6-2022

# Inquiry-based Teaching and Learning as a Tool for Achieving a Scientifically Literate Future: Combating a Post-truth World

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Western Michigan University, 2022

Truth is under attack across the world. This can be seen in the lies spread by Putin to justify his invasion of Ukraine to the misinformation spread about combatting the COVID-19 virus. The authoritative and trusted nature of science is being undermined by unfounded beliefs and opinion. Many Americans lack an understanding of how science is done nor have basic knowledge about common scientific information. What is needed is to increase the level of scientific literacy in the United States. Inquiry-based teaching and learning has been touted as a way for developing more scientifically literate citizens, because inquiry-based teaching and learning targets some of the traits necessary for survival in today's everchanging digital world: critical thinking, problem solving, decision making, communication, and collaboration skills. This paper aims to (1) review the early philosophy of inquiry as a concept and describe how it developed into a general educational teaching and learning method by exploring the history of inquiry-based teaching and learning in general and in science education in the United States; (2) discuss the success and/or failure of implementing the inquiry methodologies into the science classroom; and, (3) explore how inquiry can be an important tool in the future of education, specifically in relation to educating a more scientifically literate society in the future.

**Inquiry-based Teaching and Learning as a Tool for Achieving a Scientifically Literate Future: Combating a Post-truth World**

by

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A thesis submitted to the Graduate College
in partial fulfillment of the requirements
for the degree of Master of Arts
Teaching, Learning and Educational Studies
Western Michigan University
June 2022

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ACKNOWLEDGEMENTS

I would like to start my acknowledgements by thanking Dr. Paul Farber for inspiring me to add a master’s degree to my program here at WMU. Having taken the first class with Dr. Farber out of mere interest, the mental stimulation I encountered made me hungry for more, leading directly to this master’s thesis. It is with profound gratitude that I thank him for his encouragement, teaching style, and mentorship. I would also like to thank the other members of my graduate committee, Dr. Dini Metro-Roland and Dr. Brandy Pleasants for their encouragement, for taking the time to review my work, and their offerings of advice.

I would like to thank my husband, Mike, for standing by me throughout the entire process of my graduate education. For allowing me to cause total upheaval to his life not once, but three times in three short years, and for always pushing me to pursue my dreams. None of this would have been possible without his unending support.

I would also like to thank the fellow graduate students who helped support me both academically and emotionally throughout the pursuit of my degree. Special thanks to Shadi Adineh, Abdullah Al Farwan, and Kristen Foley. Without your friendships, graduate school would have been lonely indeed.

Lastly, I would like to dedicate this document to my little friend, Twigbert. I wish you were still here to keep me centered and sane throughout this process. It has been rough without you; I miss you terribly.

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## Introduction

Truth is under attack across the world. This can be seen in the lies spread by Putin to justify his invasion of Ukraine to the misinformation spread about combatting the COVID-19 virus. According to Mann (2018), we live in a 'post-truth' world. Post-truth became the Oxford Dictionaries' 2016 Word of the Year and means "relating to or denoting circumstances in which objective facts are less influential in shaping public opinion than appeals to emotion and personal belief" (Mann, 2018; p.573). This has led to a scientific crisis creating a large disconnect between public opinion and trust in science, over matters such as climate change, vaccine use and safety, and evolution, just to name a few. The authoritative and trusted nature of science is being undermined by unfounded beliefs and opinion. Although, many argue that this disconnect has been happening for a long time (Scheufele & Krause, 2019), the expression of the disconnect appears to have recently become more vocal and vitriol filled. Many point the finger at politics, but a recent study concluded that the gap in the public trust in science caused by political ideology appears smaller than the gap caused by race and education (Li & Qian, 2021). Corroborating this is the results from the most recent Science and Engineering Indicators Survey (SEI; National Science Board & National Science Foundation, 2020) which looked at three scientific process elements: understanding of probability, experimental design, and the scientific method. The results showed that only 43% of Americans have a good understanding of the overall concept of scientific inquiry; with 51% understanding experimental design elements and only 24% with good understanding of the scientific method. Additionally, only 62% of adult Americans answered nine basic scientific fact questions correctly on the same survey. Unfortunately, this is not a downward trend. The results from previous SEI surveys going back to 1992 show a stable trend of almost identical values for all results (i.e., we did not, as a population, gain in scientific understanding across the years). The conclusions that can be drawn from this is that many Americans lack an understanding of how science is done and have only basic knowledge about common scientific information.

