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Increasing Capacity for Innovation through an Inquiry Approach to Instruction

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Abstract

The requirements of a 21st century society are described particularly as they relate to the needs of individuals. Developmental theories are compared and reviewed in light of educational practice and goals. Assumptions regarding mankind's needs for inquiry are reflected in the processes of the human mind. The pathways are described through which cognitive processes are developed in students. This summary paints a portrait of humans as natural innovators deriving much of their meaning in life from solutions to challenges. The literature, by comparing the innovative needs of society with natural inquisitiveness in individuals, makes a compelling case necessitating reform in public instructional practice. With this in mind, the research here calls on practitioners in education to embrace the natural workings of the human mind through inquiry-based curricula in order to align goals with the future needs of society and the fundamental purpose innate in the human brain.

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Finally, all those individuals throughout life who provided me with challenges, experiences and information cannot be ignored. Any academic endeavor in the field of education eventually necessitates recognition of all personal experiences no matter how minute or seemingly unrelated to the topic at hand.

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Introduction

"Languages build up to reflect specializations in a way of life. Each specialization may be recognized by its words, by its assumptions and sentence structures. Look for stoppages. Specializations represent places where life is being stopped, where movement is dammed up and frozen."

---Frank Herbert "Children of Dune"

Changes in Modern Society

With the advent of the 21st century, educational theorists dramatically shifted their attention toward the study of critical thinking skills and inquisitiveness in K – 12 students . This change in focus was related, at least in part, to economic transitions occurring in the United States and elsewhere. Significant transformation in multiple sectors moved the nation increasingly away from agriculture as a primary economic force to manufacturing, technology and service based industries. As this occurred, it was recognized that more young citizens required different sets of skills than previous generations in order to be successful in an increasingly competitive world. In addition to disciplines that study education and human development (Lawson, 2010), other social disciplines emphasized the importance of innovation for the future productivity and well-being of the nation. With his influential work discussing deep (unaffected by policy change) parameters of the economy, Lucas (1976) spurred a revolution in economics by pointing to technological innovation as a key factor in economic advancement. It could be argued that a critical ingredient in the development of new technologies is the ability to innovate. In short, to become marketable in the modern workforce and to contribute to a growing economy, a citizen needs to have skills in innovation and problem solving.

With these ideas assumed to be self-evident, the research presented in this paper will center on two distinct yet interrelated concepts. First, it will be shown that in addition to core abilities associated with traditional disciplines, curricula need, to address those skills associated with critical thinking and innovation which have foundations in fundamental brain processes. Finally, an argument will be made towards the use of inquiry in planning, presenting, and assessing lessons as a means to an end. Specifically, this argument asserts that by requiring students to actively participate in the learning process, concept retention is increased. Further, the very act of pursuing solutions to problems and being held responsible for learning develops students into life-long learners, innovators and critics. Based on current research and theory, it is surmised that students' abilities to independently obtain knowledge and weigh options is an underlying goal crossing disciplines and grade levels.

Goals in Public Education

Silva (2009) notes that students in the 21st century should be assessed on what they can do with core knowledge rather than on their retention of core information. The Partnership for 21st Century Skills (2009) lists a number of themes in their summary of 21st Century Student Outcomes. Examples from this document closely relating to science include:

- Thinking Creatively
- Reasoning Effectively
- Using Systems Thinking
- Making Judgments and Decisions
- Solving Problems

These skills align closely with the philosophy behind teaching through inquiry. In particular, inquiry can be defined as "Any instruction that begins with a challenge for which the required knowledge has not been previously provided" (Prince and Felder, 2007, p. 15). In short, inquiry based education expects students to build their own body of knowledge about a topic rather than regurgitate the information put forth by an instructor through traditional approaches to teaching and assessment. This idea closely aligns with constructivism or the theory that "Meaning cannot be taught it must be fashioned by the learner" (Wiggins and McTigue, 2005).

When students are responsible for actual learning, an instructor's role is not reduced, rather his or her job is to present problems in such as way that students have clear goals to work towards and to be available as a resource.

This paper does not seek to prove through empirical research the value of inquiry based education or critical thinking skills in public education; rather, a synopsis of the extant literature will be made regarding the cognitive development of abstract thinking and the fundamental characteristics of cognitive development. The purpose of the review is to describe the close similarities between learning, innovation and societal needs. The complex relationships among current conceptualizations of abstract concept formation, problem solving, engagement in learning and inquiry will also be explored.   Finally, the paper will provide a framework that may be utilized in designing lessons that are responsive to the individual and societal need for innovation through inquiry based teaching, learning, and assessment.

The Inquiry Method

Definition of Inquiry

Building upon the information given above it becomes apparent that there is no easy answer to the question: What is Inquiry? Barrow (2006) summarizes the history of inquiry in education after reviewing an array of sources, suggesting that inquiry can be divided into three domains: abilities, understandings and teaching strategies. More specifically, in reference to students, the objectives should impart an ability to conduct an inquiry investigation and knowledge of what inquiry is. Haury (1993, p. 1), following a similar vein, simply states "inquiry-orientated instruction engages students in the investigative nature of science." He also mentions the ability of inquiry to stimulate curiosity. Despite these detailed definitions, neither author gives hard and fast transferable techniques that can be utilized by teachers.

In addition to an extensive review of the literature on the use of inquiry in the classroom as a basis for improving creativity, intelligence and achievement, Lawson (2010) gives a complete account of the use of the inquiry method in the classroom. His descriptions center on a learning cycle of exploration, introduction and application. A summary of his extensive introduction of development would suggest that any new endowment of knowledge must build off of the information the student has already learned in his or her prior studies. In his adaptation of inquiry or problem solving concepts to Piaget's formal operational stage he lists five general reasoning patterns:

1) Combinatorial Reasoning;
2) Identification and Control of Variables;
3) Proportional Reasoning;
4) Probabilistic Reasoning;
5) Correlation Reasoning;

In requiring the use of these concepts, an inquiry lesson will necessitate a connection or transfer of results or effects from known bodies of knowledge to the problem in question. Lawson (2010) stresses the use of hands-on activities, discussion and student led research in achieving an inquiry based learning environment. To summarize, an inquiry lesson will add information to bodies of knowledge already retained by the student. The lesson will then require the student to use this information along with existing experience to solve a problem that is new to the student. As a teacher guides the student through the application stage, his or her role ultimately becomes one of a facilitator of learning rather than a distributor of information.

Inquiry, Innovation and Science Defined

From the statements above, it is recognized that society benefits from innovation. It might be argued that all innovation occurs through science yet that statement may lead to confusion if science is viewed as a process requiring a lab with extensive apparatus or a biologist observing animals, for example.

