They both indicate the deployment of critoeconoesis, but they both suggest different trajectories for in what ways *Homo sapiens* can use its MTT ability to prevent further damage inflicted on biological diversity and their nonhuman inhabitants.

Seen from an evolutionary perspective, children's responses presented an optimal solution that no undergraduate student had conceived. It also did not emerge from a mind that has a matured understanding of what sustainability means. The curious question here might be that we are witnessing a retrograde developmental trend that violates the expected trend that with more education, the better problem identifiers or solvers students become. It could be that with more matured heuristics in some domains, such as the ability to perceive and make sense of the world through relativistic thought, adult minds (unless trained to see technological,

design, and engineering problems that lead to safety issues), are not particularly prone to foresee the environmentally harmful effects of certain technologies. This provides partial support to an earlier neuropsychological argument (see Chapter 2) that the brain structures responsible for MTT ability (although near-universal across species) has specialized with respect to the disequilibria endemic to industrial-urban niches.

Future studies need to replicate this effect. Although I must remain skeptical about this stack of discovery, I believe the congenital side of biophilia has more votes. Children found out about Luna's death in a run in with tugboat. They became upset and even angry. We asked them what could have been done differently to prevent the incident. Receiving that stimulus, they synthesized their episodes, which resurfaced the image that Luna was interacting with the propellers. As in one Grade 7 child who evaluated the government agency's involvement positively argued,

EP-68: When the film showed footage of the risks of boat propellers to marine animals....It shows the BC Department of Fisheries and Oceans' reasoning to set rules in place about interacting with Luna. I could tell that that scene was quite graphic to most people.

Children, by using their innate tendency to reject mutilated bodies (Epley et al., 2007), determined that the propeller and motor boats were existential threats to the killer whale. Some children took this route and synthesized the relevant episodes into an insight, and suggested that propeller and motor boat activity should have been prohibited or suspended. But even a smaller group of children made different kinds of linkages. They did not stop there; they synthesized their episodes of First Nations using canoes, and recreationalists using kayaks

when interacting with the whale. They determined that this was the safer option that allows steady-state interaction for both parties without anyone getting injured.

In an odd sense, children's somewhat innate tendency to seek equilibrium and using inductive logic became an asset to the solution of the problem; simple, but down to the point: everyone should have used canoes and kayaks just as First Nations and recreationalists did. The problem is solved! It presented itself as a combination of many processes. Indeed, the First Nations of West Coast have been successfully interacting with orcas for thousands of years, without making any dent in their population (Baird, 2002; Knudtson, 2004; Francis & Hewlett, 2007) (And it is unlikely that children took into account this fact as well when synthesizing their solution headspace!). The curious question is, why has not any undergraduate student, DFO representative, or marine biologists, who have engineering, biological science, and psychology background, as well as far more sophisticated cognitive modules notice this?

We must therefore ask the same question that Klein asks: "What prevents us from grasping an insight? Even when it sits dangling in front of our eyes, ripe for the plucking? Even when others brighten at what they have unexpectedly discover?" (2013, p. 3).

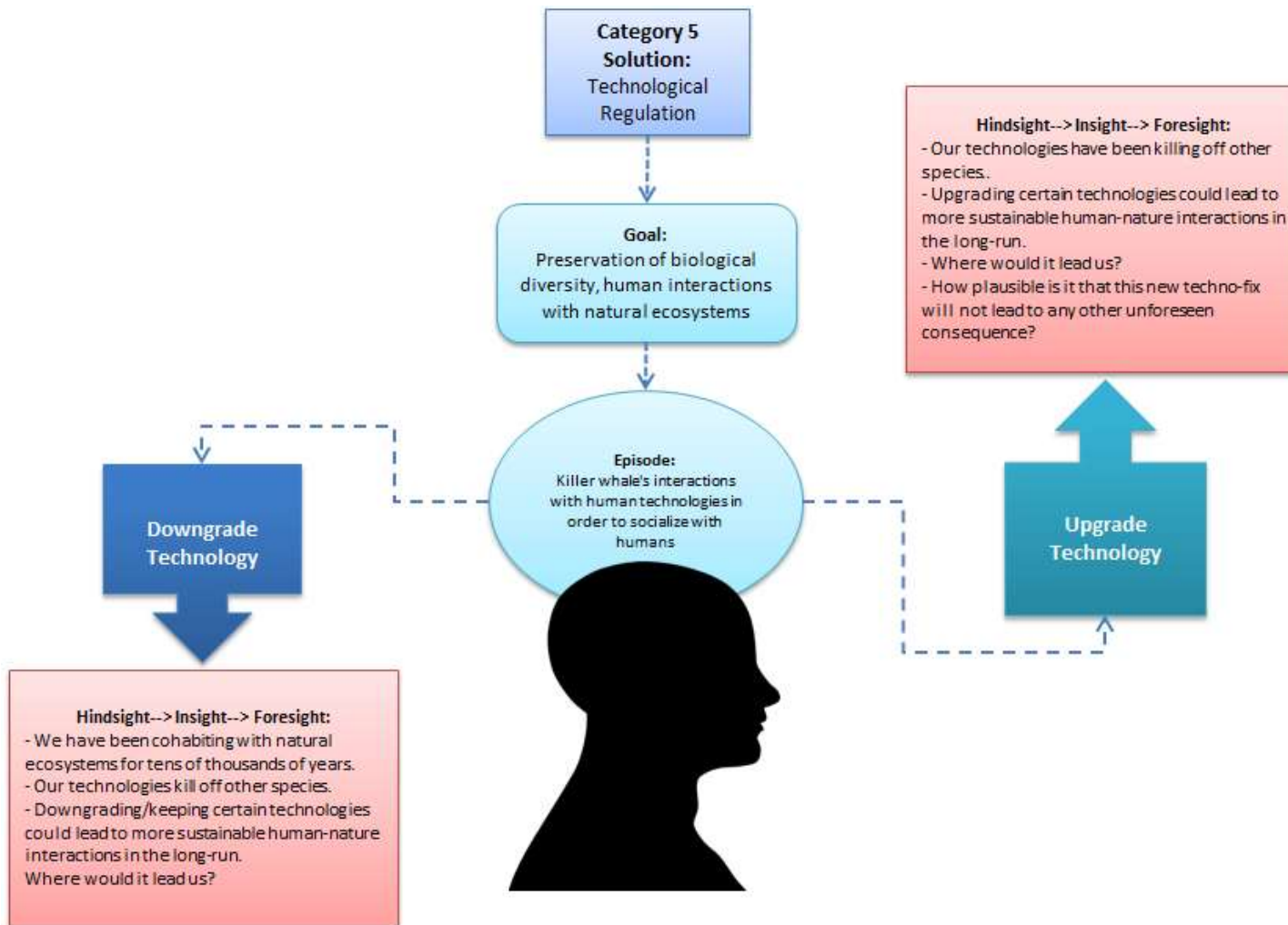


Figure 4.4. A model representing two different types of critoeconoetic assessment, leading to vastly different effects in the real world.

4.8. Emerging research questions

The findings emerging from this exploratory grounded-theory based study enables researchers to consider the following empirical and conceptual questions:

- In what other ways researchers could capture or engineer/design MTT-based learning in naturalistic settings such as classrooms?
- Are dynamic system problems educationally more effective when assessing the extent foresightful/prudential thought manifest itself in learners than single cause problems and puzzles?
- Is a documentary film an appropriate MTT stimulus measure?
- Three years of age is currently determined as the lowest developmental threshold for engaging with MTT tasks involving artificial tasks (Suddendorf et al., 2011). With the study presented in this thesis in mind, is Grade 5 (i.e. 10-11 years old) the lowest developmental threshold for engaging MTT tasks involving dynamic system problems?
- How common is the retrograde developmental trend observed in relation to technological regulation? In what ways could the results be replicated in future studies?
- Could MTT tools be built as educational technology, utilizing dynamic system problems, allowing students to deploy critoeconoesis when identifying ecological problems, their root-causes and overarching causes? If yes, what would be the learning differences emerging from individual or collaborative use of these tools? Which methodology would be more effective and in what ways it would be more effective?

The evolutionarily–driven theory spotlighted throughout this thesis holds that the development of foresightful/prudential intellect is contingent upon the flexibility and the reach

of MTT ability. Especially this means an active appeal to recursive learning, learning by extrapolation, and motivation to engage in critoeconoesis. If this theory is correct, then there is more to be gained both developmentally and educationally by providing opportunities that will enhance students' MTT abilities.

In addition, the findings emerging from this study, coupled with the evolutionary theory above also enables us to construct an educational hypothesis for future testing. That is, MTT ability could be stunted in classrooms involving little tasks that stimulate episodic memory and more tasks that promote semantic-procedural knowledge. In my judgment, this is a reasonable hypothesis. As our normal classroom hour observations during this developmental study revealed, students make heavy use of mnemonic devices that reduce cognitive effort and promotes appeal to technologically assisted short-cuts, rather than devices that stimulate motivation, attention, and active collaborative engagement. Although the provincial curriculum broadly advocates collaboration and critical thinking in all grade levels, it could be that classrooms are underequipped with MTT tools, or the units draw insufficient attention to MTT tasks in ways that teachers could deliberately cultivate foresightful/prudential reasoning in students.

Future studies must examine not only the developmental benefits of MTT-based learning, but also to what extent MTT-tasks are used in various curricular units – the fact that technological regulation is a marginal category that decreases even further at the undergraduate level is a troubling finding and lends some initial grounding to the hypothesis above in that the formal science curricula as well as higher education curricula in the province may not be providing enough opportunities for students to put their MTT abilities and deploy

critoeconoosis when examining the evolutionary ramifications of the current human interactions with natural and technologies systems. In many ways, the results of this research attests to Blumstein and Saylan's (2011) assessments in regards to the theoretical, conceptual, and empirical insubstantiality of current science and environmental education programs and their implementations in North America, in that they either cultivate the notions of respect and care or teach the physical facts, but do not make substantial modifications on future-oriented thinking and action regarding overconsumption and its correlate lifestyle choices. This assessment provides more grounds to why MTT-based learning, in the grander scheme of things, could be rudimentary to the long-term success and authoritativeness of science and environmental education, as well, the proliferation of an ecologically foresightful/prudential intellectual capacity across different groups via education.

Chapter 5: Two Techniques Associated with MTT-Based Learning

5.1. Introduction

Mental time travel research in education collects together a suite of research and development programs, which includes designing MTT applications, tools, technologies, and pre-test post-test interventions to assess the development of foresightful/prudential intellect in learners, interventional studies aiming to strengthen episodic memory, and training students for deploying critoeconoosis. In particular, the domain that would align best with this effort would be environmental education incorporating both physical ecological, socio-ecological, and evolutionary aspects of complex environmental issues. In this chapter, I turn my attention to MTT-based learning and explore how this learning could be applied in this domain. Two prominent exemplar techniques of MTT-based learning will be introduced: (1) the root-cause and overarching cause analyses, and (2) Klein's PreMortem technique.