According to Hopf et al. (2019), the capacity of individuals to make informed, evidence-based decisions is being undermined by the fake news/fake science cycle operating through today's media and information outlets. They further state that, at the individual level, being less knowledgeable in basic scientific information relating to personal health and welfare can be dangerous and physically harmful. They claim that in the recent past, it was the responsibility of the scientific community to determine the reliability and veracity of facts, but today it is the individual who determines the trustworthiness and truthfulness of facts, regardless of their expertise. Furthermore, having poor basic scientific literacy makes one more susceptible to belief in and acceptance of misinformation, fake information, and pseudoscientific information, regardless of the content of the informational claims (Piejka & Okruszek, 2020).

To counteract this problem, it seems the answer is easy: increase scientific literacy in the United States. That, however, has been a problem since the concept was first introduced in the 1950s (Hurd, 1958). Laugksch (2000) defines scientific literacy as what the public should know about science, usually implying a grasp of the more important scientific topics and an understanding of the nature, objectives, and the basic limitations of science. Another aspect of science that the public needs to grasp is that for knowledge to be scientifically and publicly accepted ('believed in') it must be agreed upon by a community of inquiry (i.e., a community of scientists; Reilly, 2019), because one person's evidence, by itself, is merely opinion. It is this consensus across a community of scientists that provides the authoritative meaning behind scientific findings and makes those findings more supportable to the public. Somewhere in the recent past, this idea of science as a product of a systematic process conducted and approved by an educated community of experts, has been lost. Too many now blindly accept only some products of science (e.g., medicine and technology), but shun or downright deny the existence of others (e.g., climate change and vaccines). Having a lack of understanding about the nature of scientific inquiry (how science is done) may lead to a lack of trust in the scientific processes and the products of science, thus, this potentially leads to the belief in misinformation, intentional and unintentional, and/or pseudoscientific information. To give one example, we are currently seeing currently a distrust of vaccines during the COVID-19 pandemic and the use of alternative medications, which lack rigorous assessment of their affects and safety, to treat the virus (Bray et al., 2020; Kounang, 2021).

The importance of being a scientifically literate citizen is not only the risk of being duped by fake news, misinformation, or pseudoscience. The Committee on Science Literacy and Public Perception of Science (2016) proposes four broad reasons why science literacy is important to the individual and society in general. These rationales include 1) an economic rationale, which argues that science literacy contributes to the economic success of a country across a very wide range of contexts, 2) a personal rationale, which contends that science literacy allows people to respond to the challenges that emerge in their everyday lives, 3) the democratic rationale, which states that democracy functions better when its citizens are informed participants in civic decision making, and 4) the cultural rationale, which claims that the sciences are important because they offer a potent way of understanding the world and being scientifically literate is part of what it means to be liberally educated. Therefore, it is imperative for us to have a scientifically literate citizenry that can think critically about information and make informed, evidence-based decisions.

This should be a concern for educators across the country because it appears that science education is not producing a scientifically literate populous. Science not only provides products we use in everyday life, but it also provides information based on a reliable and systematic process that includes a peer review and consensus component. Science provides information that is warranted beyond one's own observations (Scheufele & Krause, 2019). Today people need to make critical decisions in a world where information, factual or not, is thrown at them almost continuously.

Our current national curriculum standards finally reflect this need for a deeper understanding of science processes (National Academies Press, 2013). One of the suggested approaches for developing a deeper understanding of the basic science facts and an appreciation of how science is done and why, is inquiry-based teaching and learning methodologies (Bevins & Price, 2016; National Academies Press, 2012; National Research Council et al., 2000; Rutherford, 1964).

One of the reasons inquiry has been touted as a way for developing not only more scientifically literate citizens, but more literate citizens overall, is because inquiry-based teaching and learning targets some of the same traits that both educational specialists and employers deem necessary for professional survival in today's everchanging digital world (Binkley et al., 2012; Jukes & Schaaf, 2019). These traits, called 21$^{st}$ Century Skills include critical thinking, problem solving, decision making, communication, and collaboration skills. These are the same skills that are used when learning through inquiry and are now stressed in the Science and Engineering Processes from the Next Generation Science Standards (National Academies Press, 2013).

The concept of inquiry itself has been discussed and written about for millennia, since at least the ancient Greeks (~300 BCE). However, the concept of inquiry has only been in the forefront of discussion in education for a little over 100 years. Its history has been plagued by confusion, lack of implementation, and political interference. Consequently, as this paper will show, today there is no clear consensus of what inquiry is or should look like in the classroom. So, how did we get here? Can we learn from our past successes and mistakes? Can inquiry teaching and learning be utilized to increase scientific literacy for our students? To explore and potentially find answers to these questions, this paper will 1) review the early philosophy of inquiry as a concept and describe how it developed into a general educational teaching and learning method by exploring the history of inquiry-based teaching and learning in general and in science education in the United States; 2) discuss the success and/or failure of implementing the inquiry methodologies into the science classroom; and 3) explore how inquiry can be an important tool in the future of education, specifically in relation to educating a more scientifically literate society in the future.