A distinction needs to be made between science as a process and natural science as a discipline.[1] Natural science can be viewed as the sum total of phenomena existing outside of experience. That humans influence this natural world there can be no doubt and this interaction is a relevant topic within the field of natural science. However, certain principles, such as the boiling point of water or the number of electrons in a hydrogen atom, at present, exist outside of human influence; these concepts providing the fodder for empirical scientific investigation with all empirical work in natural science being conducted under the assumption that any human influence is controlled, accounted for and/or nonexistent. Science, in contrast to natural science, does not imply control of the situation, rather it only requires that an individual accommodate and assimilate knowledge to draw conclusions. For the purpose of this paper the term “science” will be used to describe this problem solving activity and should not be confused with the scientific method (although similar) which is commonly promoted within those courses covering the natural sciences. The main distinction is that, in science, the accumulation of replicable data is not always possible. In short, it is important to recognize that while public schools seek to impart knowledge in natural science, social science, mathematical science etc., that the ultimate goal of human experience is of a problem solving nature (problems may be internal, external or related to expression) and represents the more overarching conception of science as a process of inquiry. Inquiry, serving as the vehicle through which problems are solved and new concepts created, is closely related to innovation. This paper does not use the terms innovation and inquiry interchangeably; however, Innovation is defined as a new solution

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[1] Science – systemized knowledge derived from observation, study, and experimentation carried on in order to determine the nature or principles being studied (Webster’s New World College Dictionary, Fourth Edition)

to a new or old problem. Innovation occurs through inquiry in that a person or group must seek out previously unknown information or ways of organizing information to solve problems. However, inquiry can occur without absolute innovation when a student solves an 'old' problem. The underlying point of this paper is that this inquiry process, by its very nature, encompasses the internalization of factual knowledge already learned through schooling and/or other experiences and includes the ability to reason, think critically and problems solve.

Previous Literature

Empirical Support of Inquiry

Numerous studies have sought to measure the impact of inquiry education on student knowledge retention. Overwhelmingly, studies referencing inquiry have concentrated on what has been described above as the natural sciences. Minner, Levy and Century (2009), in a synthesis of studies regarding inquiry exclude all research that does not directly reference life, earth, or physical science. Their review reveals modest positive relationships between inquiry and content learning and somewhat stronger relationships between inquiry and conceptual learning. Since inquiry based studies specifically reference conceptual development, this makes intuitive sense.

Anderson (2002) simply notes that inquiry produces positive results and references the work of others in this conclusion. He defines inquiry in terms of the National Science Education Standards and directly discusses the process in terms of natural science. He states that inquiry is an active process requiring the student to draw conclusions based on information they obtained themselves. While his work is essentially a research summary, he organizes the concept of inquiry as a teaching tool and discusses the barriers to implementing it in a classroom or school. In particular, Anderson (2002) notes that the implementation of inquiry lessons is time-intensive and is best done in a collaborative environment with an emphasis on overcoming teachers preconceived ideas regarding educational practice. Brickman, Gormally, Armstrong and Hallar (2009) take a different approach in a university setting measuring increased student confidence in science processes as the result of an inquiry based lab. They also show gains in literacy and skills which could contribute to the positive student self-perceptions.

In a well cited critique of Minimally Guided Instruction, Kirschner, Sweller, and Clark (2006) discuss the downfall associated with instruction that is directed in a large part by the learner. As will be discussed later, inquiry is not minimally-guided; rather the guidance offered seeks to extend into that realm of education characterized by cognitive processes. (Hmelo-Silver, Duncan and Chinn 2007). To clarify this point, Kirschner, Sweller and Clarck (2006) state in a literature summary that “expert problem solvers derive their skill by drawing on the extensive experience stored in their long-term memory and then quickly select and apply the best procedures for solving problems.” These additions to long-term (permanent) memory are best made through direct guided instruction stemming from the teacher. If the problem presented to an individual has been seen before and internalized, there is little reason to think this principle would not apply. In light of this, one must consider what new value to society is created by re-solving problems? Kirchner et al. also stress the overload placed on working memory through minimally-guided instruction. However, other researchers point out that extensive use of working memory leads to permanent connections in working memory (Marzano, Pickering and Heflebower, 2011). Hmelo-Silver et al. (2007, p. 105) pose an important question: “What are the outcomes for which they [inquiry-based practices] are effective?”

Based on these reviews, it is apparent that if the desired outcome is the recall of pieces of information, then the best educational approach will, quite simply, be a requirement to memorize. That is, the view that students should use declarative knowledge in any way they see fit requires only that the knowledge be given to them and assurances put in place that it is retained. If the desired outcome is a conceptual synthesis, an ultimate contribution to society, and the growth of personal worth through innovation, then educational activities which promote these outcomes should be the norm. The following discussion will outline the development of concepts and their connections to human thinking and detail the resulting contributions to individual development and society. The author believes, as a practicing teacher and member of a democratic society that, above all, individual learning is paramount in education and critical thought stands as a close second.

The literature directly referencing inquiry as a teaching method demonstrates some success. Yet, statements of positive outcomes must be interpreted in terms of study design and variables analyzed. This section is included in order to address current views in academia and public education towards inquiry. Taken as a whole, the research tells us that if lessons are designed around problem solving students will get better at problem solving and that through this process they will internalize numerous pieces of factual information along the way. However, the literature also recognizes that if the purpose of education is memorization of factual knowledge then the requirement to memorize is the best approach. The idea put forth in the following sections address inquiry, not as a simple style of lesson design, but rather as a fundamental process linked to brain development and knowledge construction in humans.

Engagement in Learning

Due to the active nature of the process it is prudent to start a discussion on inquiry education with reference to the engagement of students on the subject matter (Anderson, 2002). Even a meticulously planned lesson will create few new synapses of knowledge in a young mind without the full participation of the individuals being taught. In fact, it can be argued that not only is the participation of individual students important in a learning environment, but the entire class should be engaged as a group in a culture for learning (Danielson, 2007). A separate discussion (or even career) could be made detailing the classroom techniques used to engage students. Many teachers anecdotally will list practices ranging from interesting demonstrations to games to rewards. This paper will not cover this topic in its entirety; rather the intent is to show how one method of instruction, inquiry, can provide a tool for the educator's engagement of students.

Marzano, Pickering, and Heflebower (2011) note that for information to be retained in the permanent memory of a student it must pass from sensory memory through working memory. Working memory is the place where information from the senses is actively processed (the conscious mind). The description of information being processed implies that a student is using the information for some purpose. This purpose could be as simple as trying to memorize the information for a test or as complex as using the information to solve a problem. Irrespective of the purpose, the longer a student holds information in working memory, the higher the probability is that it will be encoded into permanent memory (Marzano, Pickering and Heflebower, 2011). It could be simply stated that the ultimate goal of a teacher is to sustain information in their students' working memory for as long as possible. The ultimate question for a teacher becomes: "How will I accomplish this??