5.2. Exemplars of MTT-based learning

There are two prominent techniques that spotlight how MTT-based learning occurs. These techniques have recently found appropriate applications in fields such as business management, health, safety, and environment, and engineering sciences. An examination of these techniques shows that they are essentially MTT practices aiming to enhance individual decision-making capacity or sustainable learning from past events. Here I extrapolate these techniques to the domain of environmental education and show how they can be made part of

science and social studies teachers' arsenal, to be used as a way of supporting the development of foresightful/prudential intellect.

5.2.1. Technique 1: Root-cause and overarching cause analyses

A potential way of harnessing our MTT abilities and enhancing our capacity for critoeconoesis is to engage in root-cause and overarching cause analyses. Specifically, root-cause analysis techniques originally emerged from human factors researcher James Reason's (1990, 2000) Swiss Cheese Model. This model demonstrates how an emergent phenomenon is materialized upon passing through various human made safety and integrity barriers. These barriers are procedures, policies, rules and regulations, backup systems, technological measures, and checkpoints. They are artificially designed and/or engineered by professionals in various fields (e.g. health care, engineering, administration) where safety and integrity is part of professional gatekeeping practice to prevent damage to the institution, systems, technologies, and individuals. Reason likened these barriers to Swiss Cheeses, showing that regardless of the engineered safety barriers and scaffolds, an emergent phenomenon manages to locate the holes in those barriers, resulting in an incident, event, or accident that produces disequilibria in the system.

Most root-cause analysis techniques carry the Swiss Cheese Model in their kernels and are employed widely in the investigation of industrial and workplace incidents and accidents (e.g. Mobley, 1999; Paradies & Unger, 2000; Andersen & Fagerhaug, 2006). In professional engineering practice, a root-cause is identified as "the most *basic* cause (or causes) that can *reasonably* be identified that management has control to *fix*, and when fixed, will prevent (or

significantly reduce the likelihood of) the problem's recurrence" (Paradies & Unger, 2000, p. 52). The aim of finding root-causes is not to find errors of individuals, but to find out recurring or insolvent problems within a system with the aim of long-term prevention. In the professional practice, investigators often reconstruct events via tree-based models, sequence-of-event diagrams, or checklist forms, supplementing them with photographs, diagrams, and witness statements as appropriate. Once the chronology is appropriately constructed, the investigators conduct causal analyses and decompose the flow of events until an effective or fixable solution is found. Experienced investigators often employ "stop-rules" to prevent redundant analyses or making inferences based on missing or limited factual evidence (Rasmussen, 1990). As an example, in the Fukushima nuclear powerplant incident, where radiological release caused long-term damage to people and the environment, the direct/visible causes are often attributed to the organization; whereas investigations show that underlying causes are linked with insufficient disaster preparedness and failing to update basic safety procedures in regards to international agreements (Lipsky, Kushida, & Incerti, 2013). Similarly, in the Prince William Sound oil spill that caused long-term damage to the fish, mammal, and other organisms on Alaskan shores, where the direct causes were attributed to the ship's captain's behavior, further investigations revealed underlying causes associated with regulatory compliance, design and engineering, and basic safety procedure neglects.

Root-cause analyses epitomize the most practical forms of learning as they strengthen organizations' and professionals' capacity to sustainably derive preventative actions from those events' technical, social, and situational details with the end goal of long-term prevention of

financial/material, individual, and integrity loss. Since their function is more deliberate, they work differently than solving problems via insights (cf. Klein, 2013).

Because root-cause analysis prompts investigators to back-track the evolution of incident/accidents and determine anomalous events within that evolution, investigators are almost always compelled to mentally construct those events, and make causal inferences based on those constructions. By analyzing witness statements, photographic evidence, and sampling previous episodes, investigators construct semantic particularities embedded in incidents and accidents. Indeed, incidents and accidents are essentially episodes that occur only once within a given time frame. Unbeknownst to engineers, it could be argued that the tools that structure the root-cause analysis processes are indeed basic MTT tools as they aid their users to manage their otherwise sporadic and unreliable episodic memory systems. They are more than basic mnemonic devices that help retain information or memorizing.

In that sense, root-cause analysis tools are more than basic mnemonic devices that help retain information or memorizing; they are technologies for training individuals to deploy critoeconoesis, enabling recursive learning by virtue of categorizing, encoding, and organizing information and evidence. In that respect, they are tools that aid information processing.

The ability to perform root-cause analysis is a relatively new industrial skill and one that is likely to be higher in demand in future science, technology, and engineering careers. This is particularly systems currently regulating innovation and process designs operate in far more complex environments than those seen in 20th century (Perrow, 2011). Many organizations relying on high-tech processes feel the need to perform such analysis in order to ensure that the processes, best practices, and organization's culture, reputation, and environmental

performance are sustainable. On the other hand, organizations also routinely lack reliable assessment techniques that facilitate causal analysis training (Katsakiori et al., 2009; Drupsteen & Guldenmuld, 2014). Accordingly, it could be said that with the retirement of aging populations in developed countries, including Canada, organizations are lacking expertise for identifying and assessing hyper-causal, dynamic system problems now increasingly endemic in their routine operations.

The question is whether or not STEM education can assist attending to this need. In my judgment, this is one of those areas where MTT-based learning can find ample applications. Techniques such as root-cause failure and success analysis are not yet considered core competencies in STEM careers (with the exception of chemical process engineering); however, an MTT-based learning frame can potentially turn such techniques into core competencies, facilitating learners to *grow* those skills from earlier stages. Not only these techniques can be applied for learning how engineered systems work; it can also be used to *teach* how dynamic system works – especially, problems that have ramifications for long-term environmental sustainability and stewardship.

Indeed, those five categories which students appealed when they were mentally constructing “what could have been done differently” could be embedded into what can be called a “mental time travel tool.” Such tools allow its users to harness their episodic memory systems, especially, if they provide sufficient scaffolding or a logic pathway for its users. As an example, an MTT tool designed to examine the Nootka Sound accident could have the following problem identification process rationale and design (see Figure 5.1. below):

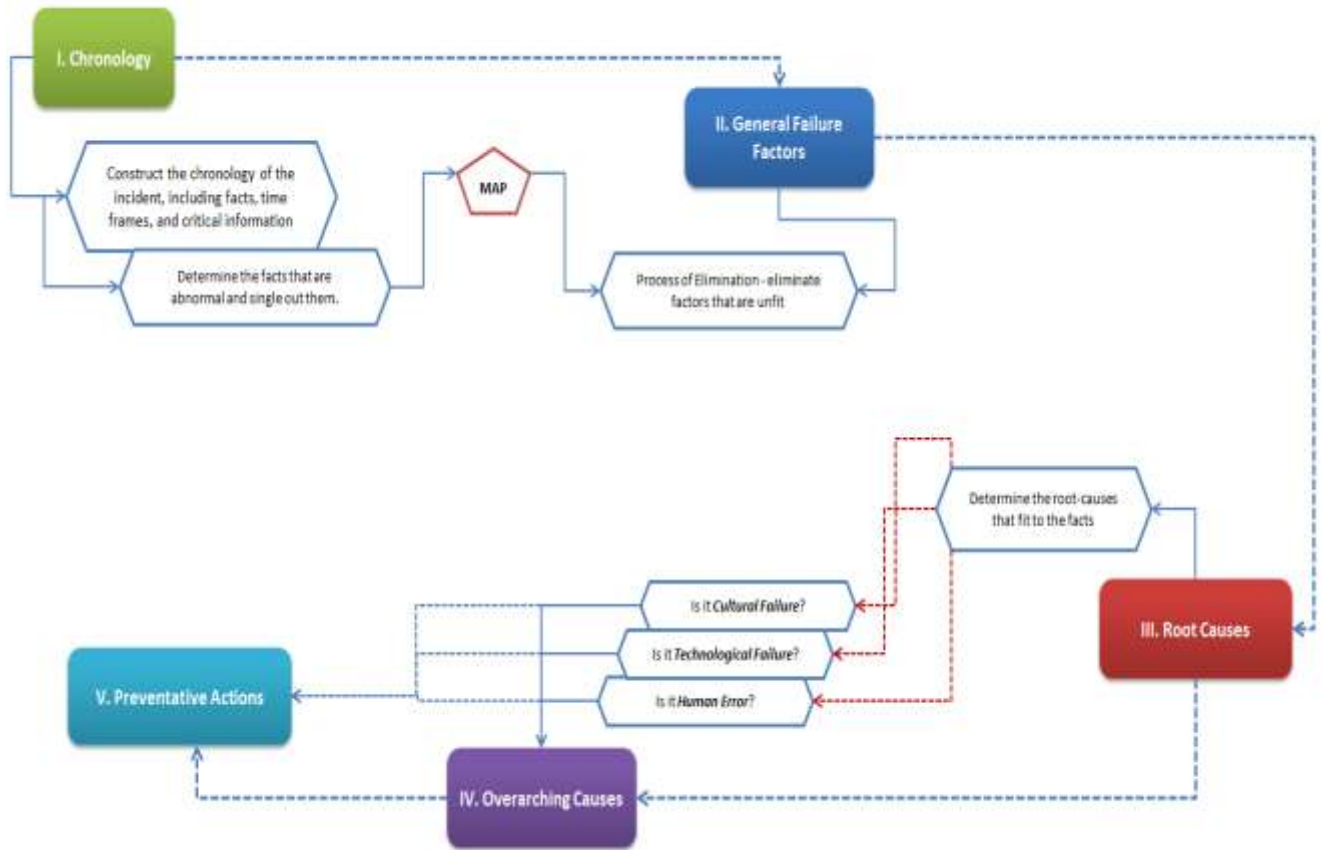


Figure 5.1. This design layout illustrates that through following these steps, a learner can mentally generate a back-forth investigation style and harness his episodic memory in a structured way. Figure 5.2. illustrates a prototype incident investigation tool where this design logic can be implemented.