## Methodology

The literature used in this study were located by using ProQuest®, Google Scholar, ERIC through the EBSCO portal, and the Western Michigan University Library holdings. Keywords used to search these databases included: inquiry, philosophical inquiry, scientific inquiry, inquiry science teaching, inquiry science learning, inquiry in the classroom, educational inquiry, discovery learning, active learning, inquiry-based science, inquiry-based learning, inquiry-based teaching, inquiry + Plato, inquiry + Aristotle, history of science teaching, history of science philosophy, philosophy and education, history of inquiry education, science literacy, scientific literacy, pseudoscience, fake news, and trust in science. Different permutations of these key terms were also utilized in the literature searches. The reference sections of collected papers were also searched for additional resources and resources the author already had available were also used. Collected resources included books, print reports, journal articles, video blogs, and unpublished dissertations.

Inclusion criteria were broad so as to encompass enough information on the category of scientific literacy, the philosophy of inquiry, the history of inquiry in education, and specifically, inquiry teaching and learning in science education – past, present, and future. Approximately 150 resources of various types were collected and examined for this study. All resources were perused carefully and those that did not add important and/or distinct information to the discussion were excluded.

The author acknowledges that the terms inquiry, inquiry-based teaching, and inquiry-based learning are not equivalent. However, for this paper, they will be used interchangeably. Since the purpose of this paper is, in part, to present a broad overview of inquiry, the conflation of these terms was deemed appropriate.

## What is Inquiry?

An argument has persisted for centuries over whether there are truths about the world, whether we can perceive them, and if so, how. A truth is defined as something in accordance with fact or reality (Oxford Languages, 2022). A fact is a thing that is known or proved to be true; or in law, a fact is the truth about things or events as opposed to their interpretation (Oxford Languages, 2021). Development and discovery of facts is one of the fundamentals of philosophical inquiry and the goal of critical inquiry (Nola & Irzik, 2005). This debate, over the existence of facts/truth, is essential to education since education is concerned with learning truth from falsehood, and knowledge from opinion (Barrow, 2010), concepts that are exceedingly important in today's climate of fake news! The early Greek philosophers (Plato, Aristotle and Socrates), although with different methods and ends, thought that we must use critical inquiry to discover truth. Yet, our efforts would only be successful if we (the individual) conducted the inquiry into truth ourselves (Nola & Irzik, 2005). In other words, truth could not be found from knowledge given by others but must be discovered by the individual. These ideas run through most of the usages of the word inquiry, from its philosophical roots to the modern concept understood in science education today.

## Inquiry as a Way of Thinking

### *Philosophical Inquiry*

Philosophy is both an activity involving thinking about all kinds of questions and involving the construction of sound reasons or insights into our most basic assumptions about the universe and our lives. Philosophy also involves new assumptions or presuppositions as reasons for the explanation of natural phenomena (Archie & Archie, 2004). In other words, it is the exploration and development of knowledge, which is how it can be linked to scientific inquiry. It is often acknowledged that much of Western thought stems from the writings of the Greek philosophers. Among these philosophers, much of what we think about knowledge and truth comes from Socrates, Plato, and Aristotle (Woelfel, 1987).

Therefore, before we begin our discussion on the philosophy of inquiry, a definition of knowledge needs to be established. Epistemology can be defined as the study of knowledge and how we come to know things (Driscoll, 2014; Pritchard, 2018). The concept of knowledge is not singular, nor is it unchanging over time. Knowledge is also not achieved by one person alone in a single action, instead it is attained through the acts of many over many circumstances. Our knowledge is dependent upon the contributions of many in an intellectual community (Zagzebski, 2017). One conception of knowledge is that it is *Justified True Belief*, which can be dated back to the time of Socrates and Plato, and has held up as the definition of knowledge until fairly recently (Nola & Irzik, 2005; Zagzebski, 2017). We can say that knowledge and truth are related and that methods of inquiry are “truth-acquiring” because the aim is to secure an agreement to the answer (i.e., knowledge) for a question.