In reference to science, the engagement of students is paramount. The very nature of the process implies participation in a problem solving activity or in the systematic organization of information. Driver, Squires, Rushworth and Wood-Robinson (1994, p. 6) state that "Scientific Ideas and theories result from the interaction of individuals with phenomena." In interacting with phenomena, a scientist (or student) by the very nature of their interaction will modify the system or become immersed in the system and will subsequently reflect on their modification or experience. This approach to learning requires not only that students have prior information about the system but that they draw conclusions in reference to their prior information and experience. This definition of science aligns with Lawson (2010) who posits that a primary intent of public education is to impart the ability to reason and fits closely with the idea that students need to use information to make decisions about their world. In short, the act of problem solving in science provides engagement, thereby requiring the use of working memory by the student for extended periods of time. The use of scientific inquiry, or the active pursuit of explanation, becomes a means to an end. A similar question raised again is: How does the human mind (or brain) prefer to be engaged in this process?

Engagement and the Human Mind

Early Development as Inquiry

A new human is born with a relatively clean slate. He or she possesses a bundle of neurons comprising a brain; a brain with an infinite number of neural configurations. Through its egocentric pursuits, the infant gradually uses its senses to construct a parallel (permanent) world in his or her head which mimics the world around it. This construction essentially constitutes the process of inquiry in the crudest (or possibly most pure) sense in that the child, through trial and error, seeks to solve problems relating to its own survival. Gradually, the child comes to understand that objects exist outside of their sensory field. The infant's thinking "Unfolds itself in time" (Vygotsky, 1978, p. 36). At this juncture the child comes to understand that there exists a set of processes which will help her achieve her goals. Furthermore, the child recognizes that there are tools or actions and objects that can help him meet these objectives. Namely, the primary caregiver becomes the tool through which the infant meets his or her needs. As a result of the infant's interaction with this adult, communication arises through signs (words). The child is conditioned to make certain signs which represent certain wants. It is an inquisitive child that actively seeks new signs and uses these signs to solve problems. Egocentric speech which begins out loud, accompanies the problem solving process, and eventually moves signs into the mind and where their use precludes the problem solving process. For example, a child will first talk his or her way through a problem while it is being solved and will later seek to solve the problem before attempting action. Quite possibly, the degree to which a child is capable of solving a problem is influenced by the amount of self-talk he or she engages in beforehand as compared to during the act of solving the dilemma.

During this period of accumulating signs (language) and using these signs to meet selfish goals, the child accomplishes an extraordinary transfer of skills in which he or she leaps forward into a new realm of awareness characterized by a permanent internal world represented not only by sensory experiences but by signs. These signs begin to represent complex, internal ideas. The discomfort from an empty stomach is now the word “hunger.” The whole of the area external to the dwelling becomes “outside.” This new awareness organized and described through signs and gleaned from society and the world through inquiry is the basis for thinking that is distinctly human.

Advent of Formal Schooling

The process described above is characterized by Piaget as two distinct stages, sensorimotor and preoperational. Essentially, the typically developing child is expected to be able to internalize the problem solving process through the use of speech or signs by the ages of five to seven years of age (Meece and Daniels, 2008). While there is controversy over the nature of this theory in its delineation of stages and assignment of ages, it should be noted that at this point in a child’s development he or she has the skills necessary to meet the basic needs of human survival as they are generally provided by society.[2] It is also roughly the point at which education in the United States and elsewhere becomes compulsory. Up until this point the child either voluntarily learned skills or was provided the opportunities to learn skills through his or her

[2] This discussion would question whether development (biological potential) precedes learning or learning causes biological development. Vygotsky (1978) posits that the ways in which humans think has changed since the beginning of recorded history and that it would be highly unlikely that the biological basis for processing centers in the brain could have evolved significantly in such a relatively short time. In short, at some level the brain accommodates itself to the imposition of other humans.

family or contexts in which the family placed the child (day care, relatives, family friends etc.) The next major developmental hurdle the child must cross involves the ability to write, or transfer speech temporally, and the refinement of two additional processes that, while previously developed, have not yet been applied beyond an elementary egocentric use. These processes signify the gateway to abstract thinking and are identified as classification and seriation or organization of complexes.

Throughout the primary grades the refinement of signs through writing and artistic expression occurs. For the child, writing and the creating of text becomes an extension of the student's working memory. For example, while it is impossible for even an adult to hold the answers to a series of multiplication problems in his head, a pupil in the second grade can easily compile a list of answers to numerous mathematical problems on a sheet of paper to be turned in to a teacher. The ability to write is a product of the organization of letters while mathematical functions result from the organization of numbers. Further education leads the child through any number of serial processes such as telling time or reciting a song.

In addition to these abilities to place objects in order, the child expands on his or her ability to place objects into groups or to classify objects; such as hairy animals into the mammal group and animals with fins into the fish group etc.. At this point it is common for the child to consider both fish and mammals as members of the animal group and a connection between them is present. The purpose for this appears to be one of organization and efficiency. By placing an animal into the group "mammals," the student ties all characteristics associated with mammals to it. In short, characteristics for mammals need only be remembered in terms of a sign 'mammals' and not in terms of individuals in the group. In a sense, the child internalizes a group (with associated characteristics) which can be used in subsequent mental calculations. These groups and the orders within them become the basis for that abstract thought which is a primary topic of this paper.

Before elaborating further on the concept of abstract thought, it is important to note that the motivation to learn the basic or initial concepts put forth through formal schooling (reading, writing, math and categorization of natural phenomena) do not stem directly from a child's desire to survive physically. That is, these skills have almost no value in isolation from other factors.. Their value stems from their assimilation and subsequent application. While an exhaustive list will not be covered in this paper, some sources of motivation potentially considered by teachers would include those presented by Maslow, 1970:

-Fear of repercussions from parents or teachers (desire to belong)

- Desire of future economic rewards tied to skill (safety in society)[3]

-Curiosity towards subject matter tied to the skill (to know and understand)

The first two sources of motivation tie directly to basic survival needs as we know them. Human existence, though possible, is difficult without the services of society. Specifically addressing the third motivator, there is a body of research that shows that at some level humans are naturally curious beyond that inquisition which meets physiological needs (Caine and Caine, 1990). *It is this motivation to learn without a definitive or recognizable external purpose which concerns this paper.*

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[3] Maslow (1970, p. 18) lists these as safety needs: Security; stability; dependency; protection; freedom from fear, anxiety, and chaos; need from structure, order, law, and limits; strength in the protector. In a primitive society much of these needs might be met through a family or social group. However, in a modern society these needs are either met by the individual through economic expenditures or as public goods provided by the government through allocation of tax revenue. Quite possibly even the family unit would not provide any services without the protective bubble provided by tax financed modern institutions.