Individual use
 Collaborative use

Type the #Code of Event _____

A GENERAL FAILURE FACTORS *Is it related to...* → **B ROOT-CAUSES** *Revisit the facts and ask why?* → **C OVERARCHING CAUSES** *Why?*

HUMAN BEHAVIORAL RESPONSE <input checked="" type="checkbox"/> <input checked="" type="checkbox"/> <input checked="" type="checkbox"/>	<input checked="" type="checkbox"/> YES <input type="checkbox"/> NO	<ul style="list-style-type: none"> • Lacking safety perception • Insufficient ownership • Insufficient long-term thinking • Lacking knowledge of wild species 	Human Error
INSTITUTIONAL PROTECTION <input checked="" type="checkbox"/> <input checked="" type="checkbox"/>	<input type="checkbox"/> YES <input checked="" type="checkbox"/> NO	<ul style="list-style-type: none"> • Insufficient problem-solving • Unsuitable techniques applied • Insufficient monitoring • Non-adaptive policy making 	Technological Error <i>No evidence of environmental regulation enforcement for the use of boat propeller shields in a hot biodiversity zone.</i>
DESIGNED & ENGINEERED PROTECTION <input checked="" type="checkbox"/> <input checked="" type="checkbox"/>	<input type="checkbox"/> YES <input checked="" type="checkbox"/> NO	<ul style="list-style-type: none"> • Not complied with environmental regulations • Environmental regulations absent • Older design used • Alternative designs not considered 	Cultural Failure <i>Alternative stewardship methods (such as those of Mowacht-Muchalat's canoe-based interaction) were not considered or applied.</i>
COLLABORATIVE PROBLEM SOLVING <input checked="" type="checkbox"/> <input checked="" type="checkbox"/> <input checked="" type="checkbox"/>	<input type="checkbox"/> YES <input checked="" type="checkbox"/> NO	<ul style="list-style-type: none"> • Insufficient communication • No communication • Delayed communication • Non-cooperative attitude 	

D Preventative Actions

Please select those that describe the best preventative action to the problem:

- a) Discussing safety issues openly
- b) Leading by example
- c) Researching
- d) Enhancing knowledge of animal intelligence
- e) Communicating better
- f) Reporting small problems in a timely manner
- g) Seeking expert advice
- h) Other: _____

Figure 5.2. M3T prototype incident/accident investigation tool combining both root-cause analysis and overarching cause analysis. In this sample, an abridged version of the Nootka Sound accident investigation is presented. The root-causes and overarching causes are found via following the abovementioned problem identification process rationale. A fuller version of this educational tool is currently being designed and developed by Parlar.

The basic issue is that if a tool such as this can be developed and taught in science classes, teachers will be in possession of not only a teaching tool, but also an assessment tool, as well as a research tool, all of which can contribute to enhancing the likelihood that students will harness their MTT abilities, deploy criticoeconoesis more frequently, and reasonably identify the root-causes and overarching causes of environmental problems such as Nootka Sound. A preliminary study shows that not only are such MTT tools found to encourage participants to enter into a collaborative problem-solving headspace (Parlar, in preparation), but also they educate their users to deploy more deliberate reasoning as collaborators serve as 'stop points' to one another, preventing impulsive judgments from forming.

More could be gained for supporting the development of foresightful/prudential intellect if such tools are developed and used in classrooms and other learning settings. This argument can be justified on the grounds that not only such tools harness our biologically primed MTT ability, but also they provide the necessary vocabulary to learners. Such vocabulary can allow learners to focus their attention more to the long-term ecological consequences of the events under investigation. Starting with a (1) chronological breakdown of events, (2) mapping abnormal events to general failure factors as a way of eliminating categories that are not suitable, (3) reasonably determining the root-causes, (4) determining the overarching causes, and finally (5) producing preventative actions is a structured process that can allow the emergence of a complex learning process and continuously stimulate MTT back-and-forth. Through the use of such structured problem-identification and solution design (as embedded in the tool), educators can determine ways of enhancing the likelihood that more students arrive at the Technological Regulation category. Through this dynamic problem identification and

solution interface, educators can also teach why the escalating conflict between *Homo sapiens* and nonhuman ecosystems is sourced by unbridled technological sophistication and pervasiveness.

A common criticism of environmental education today is that environmental problems are often over-politicized and used as shock and blame instrument as opposed to prompting individuals to take action with regards to cognitive transformation or cultural evolutionary change (Blumstein & Saylan, 2011). As Turner (2013) also argued poignantly, “neither the general public nor even most of the environmental community appreciates the wild, self-willed, autonomous, self-organizing aspect of the physical sciences” (p. 44)²¹. As a result, environmental education researchers dedicated too little time and effort to designing, developing, and testing practical learning tools for students. As examined previously, the literature up until this point passionately advocated for educating a responsible environmental citizenry through the use of critical environmental discourse or cultivating pro-environmental behavior through experiential learning, technology, and participatory action within communities. However, none of these approaches specifically taken into account what I described as the bottom of iceberg in Chapter 1, where educationalists regularly encounter problems of cognition, motivation, and memory. Consequently, environmental education in North America has focused disproportionately on either cultivating respect for nature (countercultural tones) or teaching environmental science topics as set of facts impervious to critical input, exploration, and improvement (Blumstein & Saylan, 2011). Therefore, we know very little about what types of cognitive transformational benefits can be reaped (e.g.

²¹ Whether or not science teachers themselves focus on this aspect of the wild nature in their classrooms could also be researched in future studies.

foresightful/prudential intellect) if practical causal analysis tools and techniques are designed and used in classrooms when teaching environmental topics. Under the rubric of MTT-based learning, future research needs to focus more on the design, development, and testing of such tools and the types of learning they generate.

5.2.2. Technique 2: Klein's PreMortem technique

This evidence-based technique has been developed by Klein (2007) as a measure of strengthening the decision-makers' project estimation outcome. Klein built this technique based on a classical study of prospective hindsight effect (Mitchell, Russo, & Pennington, 1989), which enhanced the success of the target project by a margin of approximately 30%. Klein and colleagues (2010) defined the PreMortem technique in the following sense:

A post-mortem refers to an autopsy conducted on a patient to determine the cause of death. The autopsy provides useful information to the medical community and to the family but it does nothing to help the patient. The PreMortem method moves the "autopsy" forward. Thus, a project team may include a PreMortem during the Kick-Off meeting. A Pre-Mortem is an exercise conducted around the premise that a program or plan or project has failed. The team generates plausible reasons for this failure, and these reasons become the plan critique. (Veinott, Klein, & Wiggins, 2010, p. 2)

Here, the PreMortem technique is identified as including the following steps: "(1) Prepare by getting familiar with the plan; (2) Imagine the plan completely failed – a fiasco; (3) Generate reasons for failure; (4) Consolidate the lists of reasons; (5) Revisit the plan: What can be done to prevent the fiasco?" (Veinott et al., 2010, p.2). According to Klein, PreMortem

technique is a crucial adjunct of post-mortem-based techniques and can enhance learners' ability to decentralize, reduce subjective overconfidence, and engage in critical thinking via collaborative fault-finding. In its essence, Klein's technique is an exemplar of basic collaborative MTT application that promotes the solution of problems by virtue of both deliberate analyses and insight-based problem solving in naturalistic settings such as workplace and classroom.

There are currently no investigations showing the benefits of this sort of technique on school-aged children's learning of environmental problems. Although collaborative learning has an established track record in educational research (e.g. Mercer & Sams, 2006; Slavin, Groff, & Lake, 2009), Mercer (2013) noticed that "much of the group activity which goes on in classrooms has little educational value" (p. 158). Indeed, my observations during regular classroom hours of Grade 5 and 7 classrooms in three of the CBE schools showed that more often than not, group-based studies in classrooms lead to increased socialization, and yet little significant intentional learning. More often than not, I observed the formation of mob attitude (particularly around internet use) and insufficient scaffolding in relation to the critical goals and outcomes of collaboration.

As Mercer (2013) argued, "[t]he ability to think collectively may be an important and defining characteristic of our species, but that does not mean that children are born knowing how to do it well" (pp. 158–159). Equally clearly, collaborative learning does not mean joining together and discussing about topics. Often times, collaborative learning needs to involve clearly outlined criteria and stop points towards which students can work, and most importantly, share intentionality (Tomasello et al., 2005). Although we are evolutionarily

predisposed to collaboration, unless collaboration activities scaffold for shared intentional problem identification, little significant learning would be gained from those efforts.

The benefit of techniques such as PreMortem is that it can produce a tangible, structured pathway that demonstrates why collaboration is *required* to identify and solve a problem. PreMortem or relevant techniques are particularly useful when examining dynamic system problems, as the use of the technique reduces confidence in collaboratively working problem-solvers (Veinott et al. 2010). Reduction of problem-solving confidence in an individual should not be interpreted as a negative development. With appropriate pedagogical scaffolding, a decreasing overconfidence could signal the formation of foresightful/prudential thought patterns in learners. Indeed, one of the chief root-causes of the current anthropogenic environmental change could be linked to the fact that decision-makers and stakeholders tend to overestimate organizations' and new technologies' abilities for identifying and solving problems that emerge in complex and unpredictable ways.

Especially, if students use relevant techniques and are subsequently prompted to present their findings to the classroom for peer-feedback, the collaboration could lead to the formation of a type of "doing science" identity in them. Indeed, a neglected issue in science education today is the formation of the image that scientific research that leads to discoveries is conducted by forming teams where individuals with different disciplinary strengths contribute to the identification and solution of a problem (Wilson, 2013). In that sense, techniques such as root-cause analysis and PreMortem can additionally help build the formation of a scientist's identity in students, which is necessary in order to cultivate their interest in science.

Finally, if used in conjunction with dynamic system problems where attractive science topics such as animal intelligence are spotlighted (i.e. the Nootka Sound Accident), techniques such as root-cause analysis and PreMortem could potentially motivate students to further engage in MTT in a collaborative fashion. In that sense, the argument is that teachers must determine not only which technique to use, but also the types of problems that could motivate students to join together and identify the issues embedded in those problems.

5.3. Ideological barriers to MTT-based learning

Despite increasing input and interest in inquiry-based or problem-based learning (e.g. Kirschner, Sweller, & Clark, 2006; Hmelo-Silver & Azvedo, 2006; Hmelo-Silver, Duncan, & Chinn, 2007), dynamic system problems is not a well-studied area in science and environmental education. Particularly in affective-meta-ethical awareness environmental education research, the word problem-solving gathers storm clouds (Jickling, 1991; Sauvé, 2005). This is epitomized in Jickling's (1991) statement:

[P]roblem-solving denotes a level of precision, exactness, and plausibility alien to the careful investigation of environmental issues. Expecting a child to solve environmental problems without proper regard for their infinite complexities, is setting the child up for potential failure. (p.153)

In my judgement, the term "problem solving" has suffered from overuse and exceedingly narrow applications in education. We clearly cannot and should not expect a 10 year old to come up with a low-cost, high-yield energy resource that does not rely on extracting hydrocarbons from soil, and then solve our energy problems in the next few decades. As I

mentioned earlier, we cannot expect young people to have matured heuristics and biases to appreciate the sustainability predicament, an evolutionarily unprecedented ecological problem of *Homo sapiens*; in that regard, given Jickling's (2001, 2006) poignant critique of the education for sustainable development paradigm, his point is agreeable. On the other hand, one cannot help but notice that we might be underestimating children's developing intellectual competencies, and more broadly, our species' evolved capacity to solve ecological problems through MTT.