Plato thought that inquiry should be the pursuit of truth while engaged in worthwhile endeavors. Inquiry to him was intimately tied to morals, ethics, and justice. He thought education should be for the development of a just society, his ultimate worthwhile endeavor (Barrow, 2010; Vassallo, 2004). In fact, Plato invented the philosophy of education as we know it today, although it has been highly modified since Plato’s day. According to Williams (2010b), Plato identified the fundamental components that should constitute the area of educational inquiry. These are that (1) educational practices are directed toward the moral development of individual souls; (2) the fundamental purpose of education is to produce just citizens; (3) education would be compulsory and exclusively provided by the state; and (4) individual children would be directed toward the kinds of work best suited for them based on their abilities which would lend ultimately to their proper social class.

Each of these have been asserted as goals of education in the United States at times in its history (Egan, 1997; Urban et al., 2019). Yet, for Plato, ideas about philosophical and educational inquiry were basically the same. Inquiry was about asking questions and how to ask them, although he never really described a method for approaching inquiry. Much of what Plato developed in his way of inquiring about truth was gained from his long association as a student of Socrates. In establishing his dialogic method, Plato wanted to mirror as closely as possible the actual process through which he, his teachers, and his students contemplated philosophy (Vassallo, 2004). This ‘Socratic method’ of critical inquiry was accessible to anyone because it was based on the use of rational thought to dissect and discuss questions designed to bring about knowledge through the unveiling of truth. No special education was required. Both Socrates and Plato felt that little true knowledge could be conveyed to a person through direct (didactic) means. They believed that the path to knowledge, and therefore truth, can be best achieved through a person experiencing the steps of reasoning by themselves. This experience is the only way that a person can make fully explicit to themselves the reasons for the true answer to their inquiry, and therefore the only way a person can truly gain knowledge (Nola & Irzik, 2005).

Aristotle's ideas of inquiry mirror Plato's in many ways. However, Aristotle's approach to inquiry was more systematic. His concept was of a dialectical method that had the main purpose of reaching a conclusion. He believed that the search for truth must be from many directions (art, science, intuition, etc.) not through one specific method alone (Nola & Irzik, 2005; Vassallo, 2004). So, how does one become conversant in art and science (using two disciplines mentioned by Aristotle)? You need to gain knowledge in these disciplines. But, before you can become conversant in a discipline, you need to know the questions to ask to become knowledgeable in that discipline. Therefore, to Aristotle, inquiry becomes a circular process. You use inquiry to seek knowledge and truth in a subject, but you need knowledge about a subject to conduct further inquiry. It is, or should be, a never-ending process.

***From Philosophy to Science***

From the ancient Greeks to the present, science has been interwoven with philosophy: science, metaphysics, logic, and epistemology have been inseparable. Scientists were called "natural philosophers" up to the middle part of the nineteenth century. But, by the end of the nineteenth century the separation of science and philosophy took place (Frank, 1952).

Science, as is true of any field, is a product of its time. Therefore, the philosophical ideas of any time period concerned have had a major influence on the science being done and the scientific products being created at that time. Scientists think, write, and talk with the language, cultural, and conceptual tools accessible to them at that time. A scientist's understanding and approach to the world is formed by his/her education and environmental milieu; and this milieu is permeated by the philosophies of that time period (Matthews, 1994). Thus, the transition from philosophical thinking to scientific thinking regarding inquiry was almost a non-issue. However, as the sciences developed throughout the $19^{th}$ and $20^{th}$ centuries, science became thought of as a special way of gathering knowledge about the world and our ideas concerning science became more firmly established.

**Inquiry as a Way of Doing: Scientific Inquiry**

It can be assumed that the goal of science is to generate knowledge. Historically in the United States, science itself was not valued prior to the mid-nineteenth century, and it appears we may be backsliding today. Science, metaphysics, logic, and epistemology were inseparable until the division of the scientific disciplines in the late $19^{th}$ century. However, even at this point, faith was at least as important as empirical data and, in many instances, it dominated the practices of science (Bybee, 2000).

Scientific inquiry can be thought of as the many methods that scientists use to study the natural world, gather evidence, and then propose explanations based on that evidence. The backbone of scientific inquiry is the scientific methods used to investigate questions about the world. Scientists construct knowledge from evidence and observation, through a systematic process of establishing theories, collaboration, and consensus.

Some philosophers of science, would contend that the scientific method is the only reliable way of acquiring reliable information or truths about the world of nature, man, and society (Kim, 2003; Ziman, 2001). But, for the most part, science, and the process of thinking scientifically is viewed as different from, and superior (until fairly recently) to, other ways of knowing (Stinner, 1989). Historically, and to some extent even today, the standard view of scientific thinking was that assertions of knowledge, laws, and theories are assessed impartially with regard to the evidence only, no outside influence, except that which is shown in the evidence, is used to draw a scientific conclusion. In other words, to be worthy of being believed as scientifically true, an idea must be able to be objectively and empirically tested (Maxwell, 2003). Additionally, not only was science and scientific thinking viewed as unique, those practicing science were also viewed as special. A prime example of this is the philosopher of science Charles Peirce's concept of a scientific man. Reilly (2019), in a treatise on Charles Peirce's theory of scientific method, states that Peirce saw science as the milieu of a particular type of man, the scientific man. This man was characterized by the love of learning and the pure love of knowledge for its own sake. Scientific man's goal "was the diligent inquiry into truth for truth's sake" (p. 10). This view of the 'man of science' is a contributing factor in the current distrust of science. The public sees scientists as apart from reality and the real world, intellectual and out of touch, leading partially to the distrust.