The motivation to learn seemingly esoteric skills provides a dilemma that is difficult to explain empirically or dialectically. Furthermore, identification of the pathways, biological or psychological, through which this motivation manifests itself, is quite possibly one of the most compelling tasks for educational researchers to investigate. Howard-Jones (2008) notes that the interface between Neuroscience and Education is, as of yet, not reconciled. He cites Harre (2002) in reference to the brain as an organ of electrical and chemical actions. Related to this, there is a vast body of knowledge describing the development of cognition within the human mind as we know it. A volume could be compiled contrasting theories presented by Piaget, Vygotsky and others in terms of theories of cognitive development. The literature recognizes that at some neurophysiological level, the processing of information in the brain follows a series of principles closely related to the concept known as "inquiry." The focus for this paper lies in the disconnect between the organization of learning in schools and the desire of students for information and skills. The seemingly academic and abstract nature of learning categorical knowledge is difficult to justify and impart to students if viewed as a standalone requirement. Yet, in looking at the nature of knowledge construction in the human mind and the eventual capability of abstract thought formation, this developmental learning requirement is essential if innovative thinking is going to occur in adulthood.

Fundamental Brain Process

Caine and Caine (1990), in a succinct article discuss twelve principles to understanding the human brain in terms of learning and education. While all twelve principles relate directly to the classroom, a few have direct implications for inquiry based lessons. That is, there are certain brains processing functions that can be accommodated through lessons that ask the student to construct a complex answer to a posed problem. Caine and Caine (1990, p. 67) assert that "The search for meaning is innate," suggesting that as a survival mechanism, humans search for a purpose in all activities. Its stands to reason that schools, in their roles a transmitters of cultural history, values and practices, will be teaching material with societal origins. Therefore educational material will provide information that promotes an individual's ability to survive in society or, even better, thrive in society. One of the best ways a classroom lesson can appeal to the search for meaning is to be responsive to notion that the brain processes all information in parallel. That is, fact, figures and ideas are all taken in through centers related not only to conscious thought but also through centers that process emotions and stimulate imaginative thinking. In an ideal learning situation, this translates to the use of material related to a student's prior experience and learning and explicit connections to an individual student's preference for specific patterns of information processing in the brain. The brain connects new information to old information by making use of patterns. When new information does not fit the existing pattern, the brain holds it in isolation and has a hard time assimilating it with prior conceptions of reality. In short, there are two fundamental implications for an inquiry-based lesson relating to both the material presented and the style of delivery. First, lesson content must connect to previous knowledge held by the student to allow for the attachment of new information to existing patterns. Following the theories of development reviewed above, this translates into connection of words to stimuli, categories to words, and concepts to categories. Finally, in terms of delivery, an instructor must appeal to a student's sense of meaning. This might be accomplished through connecting to an existing purpose in life or through a proposed modification of an existing purpose. For instance, a lesson might utilize a student's existing passion and valuing of flowers and translate that significance into a more comprehensive valuing of the environment. In this instance, a teacher attempts to activate three processes within the student simultaneously; namely, she assists the student in making the connection between the concept of environmentalism and the student's knowledge of flowers, she ties the concept of environmentalism to a subject that the student is emotionally attached to, and she helps the student connect a personal sense of purpose to the concept of environmentalism and it's mission to preserve all living organisms on the planet. .

To summarize, the review of literature has shown that humans are endowed with brain processes that naturally seek challenges. By searching for the solutions to these challenges, individuals extend their internalized reality by constructing patterns. These patterns take the form of structures or spatial assemblies in which all parts are interrelated. While it is relatively easy to explain this natural orientation toward solving problems when it is used as a mechanism for basic survival, it is far more challenging to offer applications to solving the problems of modern society with its elaborate social, scientific and physical conundrums. . Researchers seek to understand why humans are perpetually compelled to create ever more complex social and technological constructs and what drives the brain toward increasingly complex organizational capacity. There is also a great deal more to be discovered regarding the nature of the organizational patterning used by the brain to organizes itself as it moves towards these goals.

Abstract Thought and Aesthetics

Caine and Caine (1990) discuss a closely related principle regarding brain based learning, namely, the preference of humans for challenge. This concept can be seen throughout modern life by observing human demand for games, puzzles and competitions. Much of our free time is spent participating in challenges of our own or living vicariously through the challenges of others through books, television or direct observation. This preference for challenge may have evolutionary ties evidence in our tendency to seek out problems that increase our quality of life.

Most adult challenges are solved using developed skills in abstract thinking that allow application of prior knowledge to new, relatively different, situations. This ability to use abstract thought is based on connections between categories which become complexes in the human mind (Vygotsky, 1962). When these complexes are summarized and then synthesized, a human creates new ideas that are different from the previous complexes. These new ideas may then be applied to problems that have not been directly experienced. That is, the human mind might, by loosely connecting complexes, solve an abstract problem using a unique solution. Through this process, abstract thought aligns with the definition of innovation.

There are a number of well-known theories that discuss the motivation behind human creation of concepts. Maslow (1970) touches on the aesthetic needs of humans, describing this as a desire for beauty in a perceived world. A common description of this idea concerns the appreciation of finished works of art. Yet, there is some suggestion that the motivation for aesthetics in an artist stems not from the finished product, but from the process in creating the work of art. If we assume that abstract concepts are fundamentally works of art, most scientists will agree that there is a tremendous amount of satisfaction involved with a scientific endeavor. Just as we do not hang crossword puzzles on the wall, most research details a path for future undertakings providing direction for the next challenge; this paper is no exception. Specifically, our brains thrive on experiences that help us make sense of our world in a complete way, i.e., we strive to piece together all parts of the puzzle. Dewey (1934) calls this an aesthetic experience and stresses the internal components or internal process involved in a creation as fundamental in art. He concludes that inquiry is art with the work of art being the completed concept. In his short book entitled *Experience and Education* (1938), Dewey calls on educators to foster activities and utilize subject matter that provides experiences in the classroom and directly connects with prior understandings in school age children. He also makes the point that education should not fall back on pedagogical structures that were in place before the advent of scientific thought in society. Dewey’s approach, in fact, foreshadows a future movement in education known as constructivism Many components of our current educational model direct students to be aware of their world as it is currently explained by society rather than pointing them in a direction to develop new questions and subsequent new solutions. Quite possibly, educational activity should embrace challenge and problem solving as the core of modern civilization and stress its importance in training new citizens.

Connecting Individuals to Society

Throughout the first part of this paper, it is shown that disciplines such as natural science, technology and economics are being increasingly challenged to innovate or solve new problems. Based on the review of leading developmental, cognitive- research and theory, it is apparent that the human mind is naturally inclined to be inquisitive. This paper seeks to build a connection between a need for innovation in society and a fundamental drive for challenge in the participants of society. The critical link in this relationship is the school or more specifically, the curriculum and style of instructional presentation that students experience.

The literature paints a succinct picture of growth in the human mind beginning with inquisitive internalization of stimuli in infants and toddlers (a skill maintained through life). The acquisition of signs (words) for stimuli and internalization of a permanent reality not directly related to experience in the present follows. Subsequent to this accomplishment, the human organizes internalized stimuli represented by signs into complexes (categories) which are also represented by signs, yet are coupled to characteristics. Finally, through the connection of complexes, the human develops ideas about his or her world that directly apply to personal experience or the experience for others. When these ideas manifest themselves as new solutions for problems, innovation has occurred.