As I showed in the Chapter 2, both problem identification and solution processes need to be considered in evolutionary terms. We create, perpetuate, see, frame-reframe and solve problems in every waking hour of our lives; they are our existential drive over the course of our lifespan. In group conversations, a story is never interesting enough to hold prolonged attention unless it involves a problem or conflict that is encountered, created, or overcome. Problems constitute an essential part of episodic memory in that they are part and parcel of our constructed narratives. Throughout our evolutionary history, we have solved many problems – the problems of how to ambush megafauna, preserve information, communicate, store food, and plan for next year, as well as the problem of how to prevent other mates stealing your partner through inventing a universal symbolic convention we call marriage (Deacon, 1997). We invented language collectively to solve a rudimentary problem, rallying others in constructing a power-hunting niche (Bickerton, 2009). In hunter-gatherer societies, children absorb a problem-solving headspace from very early on, through adults who scaffold their learning by provisioning opportunities for them (Premack & Premack, 1996; Paradise & Ragoff, 2009; Konner, 2012). They learn whatever precision, exactness, and plausibility is required to do a job

from earlier stages in their childhood by simply hanging out with their fathers, mothers, cousins, grandfathers, grandmothers, extended relationships, and sometimes, with their domesticated or tamed animal companions, such as horses, falcons, and dogs: Cannot travel from region A to B fast enough, recruit horses; cannot track the game efficiently, recruit falcons; cannot track the smell of a food source, domesticate wolf pups and let them do the job. Hunter-gatherers use animal companions as their living-and-breathing technologies to help them solve their ecological problems (Lee & Daly, 2004). They co-evolve with them. Today, we use machines to do those tasks because our problems are intertwined in a technological web that requires other technologies and tools to reach solutions. As shown in the second chapter, this intertwinement is the case because our MTT abilities enabled us to construct tools to build other tools, allowing symbolic culture to evolve in a cumulative fashion (Donald, 1991). Only now are we able to recognize that our engineering genius has come to undermine a future where *Homo sapiens* would be less fit and healthy as a species, both physically and psychologically (Kahn, 2011). What started out as an innocent trick led to the construction of agricultural niches, the underlying cause of our current sedentary lifestyles (Larsen, 2012), and of the unprecedented loss a biologically diverse planet where our ancestors roamed and explored with more freedom (Brody, 2002, Diamond, 2006).

Nonetheless our species' perpetual drive to solve ecological problems small or big, in its essence remains the same. Only in the modern world, because of institutionalized overprotection of children and micromanagement of child development, do we deny opportunities from children in identifying, if not solving, problems. In education, there is even a more recalcitrant issue: that is, problem-solving is often synonymous with testing culture, and

problem-solving involves something more akin to isolating children in classrooms and school laboratories, and engaging them with artificial math puzzles, toys, and related learning apparatus; we isolate five children in a laboratory, give them blocks and pencils, and tell them to go ahead and build something. This pre-existing methodological tendency has recently been a target of criticism in the learning sciences community (Barab & Squire, 2004).

In my judgement, this trend is what environmental education adhering to experiential learning seems to abhor the most, in particular, the grading part (see also Jickling, 2009). The point of experiential learning researchers could be agreeable in the sense that those problem-solving tasks are studies of experimental psychology that provide insight into children's cognitive performance that can thus inform contemporary educational emphases on personal development and understanding. But it may not be agreeable in a sense that students should not solve environmental problems; quite the contrary, teachers, as cognitive engineers, should proactively help students to identify and assess those problems, and deliberately provide opportunities for them to get into the problem-solving headspace. Students may falter in the process, but this is where a positive, transformative, and indeed, foresightful pedagogical attitude can galvanize their attitude to learning and teach them to turn their failure into assets. This is how experiential readiness and tacit knowledge is built in the real world (Schank & Neaman, 2001). A foresightful/prudential teacher would teach students to observe why, where, and when they failed because the recognition of the particularities of those failures is often the most effective way of maturing students' heuristics and biases in whichever particular domains they deal with a manifest problem. Perpetual and uncritical success could have more devastating ramifications in the long-run.

Our species has been identifying and solving problems throughout our evolutionary history, by virtue of rites of passages and apprenticeships; children fail, learn to self-parody and laugh at their failures, and are taught to not repeat mistakes by their elders while on hunting and exploration (e.g. see Nelson, 1969; Konner, 2012). By way of these rites of passages and apprenticeships, children develop a secure sense of identity and pride in what they do. Evolutionarily, children are still predisposed to respond well to types of learning that involves apprenticeship and rites of passages. Same could be argued for their biological tendency to engage in fantasized mimetic rehearsals by using toys, tools, action figures, and sometimes their own bodies, or when they engage in self-talk (i.e. private speech, see Vygotsky, 1978) so as to sophisticate their auditory biases for better symbol learning – these are activities that involve MTT. Remembering the fact that mammalian brains evolve at a glacial speed (Jerison, 1973), could we still claim that human children became less predisposed to learning by doing, failing, extrapolating, imagining/fantasizing, and making practical associations among various natural phenomena in the few last thousand years?

Chapter 6: Teacher Education and MTT-Based Learning

Our future directed behavior can even go beyond merely individual needs and may carry concern for the planet itself, along with its inhabitants. That concern may also extend beyond the life span of the

individual. As perhaps the only species with such foresight, humans alone may be driven to consciously guide the planet into the future and thus be burdened with the responsibility of getting it right. We can identify future threats to our world, be they of our own doing (e.g. the consequences of human-induced global warming) or of external origin (e.g. an asteroid collision course with Earth).

Humans can forecast the outcomes and choose to act now to secure future needs. Cultures have evolved complex moral systems that judge actions as right or wrong partly based on what the actor could or could not have reasonably foreseen to be the future of consequences of the act. Law, education, religion, and many other fundamental aspects of human culture are deeply dependent on our shared ability to reconstruct past and imagine future events.

Thomas Suddendorf and Michael Corballis, 2007, p.312

6.1. Introduction

The evolutionary view firmly suggests that in its essence, teaching is a behavior of provisioning opportunities for others, as observed across multiple species (Caro & Hauser, 1992; Thornton, Raihani, & Radford, 2007; Thornton & Raihani, 2008; Hoppitt et al., 2008). Through provisioned opportunities, individuals enhance their problem identification and solution fitness, which in effect helps with the goal of survival.

Although the core of teaching as provisioning opportunities remains the same in humans, the active evolution of symbolic languages and institutional cultures has drifted

teaching increasingly away from teaching to identify solutions for basic needs. Professional teachers today are tasked with provisioning opportunities that only indirectly contribute to those needs. Schools hardly impart the knowledge of how to hunt an animal, how to cultivate food, how to attract a mate, or how to prospect new territories and resources. Where these skills are essential in a hunter-gatherer economy of knowledge (Ingold, 2000), modern schools' tasks are centered on teaching how to manage increasingly abstract symbolic language tasks over the course of one's lives. As Donald (1991) argued, the majority of activities that take place in classrooms and schoolyards are about memory sophistication in symbolic language domains.

Naturally, the social ecology of teaching and schooling falls short when the goal turns into the education of foresightful/prudential intellect in the domain of environmental stewardship. Unlike hunter-gatherers, most of us today lack the space and land to practice environmental education. Students get fewer opportunities to experience diverse and healthy natural environments with their own eyes. Our wide-range entrapment in the dynamics of urban-industrial niche construction and maintenance inevitably makes foresightful/prudential thought on the future of human interactions with natural ecosystems increasingly difficult. Only in rural or semi-rural environments, more success is likely to be achieved (Ross et al., 2003). Place-based or land-based education programs (e.g. Henderson & Potter, 2001; Greenwood, 2008) could therefore represent ideal "hands-on" strategies used teachers can use to get students think about the long-term consequences of continuous human expansion on biological diversity.

Yet even place-based and land-based educational efforts can face potential roadblocks inasmuch as we feel emotionally uncomfortable with confronting two chief issues: (1) the

growing human population pressures that demand further agricultural, urban/industrial niche construction at the expense of natural ecosystems and their nonhuman inhabitants, and (2) the demand for job mobility, which makes it near-impossible for a person to establish long-term attachments to diverse and healthy natural environments²². The second issue creates a paradox in education: that on one hand, educationalists recognize the importance of grooming students for expert/tacit knowledge with the hopes of addressing the steady decline of expertise in the current workforce; on the other hand, they encourage the need for mobility and adaptability in order to enhance employment prospects. But once we capture this paradox from the perspective of cognitive and cultural evolution, it could be that these are rudimentarily incompatible goals for a species that is largely inclined to establish long-term attachments with a favorite biological reserve (Wilson, 1984; Heerwagen & Orians, 1993). To what extent industrial/urban niche construction driven human cultural evolution modifies the genetically-based attachments to the natural ecosystems and special geographies is a crucial question; yet this question has not generated a visible research program in evolutionary anthropology or educational studies on the adaptability of human intellect.

Mathematical models of human evolution indicated that socially complex species are capable of engineering culture-based niches (Laland et al., 2000). But as opposed to other animals who do that to secure their basic needs such as shelter, food, and mate, *Homo sapiens* have engineered their currently dominant socio-ecological niches based almost entirely on their cognitive judgements. The construction of agricultural niches was based on the notion of

²² Recall the lifespan developmental consequences of John Bowlby's (1978) attachment theory here. Bowlby argued that industrial systems are inherently unstable and considered them to be contradicting an otherwise normal mother-infant attachment widely observed in rural and indigenous populations. Attachment theory could similarly be applied when understanding the relationship between individuals and their favorite lands.

controlling the natural world. From ploughing earth and domesticating wild animals, to building large citadels based on Euclidian geometric applications, the notion of control runs deep in nearly every aspect of our industrial/urban lives, seen perennially in child-rearing, language use, technology, architecture, planning, and administration. According to Brody (2002), this difference in cognitive judgement was the key to the triumph of agriculture-based niches over hunter-gatherer economy of knowledge.

The cultural evolution of *Homo sapiens* has currently hit a stage where it is becoming increasingly clear that our previous cognitive judgements have fallen short in foreseeing their ramifications. Today we largely live sedentary lifestyles; on internet, forums and news columns are filled with stories of diminished contentment and satisfaction with life; impulsive, reactionary judgements continue to dominate administrative decisions and policy-making; collaboration quality has substantially declined due to the offloading and sharing of information in computer-generated platforms; excessive neurocognitive energy is being devoted to the management of information technologies; and problems are more likely to get solved by band-aids or forgetting than root-cause analyses. These symptoms are not merely islands of pathologies that could be addressed through more/better engineering or medical improvements. They are the symptoms of a self-domesticated species that struggles to adapt to an actively evolving, globally expansive, homogenous niche. The complex mathematical models underlying niche construction theory is clear on the effects of how inheritance of constructed socio-ecological niches can modify the adaptive capacities (read: resilience) of both niche-constructing species and the species affected by this process over generations.