It is just recently that scientific thinking has evolved past this rigid empiricism and somewhat away from the elitist view of the practicing scientist. Newer ideas of scientific thinking see it as a common activity engaged in by almost all humans, instead of an elite few. And the complex social aspect of scientific thinking and doing is being recognized as a necessary characteristic (Kuhn, 2010). Also, the concept that there is a single scientific method, used by all scientists around the world, is finally being rejected. Science is complex and, although, scientific inquiry always uses a systematic approach, that approach differs significantly with the questions being asked or the discipline being investigated. Scientific information is often presented as static, as end of a process facts, instead of having a history and a changeable future. Furthermore, the myth of scientific objectivity is being put to rest. Science is not and cannot guarantee objectivity; simply because it is carried out by humans within a cultural context (Kuhn, 2010; Wong & Hodson, 2009). Science is a social undertaking firmly embedded in the culture of who is undertaking the scientific process. One cannot escape the influences of others when doing science.

In science, according to the philosopher of science Karl Popper (Phillips, 2000b), there can be no progress by proving/confirming a hypothesis, progress only occurs when our hypotheses can be disproved. Everything is tentative, nothing is proved. Additionally, a current myth is that science is absolute objectivity. This is not true, as a collective activity involving humans using data that needs to be interpreted, there will always be bias in experimentation and scientific conclusions. Unfortunately, too many textbooks do not reflect the actual process of science as a collaborative, interactive, constructivist activity involving fallible humans embedded in a cultural context (Anderson, 2006; Matthews, 1994; Phillips, 2000a; Wong & Hodson, 2009). However, this tentative nature of science can often be inflated and cause people to think that science cannot be trusted (Cobern, 2020), which then can be used by the anti-scientific community to provide evidence (ironically) for their views. Therefore, there is a clear need for a more current and realistic view of the scientist. We need to humanize science and show the average person that science is part of reality, and the process of science is our currently most reliable and trustworthy processes for gathering information. Again, one means suggested for accomplishing this is through using inquiry methods in education. The next section discusses the history of inquiry in education and the efforts to establish inquiry as a method of promoting scientific literacy in an American context.

## The History of Inquiry in Education

For most of history, children were not thought of as ‘children’ as in the modern sense. Instead they were treated as miniature adults, and education for most people was unattainable (Urban et al., 2019). A ‘classical education’ was seen as the purview of the upper-class male, not for attaining a job or career, but as a mark of their social class or functionally for those who entered the clergy. Education mainly consisted of instruction in classical languages (Greek and Latin), reading, writing, and some arithmetic (DeBoer, 1991). As we approached the middle of the 19$^{th}$ century, more children, of all classes, were being educated (Rury & Poth, 2019; Urban et al., 2019). At this time, education centered on the transmission of bodies of knowledge from one generation to the next through teachers ‘preaching’ to docile, receptive, obedient students. This type of education was typified as an imposition of knowledge from above (teachers) and outside (not necessarily related to a student’s life) of the student. Little student participation was expected or desired, and student conformity was an end goal. Additionally, the information portrayed was static, in the sense that little thought about how the information was derived or how it will change in the future.

However, by the end of the 19$^{th}$ century, economic and social changes were occurring that would result in major educational changes. Social unrest, a reaction to the excesses of the upper classes during the Gilded Age, was on the rise. Furthermore, increasing industrialization of America was stimulating the call for a change in curriculum being taught and the methods of teaching, so that the populous could adapt to the quickly changing world. This was the start of the Progressive-Education movement in America. Promoters of this ‘new education’, thought that all children should be educated in a more humane, naturalistic manner. Learning should occur through active learning and sensory experiences; not through textbooks and passive reception of information from an expository teacher (Page, 1990; Reese, 2001). This may sound like the beginnings of inquiry in education, but it was not until John Dewey, in the early 20th century, introduced his concept of 'experiential learning', that a true notion of inquiry became part of American educational thought (Page, 1990; Reese, 2001; Rury & Poth, 2019; Urban et al., 2019).