Some of the problems discussed in this review demonstrate the failure of public schools to provide learning activities that align with these goals. Compulsory education often emphasizes rote memorization of information with little regard for the student's need to manipulate and construct knowledge. The research literature clearly points to a fundamental human need for inquiry, challenge and aesthetic organization. In lay terms, it might be simply stated that a student seeks knowledge that serves a purpose and makes sense. If one views factual knowledge as a subset of other types of knowledge, all embedded in the more abstract notion of conceptual creation, instructional best practice would be conceived as a task in problem design. The desired outcome resulting from this form of instructional activity would be the student's acquisition of information for the purpose of solving problems. Ultimately, many of the problems presented in such a learning environment would simulate those that, in the real world context, will push our collective inquiry process onward toward the solution of new unknowns.

Finally, it is apparent that the pinnacle of human mental ability is the process of increasingly complex abstract though through the assimilation (connection) and accommodation (means of connection) of concepts. The subsequent application of these concepts to real problems becomes that vehicle through which an individual may contribute to the resolution of society's dilemmas, and obtain utility economic or otherwise. It is also the process through which society is able to receive constructive input and ideas from individuals. Since many modern problems stem directly from the workings of society, it seems that humanity will inevitably benefit by constructing an educational system for its citizens that will teach the skills required to solve these looming problems. With this stated purpose in mind, the remainder of this paper will discuss the organization of public school curricula and classroom procedure as they relate to the theories that have articulated the cognitive and motivational underpinnings of problem solving and inquiry processes.

Implications for Professional Practice

Inquiry in the Classroom

It is obvious that some level of inquiry or innovative problem solving is required of individuals in society. We might broadly assume that this ability automatically results, to some degree, as a natural function of the human mind and that the only true input to steer this ability towards new problems need be the exposure to an existing body of knowledge known to man. In some instances this may obviously hold true. Yet, if we recognize that this problem-solving is developmental in nature, it is apparent that some level of instruction in problem-solving procedure is beneficial for its higher development. In fact, from the extant literature on brain development, it is shown that the brain is essentially a problem-solving machine. Since, any problem previously solved technically does not offer a problem-solving opportunity; we might argue that the ideal learning situation lies in providing the brain with new problems to solve. In order to recognize a new problem or a problem that is out-of-the-ordinary, the mind needs to be inquisitive. To solve a new problem, the brain is called upon to innovate.

In order to demonstrate the underpinnings of an inquiry-based lesson, the following section gives an example of a scientific concept and details the scaffolding necessary to support cognitive understanding of the concept. Finally, an explanation of how to organize the concept within a standards-based inquiry lesson is offered.

Based on the literature reviewed in this paper, a series of questions have been raised and answered theoretically. First, it is concluded that society needs innovation and that innovation occurs through inquiry or the seeking of unique solutions to new problems through abstract thought. Next, constructivist theory asserts that natural human development is in fact grounded in inquiry. Finally, brain-based research reveals that the human brain seeks cognitive challenge.

This challenge tends to elicit emotion and also builds upon prior knowledge. In short, humans are natural personal problem solvers; therefore, a prudent educator should include problem solving in a curriculum as an essential approach to learning.

To begin, it must be stressed that there can be two types of "new problems:" those that are new to society and those new to an individual.[4] For instance, the relationship between water and energy input has been clearly defined by empirical science yet to an 8th grade student, the concept may appear new.[5] For purposes of demonstrating the application of concepts reviewed in this paper, an analysis of water and energy in a pedagogical context is presented. The water and energy concept is selected due its familiarity, importance to human life, and its common appearance in curriculum. It is typically taught about the same time that it is assumed students are prepared for formal concept formation. Furthermore, the concept has been presented in the classroom by the author.

The figure on the following page is loosely based on the learning goal design example given by Krajcik, McNeill, and Reiser (2007) and details the construction of the concept of latent heat. This concept asserts that a significant amount of energy is stored or released during a phase

[4] Chinn and Malhotra (2002) analyze the similarity of inquiry lessons to actual research in authentic science. They conclude that many inquiry lessons reflect the neat-and-tidy structure that is characteristics of classrooms and not the messy process that many scientists undergo. They also recognize the enormous barrier to setting up authentic experiments in a school. Furthermore, many concepts are so clearly defined in our society that replicating an authentic experiment would require the suppression of readily available information. Possibly a distinction should be made between the use of inquiry as a career endeavor in science and inquiry as a part of everyday learning and thinking. While both are equally important it is the second skill that while less profound is quite possibly more commonly used across disciplines and by individuals in day to day experiences.

[5] Water provides the basis for life as we know it. Furthermore, its properties cause it to be present as a solid, liquid and gas at the temperatures common on planet earth; the temperatures resulting from our relatively (in astronomical terms) precise distance from our energy source, the sun. Water is a particularly good candidate for study in the science classroom due to its ability to model three types of energy transfer related to matter; convection, conduction and latent heat. In terms of latent heat, or the accumulation or release of energy in a phase change (liquid to gas etc.), it can easily provide data in a laboratory setting.

change in a substance.[6] The concept has a number of implications in meteorological science and physics. The related problem to be solved being simply the determination of how much energy would be required to change the phase of water. It is this property of water that causes thunderstorms (through release of energy in clouds). What the student will learn by studying the concept is shown in bold. The flow chart shows three types of knowledge. Squares represent factual, observable or declarative knowledge. For example, a student might observe ice on a lake and through prior experience will know that heat is given off by fire. The student will also know that fire needs fuel or energy. Some explanation by the instructor might simply point out that heat is the same as energy and that heat makes things hotter. Complexes shown in rounded squares demonstrate ideas that a student may or may not already have but that can be readily scaffolded from existing information. By coupling information regarding energy and temperature to the concept of phases based on temperature, a student or class might conclude that adding or removing energy results in a phase change. To arrive at this conclusion, students rely on previous perceptions of water and a previously taught concept of energy transfer (conduction, convection, and radiation).

Finally, by including an experiment in the laboratory, a lesson will allow students to quantify this relationship over time by melting ice and subsequently boiling water. They again rely upon the use of a prior conceptual skill in graphing that allows the students to interpret this data. The final concept created will be named “latent heat,” which is the immense amount of energy needed for a phase change in water.