In a sense, niche construction theory lends further support to the argument that the solution to the environmental sustainability crisis lies more in understanding, educating and training human cognition than unsophisticated, reactionary social or environmental policy. As policy-decisions are often caught in a cycle of over-interpretation, under-interpretation, or misinterpretation of critical issues, over time, they are less likely to cultivate critoeconoetic capacity in efficient ways. As argued in Chapter 1, a more efficient, long-term solution must target the bottom of the iceberg where the attention turns to questions such as “how can we enable students to engage more in System 2 thinking” or “deploy critoeconoesis on a complex environmental problem.” Equally clearly, the cognitive judgements we uncritically and unknowingly imparted to students in the last century need to be confronted with empirically demonstrable (or demonstrated) theories of human learning, problem solving, and cognitive development.

The theory that the development and maturation of foresightful/prudential intellectual capacity is contingent upon the flexibility of MTT ability should be considered a portmanteau starting point. In the last chapter, I illustrated two techniques that can provide collaborative learning frame when enhancing students’ potential for foresightful/prudential problem identification and solution in the domain of environmental science. In this final chapter, I turn my attention to teacher education and conceptualize ways of aligning the goals of teaching with the goal of sophisticating individuals’ and collectives’ foresightful/prudential intellectual capacities.

6.2. Evolutionary cognition as part of teacher professional development

Hofer (2002) argued that teacher education training tends to have the strongest influence on teachers' knowledge of student learning. In that sense, an argument could be made that in order to support the development of foresightful/prudential intellect, the ingredients that go into teacher professional development might require a set of other considerations beyond the current baseline.

Since the publication of Shulman's (1986) seminal work, teacher education programs in North America have strived to go beyond training teachers in their disciplinary specializations. Shulman's work identified the distinction between three types of knowledge that teachers need to be trained for: *content knowledge* (e.g. the disciplinary knowledge), *pedagogical content knowledge* (i.e. the knowledge of how a subject is taught with regards to its specific requirements), and *curricular knowledge* (i.e. knowledge of alternative ways of teaching a subject). These distinctions suggested that showing skill in a discipline and engagingly teaching/practicing that discipline can be mutually exclusive. Indeed, in our own schooling career, we likely have encountered teachers that were well-knowledgeable in their subjects, but could not have avoided student or parent criticism. Expertise does not always translate into effective teaching (Schank & Neumann, 2011), especially if developing expertise during one's disciplinary training becomes inert due to its abandonment outside the context of courses and workshops where those expertise are refined (Renkl, Mandl, & Gruber, 1996). A more likely argument is that expertise in a discipline and learning how to teach that discipline develop "through continuing participation in the discourse of a community, not primarily through the possession of a set of problem-solving skills and conceptual structures" (Pea, 1993, p. 271, cited

in Mercer, 2013, p. 153). Indeed, possessing a bachelor of science degree in biology does not indicate expertise in biology topics, unless the individual continues to engage with those topics deeply, or applies those topics in some fashion. However, the exception to the rule is that some disciplines and frames demand the formulation of new or more robust vocabularies, especially if predominant vocabularies used in that community cannot sufficiently articulate and advance the goals of those disciplines and frames. This formulation becomes particularly necessary if the discipline or frame is loaded with emergent possibilities, regulating the development of teaching expertise with respect to those possibilities. To invoke a previous rule of thumb, necessity is the mother of invention.

Throughout this thesis, my position has been that MTT can be best studied and made use of in education and in the service of long-term environmental sustainability by combining multiple disciplines, each of which elaborates the significance of this cognitive phenomenon in surprising and sometimes complicated ways. However, at the kernel of this effort, one foundation that fuels and drives the entire discourse has been kept constant: evolution. A central scientific-philosophical driving force of this thesis has been that the emergent learning possibilities deriving from the frame of MTT can be sufficiently reaped by employing evolutionarily-based epistemology, which subsumes the vocabulary of cognitive neuroscience, evolutionary/biological anthropology, developmental science, and ecological-evolutionary approaches to teaching, social learning, problem-solving, and intellectual development. Thus the logical suggestion is that in order for MTT-based learning (which involves designing MTT tasks, tools, and technologies) to become successfully implemented and researched in classroom-based education, place-based/land-based education, and workplace education,

future MTT-based learning practitioners need to attain mastery in the vocabularies, discourses, and theories of knowledge underlying evolution. Just as Dobzhansky (1973) who famously declared “nothing makes sense in biology except in the light of evolution”, or Richerson and Boyd (2005) who similarly echoed, “nothing about culture makes sense except in the light of evolution” (p. 237), it could also be said that nothing about mental time travel makes sense, including all teaching and learning efforts that can be developed around its flexibility and reach, except in the light of evolution.

The portmanteau discipline that brings together the vocabularies of the abovementioned fields and approaches can be called *evolutionary cognition*. As spotlighted throughout this thesis, studying this discipline underscores that understanding and claiming expertise on cognitive phenomena (e.g. MTT, intelligence, decision-making, metacognition etc.) requires working transdisciplinary. In educational theory, Davis and Sumara (2008) articulated that

transdisciplinarity compels a sort of border-crossing – a need to step outside the limiting frames and methods of phenomenon-specific disciplines. Transdisciplinarity is a term that is intended to flag a research attitude in which it is understood that the members of a research team arrive with different disciplinary backgrounds and often-different research agendas, yet are sufficiently informed about one another’s perspectives and motivations to be able to work together as a collective. (p. 35)

Evolutionary cognition can be considered a transdiscipline which requires that practitioners become sufficiently knowledgeable about each other’s expertise. This is particularly important since designing MTT tasks, tools, or technologies necessitates collaborative efforts. Indeed, a degree taken in psychology, biology, or anthropology

(disciplines where MTT is currently studied) is unlikely to cover the technical details of complex cognitive phenomenon sufficiently. However, two practitioners (one with a background in social science, and another with background in natural science) working collaboratively are more likely to cover the theoretical and empirical details and goals that need to be considered when designing MTT-based learning. This collaboration could lead to the co-creation of a robust vocabulary required to successfully design and teach MTT-based learning.

In addition, it would also be more practical for education faculties to (1) build a core curriculum of human cognitive evolution in pre-service teacher education programs that makes both the theoretical and empirical aspects of evolutionary cognition as part of their ongoing dialogue, (2) promote this dialogue among professionally practicing teachers, and (3) educate its own teachers and researchers (via its graduate programs) who can then teach practitioners how to successfully design MTT-based learning as aligned with foresightful/prudential intellect goals, and implement it in classrooms or professional workplace environments. Given the successful alignment of cognitive psychology with the goals of education (Bruer, 1997), and the current need to more strongly align neuroscience with education (cf. Willingham, 2009), situating the field of evolutionary cognition as an element of the ongoing teacher education preparation and development could be an achievable goal in the next few decades.

6.2.1. The Case of Collaborative and Adaptive Root-Cause Analysis (CARCA)

I recently piloted the testing of an MTT technique called “collaborative and adaptive root-cause analysis” (CARCA) with four pre-service teachers, enabling them to come together and make a timeline analysis of the Nootka Sound accident. Just as children, they first viewed the documentary that lays out the intricacies of the complex problem unfolded, and then they were told to construct a chronological sequence-of-event diagram (see Appendix D, for a template), revisit the events, and engage in generating critoeconoetic consciousness collaboratively.

At the date of this writing, I have not been able to follow up on this study enough to produce at least five focus group cohorts, due to time, space, and financial restrictions²³. Therefore I do not report the outcomes of this study here²⁴. However, the insight I have gained from this design experiment so far has revealed something akin to *if you complete my memories, I will complete yours*, affirming one of my contentions that collaborative MTT activities can be developed and studied. I took this cue when assessing the post-study feedback responses of the following participant whom I pseudonamed Samantha. When I asked her “Was collaborating with another colleague and making a timeline analysis helpful?” she reported:

S: It was helpful because my colleague filled in the blanks in my memory. There were moments I remembered that she didn't and moments she remembered that I didn't. This was helpful because I think it's difficult for us to remember everything, but we remember what was

²³ An additional restriction was pre-service teachers' individual time schedules, which impeded the efforts for participating in cohort-based studies. Often times, individuals cancelled their participation in cohorts due to other commitments.

²⁴ Research Ethics clearance for this study has been obtained at the University of Calgary.

important to us so we may overlook aspects and our collaboration reminded me of those moments that were in fact important.

And when I asked Samantha “has participating in this study changed an aspect of your thinking” she reported:

S: This study reminded me of the importance of collaboration. We should use each other as resources because our minds cannot absorb each detail.

Whereas her cohort-group partner I pseudonymed Jessica considered more about its classroom implications. She reported:

J: It served us well as a pair. I think it’s a very powerful tool, I would be curious to see how it works in a classroom with a large group of kids that may require constant reminder to stay on task, or work with each other.

And when I asked Jessica “has participating in this study changed an aspect of your thinking,” she said:

J: I realize the amount of effort and work required in retrieval more than I had before.

Throughout the study, I observed persistent emergence of false episodes in each individual participants, when they tried to reconstruct the event. But in moments where they engaged in collaborative MTT (e.g. joint sampling of episodes, specifically) their effort turned into an episodic memory completion task. Samantha and Jessica ended up evaluating this technique as a positive intervention that they would be willing to use in their own classes, because it compelled them towards that “memory-completion” effort. By using CARCA, they reconstructed the evolutionary complexity of the event from its inception to its end. They engaged in a type of evolutionary thinking.

Techniques such as CARCA could be incorporated in pre-service teachers' core curricula, enabling them to find root causes of teaching and learning problems, and possibilities for improvements. As an example, the CARCA technique could be built within a course, perhaps with the suggestive title of "Designing Collaborative and Adaptive Learning Techniques," which should be taken after a theory course on evolutionary cognition. This succeeding course provides pre-service teachers the opportunity to harness their theoretical knowledge and design MTT tools for their prospective students or themselves.

We can envision several instructional learning outcomes coming from the second course for teacher professional development:

- (1) Learning to design MTT techniques such as CARCA in various (read: adaptive) curriculum topics. For example, because of the context of the course, students specializing in their disciplines (i.e. science, social studies, language arts, mathematics, etc.) would acquire the opportunity to use those techniques collaboratively, and benefit from each other's perspectives.
- (2) Testing the technique with collaborators multiple times. Here, pre-service teachers have the opportunity to explore their own heuristics and biases, and *complete* their mnemonic processes through collaboration.
- (3) Developing a structured MTT tool in which CARCA is embedded. As outlined in Chapter 5, collaborative problem identification processes can be embedded within structured MTT tools. By using the CARCA technique, pre-service teachers can learn various ways of developing MTT tools for investigating different types of complex, ecological problems.