Dewey's ideas regarding inquiry were broad, but his philosophy of education was firmly entrenched in the philosophy of experience. He did not think that either the new progressive curriculum and related teaching methods nor the traditional practices were adequate for developing a critically thinking, socially aware individual. Instead he turned to what he called experiential education (Dewey, 1938). Progressive education, in Dewey's vision, should develop individuality through experiential learning and that knowledge, techniques, and skills should relate to a student's real life. He also thought that information transmitted through education should be presented as dynamic; knowledge acquisition should have a history and a future, and should reflect the ever-changing world around us (Dewey, 1938). He noted that epistemologists often divide theory and practice. They conceive inquiry as purely mental, while practice is characterized by overt action. Dewey believed that this was a flawed idea because all inquiry consists of actions, using objects as in experiments or symbols as in mathematics, and therefore there is no division between the theory and practice in inquiry for acquiring knowledge (Kaufmann, 1959).

As expected, inquiry use in science education is first noticeable in the literature at the same time as the Progressive-Education movement was developing. Ideas that may be recognized as proto-inquiry in science education can be seen in Jordan's 1890 article about the state of science in American high schools. Jordan states that science teaching should never begin with learning from textual information. Instead, learning should start with the students seeing for themselves some phenomenon and drawing their own conclusions from what they experience. Then, once they have basic ideas from their own observations, information can be presented to help them advance their understanding about scientific generalizations.

According to Barrow (2006) and Phillips & Dewey (2016), John Dewey was a strong proponent of including inquiry in K-12 science education, and thought that the practice of science was the skill that needed to be taught because that was the skill that would be relevant to life. Dewey had a very high regard for science and thought that the experimental method (the scientific method) was one of the greatest tools humans have ever devised (Phillips & Dewey, 2016). He thought that science teaching at that time put too much emphasis on the accumulation of content knowledge and not enough on science as a method of thinking and an attitude of mind (Bybee, 2000). He also thought that the inquiry problems studied needed to be relevant to students' everyday experiences and geared toward their intellectual capabilities.

Others, such as Charles W. Eliot and Lois Agassiz of Harvard, advocated for a laboratory approach to teaching science (Bybee, 2000), it is not clear whether true widespread implementation of inquiry methods happened in schools during the late 19$^{th}$ and early 20$^{th}$ century. A study by Stedman (1986), looked at evidence for inquiry-type investigations and questioning within science textbooks between the 1820's and 1910. His investigation showed some evidence of inquiry in textbooks during this time and assumes that some inquiry was being used in classrooms, especially around the turn of the century, but the practice was not widespread. However, it should be noted, that even though there is evidence of inquiry in textbooks, there is no evidence that it was put into practice in the classroom.

According to Cremin (1959), the beginnings of the dissolution of the Progressive Education movement could be seen toward the end of World War II. It was during this time, in the mid-1940s, that educators and policy makers were growing dissatisfied with the ‘new education’, as progressive practices were then called. Attacks were coming from right-wing radicals who categorized progressive education as communistic. Also, because of the practical side of progressive education practices, where students were taught practical skills, some academics claimed it was anti-intellectual. So, during the next decade, it seemed much of education went back to a more traditional methodology. Nevertheless, ideas from the Progressive-Education movement continued to carry forward under different names.

During the 1950s and early-1960s, much work on child psychology and learning was coming out from such researchers as Piaget, Vygotsky, and Bruner. Their research results suggested that students should be constructing their own learning for knowledge to be meaningful, and that knowledge construction for learning was always a social process (Driscoll, 2014; Phillips, 2000c). This constructivist outlook on education was based on the concepts that we are not born with cognitive knowledge and that information cannot be acquired by direct perception or absorption. Though born with cognitive possibilities it was only through direct experiences that we acquire knowledge. The constructivist epistemology is complex and diverse, but the emphasis is on the learner being an active participant in knowledge acquisition. It was also recognized that learning is not done in a vacuum, that all learning rests upon others and is an entirely social process. Constructivism became the ‘new’ form of Progressivism (Phillips, 2000a). Consequently, a resurgence of neo-progressive ideas in education occurred.

This was further fostered by the launch of the Sputnik Satellite in 1957 and the ensuing Space Race between the United States and the Soviet Union. This event was the push Congress needed to finally give federal financing to public education (Urban et al., 2019). The launch of Sputnik paved the way for a revolution in science teaching. Having the Soviets beat us into space caused many Americans to question the quality of science teachers and the science curriculum being taught in their schools. Funding was funneled into the sciences from federal and private sources. This provided the funds to develop new curriculum in all the sciences that emphasized ‘thinking like a scientist’ and the process skills associated with science (Barrow, 2006; DeBoer, 1991). The results of this restructuring of science education seemed to work, at least in the short run, as we beat the Soviets to the moon in July 1969.