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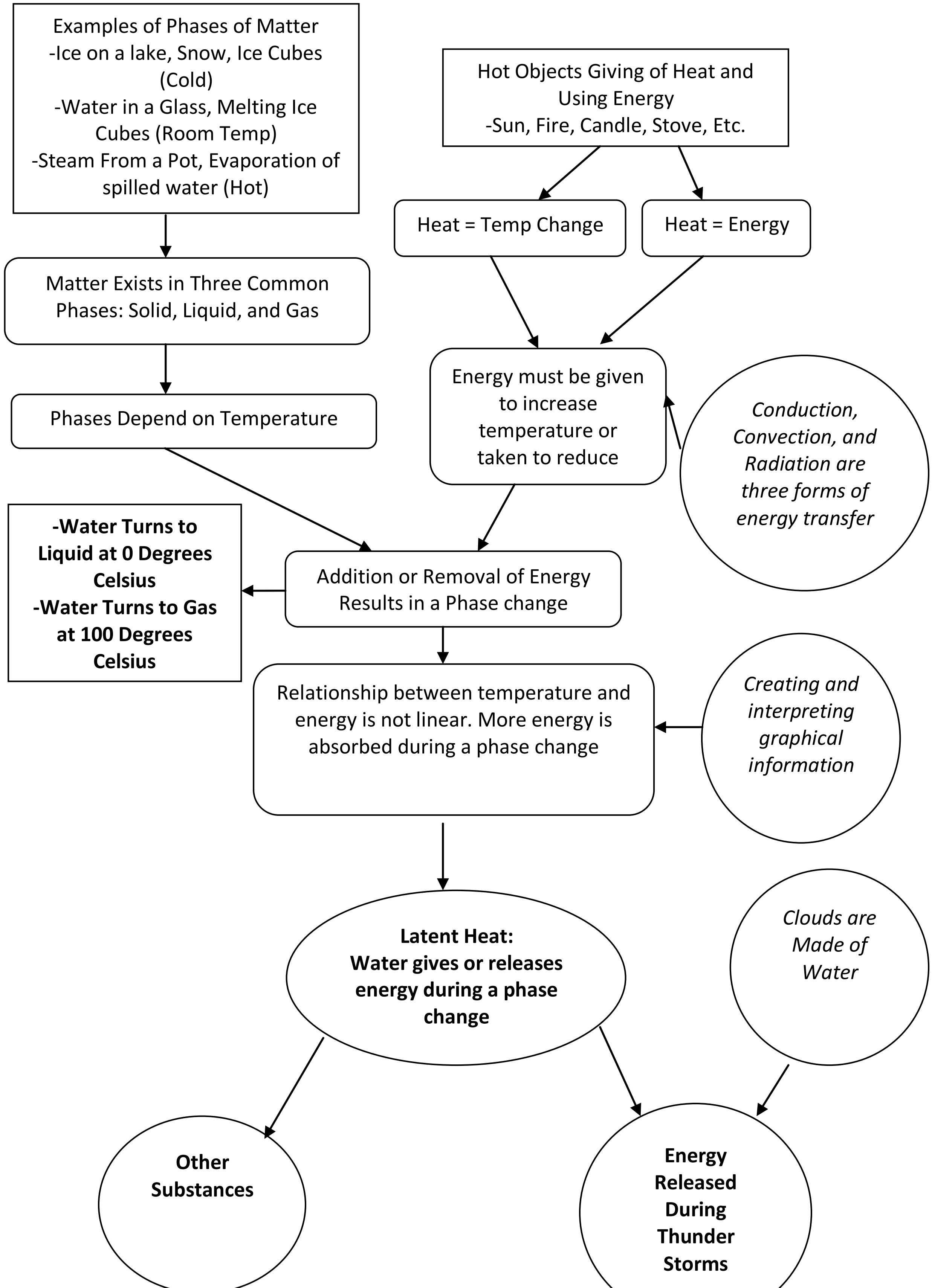
[6] Their example details national standards while the example given here is based only on a single concept and follows the theory of knowledge development put forth by Vygotsky (1978) in breaking down knowledge into stimuli, complexes (categories) and concepts. However, the interactive nature of the hierarchical relationships is the same.



Examples of Phases of Matter
-Ice on a lake, Snow, Ice Cubes (Cold)
-Water in a Glass, Melting Ice Cubes (Room Temp)
-Steam From a Pot, Evaporation of spilled water (Hot)
Hot Objects Giving of Heat and Using Energy
-Sun, Fire, Candle, Stove, Etc.
Heat = Temp Change
Heat = Energy
Matter Exists in Three Common Phases: Solid, Liquid, and Gas
Phases Depend on Temperature
Energy must be given to increase temperature or taken to reduce
Conduction, Convection, and Radiation are three forms of energy transfer
-Water Turns to Liquid at 0 Degrees Celsius
-Water Turns to Gas at 100 Degrees Celsius
Addition or Removal of Energy Results in a Phase change
Relationship between temperature and energy is not linear. More energy is absorbed during a phase change
Creating and interpreting graphical information
Latent Heat:
Water gives or releases energy during a phase change
Clouds are Made of Water
Other Substances
Energy Released During Thunder Storms

The concept is now represented by a sign (word representing a concept) for 'latent heat', and can be transferred to a later lesson involving energy, water or substances or to any number of personal experiences (sweat, thunderstorms, humidity etc.).

The lesson presented in the section above demonstrates how a concept can be constructed from existing information and laboratory experiences. It needs to be stressed that latent heat could have been defined in a 5-minute lecture; however, the research literature strongly indicates this to be an inferior instructional approach. Because latent heat is not readily observable anywhere in nature, it must be cognitively constructed, so to speak, from existing, abstract knowledge and scaffolded through hands-on experiences. The result is a simple transferable two-word term based upon these carefully orchestrated experiences designed by the teacher. A challenge remaining for teachers is how to organize a lesson around this process in a structured, quantifiable, yet engaging format. The diagram defines the concept to a teacher, stressing not only the importance of guiding the student to learn the material, but of the need to propel the student's thinking along a continuum towards a goal while periodically assessing progress in a quantifiable manner.. The following section explores the use of standards and other instructional tools to maximize student learning in this inquiry-based approach.

Standards-based Lesson Design, Grading, and Assessment

Robert Marzano (2009, 2010) presents a compelling framework for teaching that lends itself as the basis for classroom lessons. Along with Wiggins and McTighe (2005), he is a proponent of backward design, a method for creating lessons starting, not with learning activities, but with specific goals for understanding. Marzano (2009) specifically stresses the importance of the organization of these goals into learning scales or continuums of knowledge called Essential Learner Outcomes (ELO). The ELO is a scale of goals leading to a target goal. The scale usually includes a goal beyond the target goal to accommodate high achieving students; therefore, the highest score possible is not considered to be the ultimate goal. The method essentially requires a student-friendly synopsis such as the scale shown below. This teaching framework is built on the assumption that by organizing knowledge sequentially, the teacher is in a better position to use meaningful formative assessment and is thereby able to identify specific deficiencies in at-risk or struggling students. Aligned with procedures required for conducting inquiry-based lessons, this lesson framework is ideal for a number of reasons. First, it organizes knowledge in a way that allows for assessment of prior understanding and clearly defines the goals for the student. Second, it provides guidance for the thinking process the student follows to achieve the target goal. Finally, the method allows high achieving or faster students to move above the target goal if time and interest permit.[7]