(4) Learning how to use those MTT tools in classrooms to engage students' episodic memories and enable them to collaboratively identify problems. In the last leg of the course, pre-service teachers can attend to their practica, test the designed tool with their students, come back to the classroom, and give their feedback to the instructor and other colleagues.

Simply put: The instructor trains teachers on how to design and use the MTT tools; pre-service teachers design the tools, test among themselves, and go to school practica to teach their own students. Apart from the inferred benefits for teacher professional development and curriculum innovation, in my judgement, this strategy could also be designed as a developmental teacher education study using longitudinal design techniques. Through the broader theoretical frame of foresightful/prudential intellect, and the educational goal of engaging students in deliberate and carefully designed MTT-based learning tasks in critical domains such as science and environmental education, far more could be achieved in education as a scientific design discipline than what is currently on offer. Because of its connection with neuropsychology, aforementioned projects could additionally be made relevant to the emerging domain of educational neuroscience, yielding potentially fruitful studies investigating, for instance, what happens when two individuals start collaborative problem identification and engage in episodic memory completion efforts and during this process, simultaneously go under neuroimaging.

6.3. Designing MTT-based learning tasks: Theory to practice

Application of a theory to practice is often not an easy transition. More often than not, when a theory is being applied to practice or program, important components of that theory are not sufficiently integrated into the constituents of the practice or the program. As an example, the application of the biophilia hypothesis in environmental education circles is often framed through third-party references that tend to portray the concept of biophilia as a “universal love of nature” (Parlar 2014, a, b). In reality, the concept has an underlying cognitive scientific logic based in the gene-culture coevolution paradigm. This is also known as cognitive biophilia (Lawrence, 1993)²⁵, arguing that each language and culture invokes different relationships with nature. The gene-culture coevolution paradigm suggests that the evolution of these relationships co-varies with climates and geographies (Laland & Brown, 2011).

For instance, social anthropologist Brody (2002) illustrated that the modern use of Indo-European languages often lack the pragmatic associations required for cognitive processes (including learning) to become rooted in natural phenomena - such as melting of the snow, rising of the sun, cries of wild animals, namely a few. These associations can be commonly found in hunter-gatherer tongues. Brody showed that the Inuit has 40 different names for snow, each one identifying a specific form or condition of snow or ice. The Inuit dedicate considerable mental energy in remembering these associations and teaching them to their young, because it is significant for their long-term biocultural survival.

²⁵ Elizabeth Atwood Lawrence’s pioneering work on the cognitive foundations of biophilia is extended in the research program of cognitive anthropologists Scott Atran and Douglas Medin (e.g. Ross et al., 2003; Medin & Atran, 2004).

Due to this condition, a reasonable conjecture is that the development of biophilic tendencies in these communities will be based on how language is learned, used, and taught with respect to those natural phenomena. Biophilia, understood as a folkpsychological concept, does not inform us sufficiently about the Darwinian adaptationist logic underlying it – that is, pro-environmental behavioral and cognitive affiliations with a biological habitat corridor that provides certain types of essential dietary supplements, overall psychophysical security (including aesthetically pleasing ambiance) and affirms cultural continuity will be more likely to get positively selected for future generations. The suggestion is that if this term is continued to be used in education, practitioners need to learn the complex evolutionary logic underlying biophilia and ward off a sloganized, folkpsychological biophilia, which provides an insufficient scientific footing to environmental education.

In other cases, the consequences can be more severe when the subjects used are part of the mainstream, such as popular theories of intelligence. For instance, Waterhouse's (2006) examination of Gardner's MI theory indicates, "[t]raining teachers to believe that there are eight sorts of content intelligences, an easy musical route to improved spatial skill, or a division of the mind into emotional and non-emotional intelligence is training teachers in theories that stand against what is known about cognition from empirical research" (p. 221). This is more or less the equivalent of training teachers to believe that IQ-tests are predictive of student success, or Herbert Spencer's account of cultural evolution is the perfect application of Darwin's theory in the social action domain. When a subject matter that has not scientifically matured is broadcasted imprudently for short-term benefit, it could potentially lead to problematic consequences in the hands of the gatekeepers of the society.

Unlike branches of the physical sciences such as physics and chemistry, cognitive science (including brain science) is currently in its infancy (Wilson, 1999). Cognitive science owes much of its beginnings to the emergence of cybernetics and later on, to the computational view of human intellect (Dupuy, 2000); however, the association of the human brain with computer analogies and language of classical mechanics is grossly misleading when portraying how human cognition develops. As Deacon (1997) cautioned, a chief issue with brain-as-computer analogies is that they invoke progressive design metaphors. He wrote:

The problem is that our intuitive model for evolution is borrowed from the history of technological change, which has been a cumulative process, adding more and more tidbits of know-how to the growing mass of devices, practices, and records each day. In contrast, biological evolution is not additive, except in some ways very limited....Though we are on the large end of the range of body and brain sizes, this is not the result of adding new organs but merely enlarging existing ones with slight modifications (1997, p. 29)

Accordingly, one must remain agnostic about the claims of cognitive science until they are proven by rigorous conceptual examinations or factual evidence. But this necessary caution should not prevent education faculties from developing programs that prepare teachers in the known territories of human cognitive evolution. It is essential that teacher education programs should provide opportunities for pre-service teachers to explore and understand how human cognition evolves and develops, just as it is essential that education should be a critical contributor to the field of cognitive science, not spectating it or uncritically adapting its claims.

MTT is one of those evolutionary cognition subjects requiring much contribution from educational research. Not only can an MTT based approach to learning be embedded within the existing problem-based learning or case based reasoning approaches, but also it can be examined via the methods of dynamic assessments and intervention, e.g., by way of assessing critoeconoetic reasoning. Moreover, education possesses two main advantages over other fields examining this cognitive faculty: (1) the opportunity to conduct empirical research in naturalistic settings (i.e. classrooms, workplace, etc.), and (2) the ability to provide regular opportunities for developing and testing tools for specific domains and assess the development of student cognition, motivation, and learning. The advantage of MTT-based learning is that it compels students to use their episodic memory – this means nearly all curricular subjects from natural science and mathematics to social studies. As an example, in the context of producing an educational solution to the human predicament, the following contents could be stacked to create an educational synthesis:

<p style="text-align: center;"><i>Cognitive Science Content: Mental Time Travel</i></p> <ul style="list-style-type: none"> • MTT is the underlying universal cognitive faculty responsible for future-oriented thought and behavior. • MTT evolved out from theory-of-mind. Its function depends on the combinatorial performance of episodic memory (i.e. auto-noesis) and semantic-procedural memory. Episodic memory deteriorates earlier under normal ecological conditions. • MTT is responsible for offline thinking and mimetic culture. • Due to language evolution, human MTT has become immensely flexible. Humans can plan ahead, develop technologies, and learn from past mistakes. • The technological evolution and information overload have surpassed the human brain's information processing ability. The result is poor contextual learning, poor motivation to identify and solve problems via insight, over-reliance on System 1 thinking, especially in domains 	<p style="text-align: center;"><i>Science/Social Studies Content: Environmental Stewardship</i></p> <ul style="list-style-type: none"> • Overpopulation, anthropogenic climate change, biodiversity loss, soil erosion, drought, overconsumption, and improper use of water have become acute existential problems. • Human beings make environmental decisions that do not consider long-term consequences. They insufficiently synthesize the knowledge of past mistakes. They are poor at contemplating the evolutionary ramifications of their current thinking and behavior. • Long-term environmental stewardship is a key solution around which scientific and social policy must circumnavigate.
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where System 2 is required.

Educational Solution: Foresightful/Prudential Intelligence

- Educate individuals to become foresightful/prudential with respect to environmental stewardship. The extent of foresightful/prudential thought and behavior relies on the flexibility of MTT.
- This educational formula specifically requires providing opportunities for students to engage in MTT in the human interactions with natural and technological systems domain.
- Draw on curriculum topics that naturally allow MTT to be used, such as evolutionary anthropology.
- For more deliberate, goal-oriented teaching and faster cultural evolution, design MTT tools and technologies.
- These tools will primarily train students for critoeconoesis. Stronger critoeconoesis allows intellect to synthesize past learning more efficiently, consider the ramifications of current thinking and behavior robustly, and construct possibilities and alternative technologies or social policy solutions that could aid long-term environmental stewardship/biodiversity conservation.

This tentative model of curricular content knowledge syntheses suggests that in order to gain more success in environmental education, practitioners need to be able to combine the content knowledge related to both the evolution of MTT and environmental stewardship. This suggestion signals two things: (1) expanding the scope of teacher professional development so that teachers have enough opportunity to learn about cognitive evolution and develop

collaboratively useable mental MTT tools for environmental topics; (2) reduce the length of other topics that are rendered redundant once the topic of human cognition is extensively explored.

For instance, a proper curriculum on human cognitive evolution should include how human cultures and their distinct ecological problem identification and solution abilities became differentiated with respect to geography, climate, and ancestral niche construction processes that enhanced the selective impact of symbolic languages and cultures on individual variation. Learning this knowledge through the vocabulary of evolutionary cognition would make learning other types of topics, such as the poststructuralist or phenomenological accounts of cultural and linguistic diversity, naturally more redundant. Indeed, especially considering the gravity of the global environmental sustainability crisis, we need more robust and scientifically compelling vocabularies that articulate the human place in nature and the biophysical realities of the planet. As suggested throughout this thesis, niche construction theory is currently a suitable candidate for this task.

The shift in aligning the goals of teaching with an evolutionarily sound epistemology means allocating more time and energy for topics that are needed most. As an example, this shift aligns with Richerson and Boyd's (2005) recommendation to higher education that there needs to be an introductory level "*Homo sapiens 1* course" where students get "a complete introduction to the problem of understanding human behavior" (p. 245). Considering the immense impact of formal education on human cultural evolution, teacher education programs are ideal sites to implement such curriculum. This is also because such knowledge would be

more beneficial to pre-service teachers than to other students due to the ethical obligations and responsibilities of the teaching profession.

6.3.1. The case of evolution education

Before MTT-based learning and foresightful/prudential intellect emerged as a driving force of this thesis, I was more of the opinion that students needed to use evolutionary thinking or reasoning to understand the ramifications of anthropogenic environmental change (French, 2012). Evolution has been traditionally understood as the black sheep of education as it creates controversy in classrooms (Hermann, 2008). Cultivating evolutionary thinking patterns is a major struggle of evolution education, which is continuously sabotaged and distracted due in some part to creationism, and “intelligent design” movements in North America and Europe (Blancke et al. 2010; Depew, 2010; Taylor & Ferrari, 2011). It also is a struggle due in larger part to majority of evolutionary scientists trying to settle their own theoretical disagreements rather than making evolution more accessible to students (Parlar, 2013). Indeed, this trend is also somehow predictive of research in evolution education, which has been preoccupied with trying to teach students the logic of natural selection theory to combat religion, essentialism, and naïve theories (Samarapungavan & Wiers, 1997; Ferrari & Chi, 1998; Evans, 2008; Berti et al. 2010). Subsequently, an educational strategy that targets maturing students’ heuristics and biases in regards to the biophysical realities of the planet, or how our species engaged in niche destruction due to its recently short-sighted decisions and judgements has been notably absent in curricula that incorporates evolution. This strategy is clearly a different trajectory for

evolution pedagogy and curricula; however, a majority of researchers has been adamant about combatting the stranglehold of religions, defining their pedagogical path in reactionary ways.