There was evidence of inquiry being promoted in the late 1950s and into the 1960s (e.g., Joseph J. Schwab and the BSCS textbook series that focused on inquiry in science (Bybee, 2000; Lumpe & Beck, 1996)). However, from other educational leaders at the time, it was clear that in the practice of science teaching, science as inquiry was not generally taught. It also was not clear at this time as to what teaching science as inquiry really meant. F. James Rutherford, another leading educational reformer of this era, stated that until teachers are grounded in the history and philosophy of the science they teach, the kind of understanding necessary to truly teach in an inquiry-based manner will elude them. Until this happens, not much progress will be made in the teaching of science as inquiry (Bybee, 2000)

Yet, it was during this time that one saw the emergence of what was called the Discovery or Inquiry Movement (Page, 1990). According to Page, this was a two-part educational process. Discovery referred to self-learning and figuring things out, which then directly leads into inquiry. In the discovery phase, Socratic ‘inquiry’ questioning method was often used to illicit answers to students’ questions. Inquiry was composed of reflective thinking and problem solving (often using a scientific method in the sciences). However, this was a relatively short-lived resurgence.

During the mid-1960s and into the 1970s, the Civil Rights movement, feminism, the Vietnam War and the antiwar demonstrations, numerous assassinations of prominent figures, and environmental activism caused unprecedented national turmoil. Educational reform became embroiled in solving the problems of race and poverty and addressing the societal ills of the era. Across the Atlantic came the idea of the ‘open classroom’ model of education. In a synopsis by Cuban (2004), the open classroom model was touted as the way to address the problems confronting U.S. society at that time. The concepts behind open education would seem very familiar to those from the Progressive Education Movement. The focus was on students’ “learning by doing”. However, what made this different was the setting. Schools were built without walls separating the classrooms and teacher teams taught multi-aged groups of students. There were no standardized tests, whole class lessons, or a detailed curriculum. The ‘classroom’ was set up with interest centers where students encountered materials that allowed them to learn. They would move from each interest center, learning at their own pace in topics that interested them. Teachers were guides who structured the classroom activities for individual students or small work groups. The organizational structure of the open classroom was such that it promoted active learning, self-directed/student-initiated learning, and learning took place using a variety of media types. Proponents of this model saw it as a method to counteract the traditional formal, teacher-led classroom environment that they said crushed creativity and social cohesiveness. In the culture of activism, they believed the open classroom, along with desegregation, would heal the social divide that was prevalent at that time.

Although it appears that at least the concept of ‘inquiry’ might have been a component of the open classroom, students were learning by doing, there were major problems in the implementation of the open classroom across the United States, so very little true inquiry was probably taking place. Many schools were built without walls, in the model of the open classroom, but having open spaces is not necessarily open education. Most schools failed to implement the pedagogical practices associated with open education. And, by the mid-1970s, with the U.S. economy failing, attitudes concerning the Vietnam War still deeply dividing society, open education became the whipping boy of educational critics and was blamed for all the ills facing public education.

Thus, by the 1980s and 1990s there were significant changes in educational reform. During this time, educational reform swung away from progressive educational ideas and toward the side of increased accountability, curricular standardization and standardized tests (Van Heertum & Torres, 2011). A couple things pushed the swing in this direction. According to Barrow (2006) and Yager (2000), one of the pushes was *Project Synthesis*, a National Science Foundation review, completed in 1981, that focused on the role of inquiry in science teaching. Their analysis revealed that the science education community was using the term inquiry in numerous ways, and from those uses it was unclear about the term's actual meaning and that there was real confusion over its meaning in the classroom. They also found that the widespread support of inquiry was more lip-service than real in practice. They concluded that there was little evidence that inquiry is being used.

The second and more significant event that pushed educational reform at the time was the creation of the Committee for Excellence in Education and its subsequent publication in 1983 of *The Nation at Risk*, a report whose purpose was to examine the quality of education in the United States (Uno, 1990). The Committee and the report were commissioned under the direction of President Ronald Reagan (1980-1988). Although highly criticized since, at the time, this document told the American public that public education was failing both students and the country. Along with the criticism on education, the report made numerous recommendations to improve education (National Commission on Excellence in Education, 1983). The recommended improvements led to an era of accountability that we are still amid today. During Reagan's term in office, he gave back to the states most of the responsibility for improving education, a role that went primarily to the local school districts and teachers, along with major cuts in educational funding at the federal level (Urban et al., 2019; Van Heertum & Torres, 2011).