Table 1 shows an example of an ELO related to the previous example of latent heat. The first goal addresses the knowledge students are expected to know (see scale 1) previously while the target goal (see scale 4) gives a definition of the problem students are trying to solve. The ELO implies that a lab is required, yet gives little direction as to what the lab entails except that it requires energy and phase changes. A prudent teacher hoping to start the inquiry process would start the lesson with a discussion of phases and energy transfer. This represents a significantly different instructional approach from a traditional one that might simply provide a lecture and require a worksheet. Discussion allows the students to bring forth their own ideas and link the concept to prior learning easily accessed from memory. For example, use of a verbal example offered in a lecture, such as ice on a lake, might relate to the prior knowledge of students in

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[7] There are different ideas regarding grading and the range of numbers used in the scale. Marzano puts forth a scale from 0 – 4 and uses half numbers to further specify goals. In choosing a range of numbers the teacher needs to consider their grading techniques and the types of assessment they will give. The author previously used a scale from 0 to 5 due to the grading system in place at his school and the simplicity of only giving whole numbers as grades. In short teachers need to make their own decisions regarding scale ranges. However, the target goals should not be the highest goal and the first goals should in some way reference prior knowledge.

Minnesota. Yet, it should be noted that steam from a tea kettle might not serve as a good visual for a student whose parents only drink coffee and prepare this beverage in a drip coffee maker.

Table 1 Latent Heat ELO

Scale	Goal	Non-Inquiry Activity	Inquiry Activity
0	Outcome not attempted or not measurable/ phases of matter are not discussed in a relevant discussion	-	-
1	-Student identifies examples of phases of matter in nature -Student discusses the relationship between heat and energy and the ways in which energy/ heat can be moved into or out of a substance.	Lecture/ Worksheet	Discussion/ Questioning Techniques/ Open ended Essay Question
2	Using a description of the phases of matter the student relates phases to energy.		
3	Through lab activities the student graphically depicts the relationship between phase changes and energy.	Lab Instructions	Individual or Group Lab Design and Implementation
4	Through interpretation of the graph in goal 3 the student answers the question: How much energy is needed during the phase changes of water? The process is described moving both ways i.e. liquid to solid and solid to liquid etc.	Short Answer Questions	Essay Question
5	The relationship between energy and phase change is applied to other common natural processes using energy, matter and/or water.	Specific Question Relating to Latent Heat	No Direction Besides Goal

Finally, the distinct difference between this lesson and a traditional lesson resides in the laboratory experience. A traditional teacher would give a set of explicit lab instructions that would dictate the steps students would follow. An inquiry lesson, in contrast, might only give lab materials or, if students are familiar enough with lab equipment, it might only state a problem. The intended purpose of the laboratory lesson is focused and defined in the mind of the teacher; however, the student perceives a context of open-ended exploration and feels that he or she can try anything. This provides a feeling of challenge, eliciting a subsequent sense of accomplishment, which will appeal to a developing brain. Ideally, with some interaction with the teacher, a student will design an experiment to add heat to ice and time the phase change process. He or she will assume, or will be reminded by the teacher, that the energy input will be constant over time and that the temperature of the water can be measured as the experiment takes place. This design process might be done individually or as a class. The important aspects of the lesson are summarized by Lawson (2009) in his list of questions to ask regarding student behaviors:

- Are students making observations that raise questions?
- Are students generating hypotheses?
- Are students analyzing and interpreting data?
- Are class conclusions based on evidence?

At the close of the lesson it is expected that each student will in some way have observed the significant amount of time (and energy) required to change the temperature of water during a phase change as compared to just normal heating (or cooling). In short, they will design an experiment about energy and water and arrive at an entirely new concept regarding the non-linearity of the energy-temperature relationship of water.

In summary, by using this standards based approach, two important principles are accomplished. First, the teacher is compelled to design a lesson that builds on prior student knowledge; knowledge stemming from existing sensory experiences, complex cognitive constructs and concepts that may have been internalized earlier in life or quite possibly experienced earlier in that same lesson. Second, the student is afforded an opportunity to acknowledge these experiences and at the same time demonstrate to the teacher the required foundational knowledge. Next, the student is given a clear problem statement grounded in the core concepts and foundational knowledge, requiring the student to design a process to solve the problem and finally, implement the experiment using previous concepts to derive a conclusion. Furthermore, although the example used in this paper pertains to natural science, it is expected that the ability to observe scenarios (purposefully constructed or otherwise) is transferable among disciplines. For example, students may be asked to solve conflicts (social studies) based on an observation of economic situations or understand and predict how life experiences may lead to the use of specific literature styles (English). In short, problem solving is not a skill confined to use in natural science, it is a skill required throughout all of human existence.

Conclusion

There will always be room for advancement of the theoretical explanations derived from, cognitive developmental and brain-based research regarding instructional best-practice. Yet, if we accept the value of inquiry as an instructional approach, the questions are no longer of proof but rather of effective practices. As shown in this paper, instructional practice in education (and possibly much of life) can be distilled to two distinct areas: Instructional content (building concepts (from stimuli and complexes), and instructional procedure (organizing these concepts into new concepts and related problems in a way that appeals to fundamental cognitive forces in students).

In reference to what is taught and how to teach it, there is and always will be a competition among viewpoints. In the interests of providing a succinct discussion, it is assumed that growth in human knowledge is of paramount importance to human society. That is, an assumption can be made that the more highly developed the intellectual thinking processes are, the more competent an individual will be at finding innovative solutions to complex, abstract problems. These competencies will lead to possibilities that positively impact the quality of life. As such, it needs to be recognized that for an individual to experience this intellectual growth, he or she must be brought, in terms of cognitive process, to the frontier of human problem-solving skills. These skills are then applied to both real and abstract problems. It follows that an effective curriculum design should be mapped backwards in order to determine which tools, concepts, signs and categories, will provide the basis for abstract thought, problem-solving and innovation.[8]

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[8] By using the word backwards it is not implied that a researcher starts from the end and tries to follow a sequence of knowledge to its origin. Rather an initial positive approach will be needed. That is, research

Finally, it is concluded that higher dimensions of abstract cognitive development will be essential in the future to solve the increasing complexity of the world's problems. Therefore, the more individuals acquire the capacity to link ideas and solve complex problems, the better. With this in mind, the purpose of education should not be to create multitudes of identically developed pupils. Rather, an emphasis should be placed on creative and conceptual connections. Quite possibly, the inquiry model provides an effective instructional method for reaching this goal. By asking students to develop concepts in their own way based on their own experiences, teachers can promote human innovation allowing the growth of new neural networks and the opportunity to make connections as the students see fit. Finally, by creating a culture of learning and a desire to be an effective problem-solver, teachers can encourage students to recognize that learning in themselves and others moves the human race toward increased innovation and collective intellectual growth.