An unintended consequence of this hardliner stance, not surprisingly, has been that students continue to understand evolution as something to be painfully passed on in their biology classes (Hillis, 2007). Jablonka and Lamb (2007) articulated its educational consequences as follows:

How biologists describe evolution also matters. Part of the reason why many young people reject or lost interest in evolutionary ideas is that when evolution is reduced to the selection of randomly occurring changes in genes, it seems to have little to do with their own understanding and experiences of the world around them, especially their understanding of human nature. (p. 389)

Equally clearly, Pobiner (2012) stressed that unless evolution pedagogy involves more human examples, there is little success to be gained by drawing narrowly on variation, inheritance, and differential reproduction of traits in each parental generation.²⁶ Learning evolution, as one biology teacher argued (Baumer, 2009), should be more than just about changing personal beliefs through teaching new concepts; or in this case, expanding evolution curricula beyond the mechanical logic of natural selection. It could be that this *something-more-than-as-it-is* refers to a new way of conceptualizing the goal of evolution education – particularly, if we begin to see that engaging in evolutionary thinking may in fact be using the same neurocognitive resources as engaging in foresightful/prudential thinking: episodic

²⁶ This observation coincides with Dunbar's (1995) argument that because the human social brain – as a primate brain – evolved to more successfully deal with the small complexities of everyday life, it is not predisposed to a motivation to understand natural and physical phenomena. Blaming angry deities for the misfortunes of *Homo sapiens* has always been a more compelling option than understanding the human place in nature.

memory. This connection was made explicit more strongly in a series of thought-provoking questions asked by the president of American National Association of Biology Teachers (NABT)

Donald French (2012):

Do we dwell only on the proximate aspects of biological processes (such as photosynthesis, cellular respiration, action potentials, macromolecule synthesis), or do we address the ultimate ones? Do students leave [classrooms] understanding that development is shaped and constrained by evolution, that evolution explains disease, and that thinking evolutionarily enhances our abilities to predict and find solutions to both natural and anthropogenic challenges that humans face? Or do students think that evolution is a course or chapter or set of days that are to be survived or avoided? Do we teach evolution as exemplary science that lets us explain and predict, thus providing students with insight into the nature of science, or do we accidentally lead students to believe that all the research that is done is focused on trying to find descriptive evidence to support it? (p. 68)

In relation to the research in cognitive development, there is currently no positive evidence illustrating that learning to think evolutionarily and learning to think foresightfully/prudentially are the same thing and uses MTT and episodic memory as the chief neurocognitive resources. However, this relationship can be hypothesized (if cannot be directly inferred) based on the nature and function of episodic memory as illustrated in Chapter 2. The knowledge that episodic memory is responsible for the construction of both past and future scenarios should give us a clue to why it could also be responsible for understanding evolution, which compels individuals to mentally construct not only how traits evolved in the past, but

also what they can evolve in the future. Indeed, this is a vital research question that needs to be pursued in future studies in MTT and MTT-based learning; for if it can be proven that this is the case, then the development of foresightful/prudential intellect can become a chief goal of evolution education.

Although foresight and evolutionary thinking might be using the same cognitive resources, we may not observe an immediate link between these two variables if the theoretical relationship between them is not sufficiently made through curricula and pedagogy. In order to make this link, here I conceptualize a curriculum and teaching example, and suggest what it would signal for science education curriculum.

6.3.1.1. Step 1: Expanding curricular knowledge

There is currently no written learning outcome in Alberta Education's Biology 30 unit (where evolution is being taught), advancing that "by the end of this unit, students will be able to think evolutionarily about psychological, sociocultural, and ecological ramifications of anthropogenic change," or "by the end of this unit, students will have more matured heuristics and biases," or "their foresight intelligence (if indeed measurable) will increase by a margin of 0.8." The existing curriculum recommends the biology teacher to become sufficiently knowledgeable about how natural selection works, how energy is conserved and transformed in nature, how cellular mitosis occurs, how hemoglobin transmits iron to red blood cells, and so on – basically, a number of buckets of semantic knowledge items that are of empirical appeal, which the teacher can demonstrate under microscopes and in field trips. This is very hands-on and convenient for twelve year olds. Nonetheless, considering that biological science also has

implications for social theory, an existing biology curriculum that teaches students a set of dichotomies (such as nature versus nurture or genotype versus phenotype) should be considered theoretically narrowly-focused and potentially unelaborated (Oyama, 2000, 2003).

A prominent line of inquiry emerging from sciences is the need for transdisciplinary collaborations and educating students not according to archaic departmental or curricular structures, but according to the dynamic and complex nature of scientific knowledge production. In that sense, our science teacher could take a few steps further, feeling the need to couple the standard knowledge of the modern synthesis with niche construction theory. This coupling specifically means being knowledgeable about the vocabulary that draws on ecological inheritance.

6.3.1.2. Step 2: Determining the content

To contemplate an MTT-based learning, one first needs to determine the content where this type of learning could be more effectively used. As an example, the evolution of cetaceans offers a suitable content. Science education researchers more recently demonstrated that teaching macroevolution to students yields more beneficial strategies for conceptual change pertaining to evolution (Catley, 2006; Samarapungavan, 2011). In our example, the task is to appeal to children's organic tendencies to affiliate with nonhuman animals, and use this potentially interesting content to start maturing twelve year olds' heuristics and biases. Based on an expanded curricular knowledge, the science teacher can now draw on how other species – such as cetaceans – also construct niches (Rendell & Whitehead, 2001) that can remain stable for millions of years.

6.3.1.3. Step 3: Knowledge of cognitive development

In the topic of evolution, the science education research has demonstrated that young children possess essentialist frames (Gelman, 2003) and they use inductive logic (Carey, 1985; Inagaki & Hatano, 2002, 2008). Because of their non-matured heuristics and biases, they will also be predisposed to seek for validation and affirmation from the teacher and their peers. In addition, we can now suggest that students can make System 1 and System 2 judgements depending on their emerging competencies in specific domains (Kahneman, 2011). These are some of the topics our science teacher needs to become aware of before designing her lesson plan.

6.3.1.4. Step 4: Designing the lesson plan

Our science teacher's personal task for herself is to recognize the link between the hypothesized symmetrical growth of foresightful/prudential reasoning and evolutionary thinking, while teaching the subject of evolution to the students. A good place to begin is to conceptualize the types of lessons she desires to impart or the kinds of insights she would like to see students producing. Such as the following:

- While most mammals are found to be descended from marine mammals, cetaceans at some point descended from land mammals. It is a counterintuitive evolutionary trend, and a poster child of macroevolutionary adaptation (Gingerich, 2003).
- With further adaptation to marine environments, cetaceans lost their body hair, and hind legs. Their front arms became fins.

- With having to voluntarily control their breathing and dive deep in the ocean to catch prey, cetaceans experienced nasal drift over thousands of years. Their blowholes are now placed on top of their heads.
- Communicating under water resulted in the macroevolutionary emergence of echolocation ability – a complex syntax that is efficient and adapted to communicate underwater (Whitehead, 2003).
- With adaptation to different food sources, such as fish-eating cetaceans and mammal-eating cetaceans, and krill-eating cetaceans, and so on, their biological order has diversified.

In a typical evolution class, these are the lessons that our science teacher may choose to impart to show how natural selection works at a macroevolutionary scale. The lesson plan could be tentatively designed based on the above bullet points. Next, our science teacher's task is to find a way to impart these lessons to students. After some tutorial and lecturing, the science teacher can show students how to apply the CARCA technique to the evolution of cetaceans. He can instruct students to group up and collaboratively construct sequence-of-event diagrams, treating each of those evolutionary moments as events, but the entire diagram as a macro-evolutionary process. Students can construct these diagrams either by forward-sequence or reverse-sequence; in either way, they will be engaging in MTT, and get to work on their episodic memories²⁷.

²⁷ The learning effects of doing it by forward-sequence or backward-sequence could be different, and requires empirical investigation.

6.3.1.5. *Step 5: Prospection*

Here, in a typical biology curricula, the learning outcomes for the four foundations, (1) Attitudes, (2) Knowledge, (3) Science, Technology, and Society (STS), and (4) Skills are set: Benefit to student interest in science, student understanding of science; benefit to student use of technology and virtues of collaboration (e.g. CARCA technique); benefit to society at large (a student who can think evolutionarily would be less likely to use System 1 judgements). But notice that the “benefit to society” part falls rather short. And notice that the benefit to the student is not particularly emphasized. With the student, we do not mean benefit to the student learning of science, per se. What is meant is the student’s cognitive, emotional, and moral development; we are looking into the positive effects onto their heuristics and biases. The curriculum, due to what can be called ‘the standardization demand-effect,’ does not cater for the student’s selfish interest, but expects them to begin socializing into our own symbolic conventions upfront.

If benefit to the student is not emphasized well, students could be potentially led to the sort of disengagement Jablonka and Lamb (2007) indicated; especially with a fragile topic such as evolution, one needs to be able to demonstrate its benefits simply for the student’s own selfish interest. However, an even more important issue here is about why benefit to society falls considerably short in a curriculum that is simply set out to teach basic dualistic biology (Oyama, 2003). As an example, if curricular knowledge is expanded through the niche construction theory, the following expansions in curricula learning outcomes can be realized:

Teacher inquiry: What would have happened had whales did not go back to oceans from terrestrial ecosystems?

Child's Standardized Learning Headspace: There would not have been any whales in the oceans. They would have adapted to terrestrial ecosystems. Nature selected/compelled them to adapt in oceanic ecosystems.

Child's Democratic Citizenship Headspace: Whales did not have to deal with being hunted down relentlessly by humans, or their environments being polluted by humans. They have been evolving on this planet millions of years before humans spread out of Africa. It is not fair that we humans treat them as we do. We should respect them.

Child's Systemic Sustainability Headspace: We would not have found out that cetaceans possess higher cognitive abilities, including a superior communication system called echolocation, and are as intelligent as human beings, and their further evolution important to the biological diversity, future of human species, and the planet. We already respect them, but it is clearly not enough. We need to practice prudential thought and behavior, which means we need to co-evolve not with our own technologies that harm them, but with the rest of natural world. We need to give future generations the opportunity to co-habit symbiotically with cetaceans, or the possibility to co-evolve with them, such as learning to swim and hunt with them.

Notice how each curricular approach extending the scope of inquiry will likely prompt other students to engage with more foresightful/prudential thought patterns, provided that a teacher also steps into the classroom everyday with this developmental goal in mind. Notice the symbolic evolution of learning from the factual knowledge of natural selection towards showing care-respect-justice-fairness, and finally towards practicing foresightful/prudential thought and action, and moving to ecological co-evolutionary possibilities in order to establish long-term stewardship and sustainability. Not avoiding them, or setting bars and walls between humans and nonhumans, but co-evolving with them, just as most other species has done for millions of years and produced the enormous biological diversity of this planet (Ehrlich & Raven, 1964).

In essence, notice that students will also be engaging in evolutionary thinking, especially in the third and fourth levels, when they begin assessing the ramifications of anthropogenic environmental changes on human populations. Each stage will build a different cognitive momentum in a child's mind, should an otherwise fixed biology curriculum expand to such territories, thus conveying learning from social studies towards ecology and back to social studies. Such expansion could be done at the teacher's discretion provided that the teacher *foresees* that expanding curricular learning outcomes by scaffolding evolutionary thinking in children would be an asset to the development of their foresight intelligence. With each level of scaffolding, the teacher attempts to engineering new cognitive processes in her students. Here, the teacher is a cognitive engineer, whose professional task turns into a foresight building activity, and that of preventing the formation of System 1 judgements, disallowing curriculum

to become an empty asset to her students. With provincial curricula on board, I suspect far more could be achieved.

6.4. Preventing the abuse of mental time travel

As with every innate or socially learned technology, MTT-based learning techniques are inevitably vulnerable to abuse. Consider the analogy of a physical time machine here: If we have a physical time machine that enables us to go back and forth in time, what would we try to correct, or improve, or prevent from happening? In doing so, would we cause unforeseen consequences and paradoxes that imperil our present status? Just as in the physical time machine analogy, an MTT technique is also vulnerable to abuse and misuse. Indeed, MTT tools could be developed to enhance learners' ability to do more effectual financial forecasting or develop Machiavellian military and political strategies. But the present course of human societies requires this ability to be harnessed for long-term environmental stewardship from very early stages of human development. It is the society's gatekeepers' responsibility to *where* to direct our cognitive energies and in which areas we desire to be foresightful/prudential about. The application of (scientifically dubious) MTT-based learning strategies in military and economics has already created disastrous consequences which current generations are forced to deal with. Consequently, we became less foresightful/prudential about how to manage our natural resources for the long-term enjoyment and benefit of future generations and other species.

The developmental goal of a foresightful/prudential educational agenda dovetails with what we can accomplish in the domain of science and environmental education. In that respect,

foresight/prudential intellect is not merely a psychological construct but also an educational goal. And this means becoming an adept user of science, since primed foresightful/prudential intellect requires the operation of advanced scientific reasoning skills including causal analyses techniques and the workings of complex adaptive systems. The complex ecological problems we unwittingly handed down to future generations will have to be dealt with different applications of our cognitive capacities and cannot be solved via the headspace and consciousness that created them – perhaps through deeper levels of understanding that that “we should regulate technology if we want to remain sustainable or achieve symbiosis with our life-support system,” or “we should begin using canoes and kayaks as a measure of acting upon what we have already learned.” For this headspace to start up and running more robustly among collectives, education has a responsibility to assist and motivate both the current and future generations to attain more flexible and far-reaching MTT abilities in both directions of the cognitive space-time continuum.

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Appendix A

Questionnaire Sample

Open Episodic Recall Question

What is the most important/interesting thing you saw in the film? Please explain why you think that is the most important thing in a few sentences.

Authority Assessment Question

What was the position taken by the BC Department of Fish and Wildlife in regards to Luna?

What was right or wrong about that position?

Prudential Reasoning in Ecological Ethics Question

Do you think humans and wild animals can live together successfully on earth? Please tell us why or why not.

Which one do you think is more important? Sending people to Mars to colonize the planet, or sending people to oceans to communicate with Orcas? Why do you think that is what we should do?

Accident Prevention Question

What, if anything, should have been done differently?

Should anything have been done differently involving Luna's situation?

Appendix B

Coding Manual for Coder Training and Analysis of Preventative Actions

Based on the Whale Study

Summary of the Accident

In year 2001, a juvenile, orphaned killer whale nicknamed Luna appeared in Nootka Sound, British Columbia. Upon his appearance, the orca proactively sought for social contact with human beings. Luna's appearance gradually attracted the attention from surrounding areas, including Mowachat-Muchalat First Nations, Canadian Department of Fisheries and Oceans, marine biologists working via NGOs and university research centers, and visitors to the area. Over the next 5 years, Luna's interactions with human beings resulted in the emergence of a complex problem regarding the whale's welfare, conservation, its potential danger for public safety, and commercial boats and planes. In 2006, Luna got hit by a tugboat propeller and killed instantly.

Summary of the Study

Children from Grade 5, 7, as well as undergraduate students watched a documentary portraying the evolution of this accident in great detail from 2001 to 2006. During the post-treatment stage, participants are asked to evaluate the accident and articulate some of the central ethical and scientific themes emerging from it.

Coding System: General Heuristics

(Informed by Piaget, 1929; Carey, 1985; Deacon, 1997; Kahn, 1999)

The coding system is generated based upon the responses given to the accident prevention question. Participants often provided multiple justifications.

1. Misunderstanding: Do not code responses that the participant uses in the basis of a misunderstanding of a question (see also uncodable).
2. Children's Language: Children's narratives often differ from those of adults. More often than not, especially in written form, their responses involve incomplete or incorrect syntax. Children often provide snippets of pieces of information. The coder must often reconstruct their cognitive processes as reasonably as possible by 'thinking like a child,' unless the responses are significantly unintelligible and cannot be coded (see also uncodable)
3. Multiple Justifications: It is not uncommon for a participant to provide more than one justification. In those cases, code the most dominant justification and code only once. To help with this, backtrack the participant's responses in other questions and grasp the participant's overall headspace. Then inform the present coding with those responses.

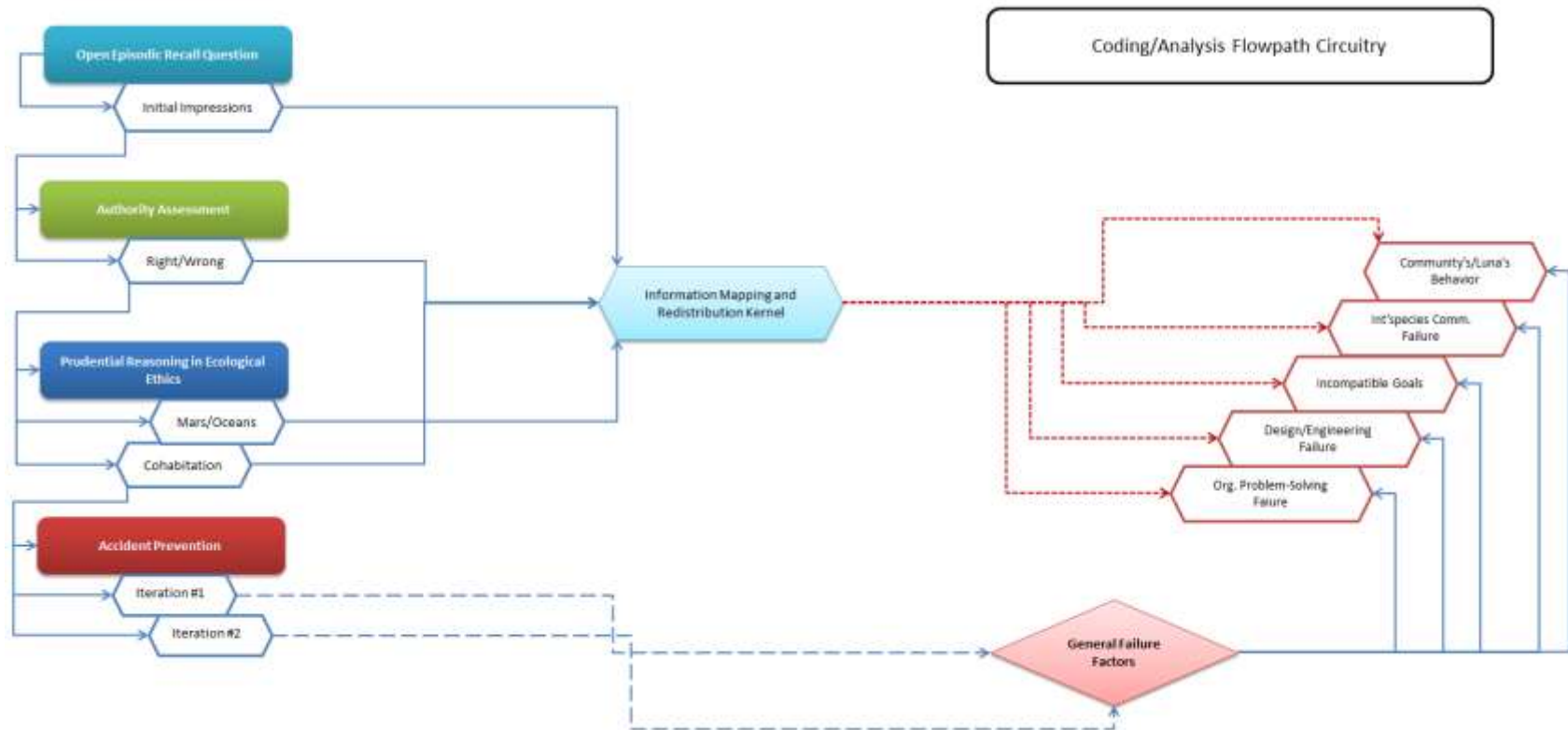
Two other items to keep in mind: (1) Should a participant repeatedly justify an evaluation by using the same category, determine that justification as the dominant category; (2) In an evaluation where there is both an elaborated and unelaborated justification, code only the elaborated justification and determine it as the dominant justification.

4. Uncodables: This category should be used in the following situations:

- Participant did not respond at all to the question.
- Responses are too unintelligible and incomplete for coding.
- When constraining the response into an existing category would substantially dilute its meaning.
- Participant answers a question other than the one he/she was asked to respond.
Retain that response if it helps capturing the participant's overall problem identification-and-solution headspace and facilitate further coding.
- Participant says he/she does not know the answer, e.g. "I don't know."

Appendix C

A Designed Assistance Tool Used in Coding/Analysis of Qualitative Responses



Appendix D

Collaborative and Adaptive Root-Cause Analysis (CARCA) Technique