Future Research

Currently there are a number of critical issues facing public education. The potential of future generations is limited by misguided government controls, budget decreases and controversy over the mission of public education. An argument has been put forth in this paper that teachers play a critical role in developing within their students the problem-solving skills that will be essential in resolving problems facing civilization in the 21st century. With this in mind, it is imperative that teachers possess the knowledge and skills that will allow them to maximize human intellectual capacity for problem-solving. There is current push in education to organize teachers into learning communities geared towards collaboration around the collective definition of learning goals (Dufour, Dufour, Eaker, and Many, 2010). Some educational

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will need to document cognitive inputs and determine resulting concepts with inputs being added and subtracted as needed to determine desired outcomes.

researchers suggest that this will solve all problems within an individual school. However, this approach lacks an adequate emphasis on the need for teachers to understand how to promote problem-solving skills in their students. The demands for teachers to develop collaborative curriculum based on state standards is insufficient for producing students who can tackle tomorrow's problems. Future endeavors in the field of educational research should continue to qualitatively define the interactions between teachers and students that promote abstract thinking and problem-solving competency. Teacher preparation and professional development programs should provide comprehensive training regarding developmental growth in students related to problem-solving skills within a context of specific curriculum goals. Specific information provided to teachers should include not only a definition of higher abstract concepts, but also the capacity to design and deliver lessons that promote problem-solving skills through inquiry-based methods. A curriculum directly referencing fundamental brain processes could become the basis around which individual inquiry based education experiences are organized. Add to this, teacher competency in creating a culture for learning in the classroom and the opportunities for students become limitless. *Quite possibly the fundamental goal of public education within an intelligent society should be the promotion of individual and group competence in innovation and problem-solving.*

References

Anderson, R.D. (2002). Reforming Science Teaching: What Research says about Inquiry. *Journal of Science Teacher Education.* 13(1) 1 – 12.

Barrow, L.H. (2006. A Brief History of Inquiry: From Dewey to Standards. Journal of Science Teacher Education. 17(?) 265 - 278

Brickman, P., C. Gormally, N. Armstrong, and B. Hallar. (2009). Effects of Inquiry-based Learning on Students' Science Literacy Skills and Confidence. *International Journal for the Scholarship of Teaching and Learning.* 3(2)

Caine, R.N. and G. Caine. (1990). Understanding a Brain-Based Approach to Learning and Teaching. Educational Leadership 66 - 70

Chinn, C.A. and B.A. Malhotra. (2002). Epistemologically Authentic Inquiry in Schools: A Theoretical Framework for Evaluating Inquiry Tasks. *Science Education.* 86 175 – 218.

Danielson, C. (2007). *Enhancing Professional Practice A Framework for Teaching.* Association for Supervision and Curriculum Development. Alexandria, VA.

Dewey, J. (1934). *Art as Experience*. Minton, Balch & Company, New York, NY.

Dewey, J. (1938). *Experience and Education.* Kappa Delta Pi. Touchstone, New York, NY.

Driver, R., A. Squires, P. Rushworth, and V. Woods-Robinson. (1994). *Making Sense of Secondary Science Research into Childrens Ideas.* Leeds City Council Department of Education and the University of Leeds.

DuFour, R., R. DuFour, R. Eaker, and T. Many. (2010). *Learning By Doing.* Solution Tree Press. Bloomington, IN.

Harre, R. (2002). *Cognitive Science: A Philosophical Introduction.* Sage, London.

Haury, D.L. (1993). Teaching Science Through Inquiry. *ERIC CSMEE Digest.* March. (ED 359 048)

Howard-Jones, P. (2008). Philosophical Challenges for Researchers at the Interface between Neuroscience and Education. *Journal of Philosophy in Education.* 42(3-4).

Hmelo-Silver, C.E., R.G. Duncan and C.A. Chinn. (2007). Scaffolding and Achievement in Problem-Based and Inquiry Learning: A response to Kirschner, Sweller, and Clarck (2006). *Educational Psychologist.* 42(2) 99 – 107.

Kirschener, P.A., J. Sweller, and R.E. Clarck. (2006). Why Minimal Guidance During Instruction Does Not Work: An Analysis of the Failure of Constructivist, Discovery, Problem-Based, Experiential, and Inquiry-Based Teaching. *Educational Psychologist* 41(2).

Krajcik, J., K.L. McNeill, and B.J. Reiser. (2007). Learning-Goals-Driven Design Model: Developing Curriculum Materials that Align with National Standards and Incorporate Project-Based Pedagogy. *Science Education* 92 1-32.

Lawson, A.E. (2010). *Teaching Inquiry Science in Middle and Secondary Schools.* Sage Publications Inc. Thousand Oaks, California.

Lucas, R.E. (1976). Econometric Policy Evaluation: A Critique, in K. Bruner and A.H. Meltzer (eds.) *The Phillips Curve and Labor Markets*, vol. 1 of Carnegie Rochester Conference Series on Public Policy, 19-46. North-Holland, Amsterdam.

Marzano, R.J. (2009). *Designing and Teaching Learning Goals and Objectives.* Marzano Research Laboratory. Bloomington, IN.

Marzano, R.J. (2010). *Formative Assessment and Standards-Based Grading.* Marzano Research Laboratory. Bloomington, IN.

Marzano, R.J., D.J. Pickering, and T. Heflebower. (2011). *The Highly Engaged Classroom.* Marzano Research Laboratory. Bloomington, IN.

Maslow, A.H. (1970). *Motivation and Personality.* 2nd Ed. Harper and Row, New York, NY.

Meece, J.L. and D.H. Daniels. (2008). *Child and Adolescent Development for Educations.* McGraw-Hill Higher Education, New York, New York.

Minner, D.D., A.J. Levy, and J. Century. (2009). Inquiry-Based Science Instruction—What Is It and Does It Mattter? Results from a Research Synthesis Years 1984 to 2002. *Journal of Research in Science Teaching.* 47 474 – 496.

Partnership For 21st Century Skills. (2009). *P21 Framework Definitions.* Accessed Online April 21, 2011 <http://www.p21.org/documents/P21_Framework.pdf>

Prince, M. and R. Felder. (2007). The Many Faces of Inductive Teaching and Learning. *Journal of College Science Teaching.* 36(5).

Stiggins, R.J. (2008). *Student –involved assessment for learning.* Pearson Education Inc. Upper Saddle River, New Jersey.

Silva, Elena. (2009). Measuring Skills for 21st-Century Learning. *Phi Delta Kappan*. 90(09) 630-634.

Stiggins, R. (2008). *An Introduction to Student Involved Assessment For Learning.* Pearson Education Inc. Upper Saddle River, New Jersey.

Vygotsky, L.S. (1962). *Thought and Language.* The Massachusetts Institute of Technology.

Vygotsky, L.S. (1978). *Mind in Society.* President and Fellows of Harvard College, United States of America

Wiggins, G. and J. McTcighe. (2005). *Understanding by Design: Expanded 2nd Edition*. Association for Supervision and Curriculum Development.