Reagan's education policies were adopted by President George H. W. Bush (1988-1992) with little change. The big difference was that Reagan did not believe that the federal government should have a large role in education, whereas George H.W. Bush wanted more federal control of education, instigating national testing, and nationally dictated standards. When President Bill Clinton (1992-2000) was elected, there was hope that education policy would swing back to more progressive thinking. However, Clinton was an advocate of keeping the control of education at the federal level, thinking it kept the US more globally competitive. So, the concepts of accountability across state lines, national uniformity of the curriculum, and national standardized testing continued.

As standardized testing and accountability continued to grow throughout the 1980s and 1990s, much of the autonomy, creativity, and pedagogical options for teachers in the classroom decreased. Studies suggest that standardized testing and accountability have not really improved the quality of learning and instead suggests that imaginative instruction has been sacrificed for teaching to the test and loyalty to a standard (Knudson, 2011; Sion, 2004). Adding to the standardization problem during this time was the rapid privatization of education, from textbooks and curriculum to the charter school movement. Although this might not have meant a shift away from more active inquiry-based pedagogy, when the desire to make a profit is coupled with standardized tests and accountability, many teachers are motivated to teach to the test. This yields to a decrease in the breadth of curriculum and pedagogy (Knudson, 2011). Thus, one must assume that pedagogies like inquiry, that take more time than traditional teaching, will be neglected for more efficient methods.

For the sciences, however, the situation started to change in 1996 with the publication of *The National Science Standards* (National Research Council et al., 2000; National Research Council (U.S.), 1996). Such standards are a relatively recent development in education (Labov, 2006). This first set of national standards had an emphasis on inquiry in the science classroom, giving the potential to change science education overall.

## Inquiry in Education Today

### Standards and Inquiry

Evidence of coordinated efforts at developing educational standards is mostly absent in the literature prior to the mid- to late-1900s (Labov, 2006). However, one of the early attempts to develop standards for the sciences can be seen in a report published in 1971 by the Council of State Science Supervisors (Dowling, 1971). A primary outcome of this report was a comprehensive operational definition of Science Education. The report states that the goal of science education is “to develop a scientifically literate individuals who have a good understanding of the conceptual structure and processes of science and who are able to apply this understanding to interpret information presented to him” (p. 1). The report expands on the definition by stating that there are 4 major curricular areas in science that need to be addressed in our science classrooms. These are: 1) The conceptual structure of science, meaning the contextual information, the facts and concepts, the product of science; 2) the processes of science as applied to learning, that is, the explicit notion that the process of science is a mode of inquiry which needs to be incorporated into the curriculum; 3) the nature of science, such as the collaboration, fallibility, bias, and culture, which all interact with the process of inquiry; and 4) the relationship of science to society, which relates to the nature of science and therefore the process of inquiry. The standards and recommendations contained in this report did not officially call for inquiry-based teaching or learning, but recommendations did call for a more active, student-centered, exploratory type of science education. Although this was not the first time that inquiry was deemed important to include in science education, it was the first time an organized group published a set of standards to be implemented in a science classroom that included the concept of science as a process of inquiry. It was a good first step, with a goal that is directly aligned with the target of increasing scientific literacy of the kind so desperately needed today. Unfortunately, there was no incentive for schools to adopt these standards and they were primarily used as suggestions or as a template for science curriculum at that time.

Standards, at the federal level did not appear again until the aforementioned publication of the *National Science Education Standards* (NSES; National Research Council (U.S.), 1996). This set of standards had broad support from the National Science Foundation, the U.S. Department of Education, the National Aeronautics and Space Administration, the National Institutes of Health, and the National Academy of Sciences. Again, the goal of implementing these standards was to produce scientifically literate citizens. These standards defined inquiry as a complex activity that involves making observations; asking questions; examining sources of information to see what is already known; planning investigation; assessing what is already known in light of experimental evidence; using tools to gather, analyze, and interpret data; proposing the results and conclusions. Inquiry requires identification of assumptions, use of critical and logical thinking, and considerations of alternative explanations. The standards use the term "inquiry" in two different ways. Inquiry as content, which means both what students should understand about scientific inquiry and the abilities they should develop from their experiences with scientific inquiry. And, also, as it refers to teaching strategies and the processes of learning associated with activities oriented to inquiry (Bybee, 2000).

For the first time, inquiry, by name, was declared central to student learning. Science is a process and learning science is something that students do, not what is done to them. These standards also recognized that inquiry-based teaching is not the only way in which science should be taught. This truly harkens back to Dewey's experiential learning. The standards advocated that a teacher needs a diverse toolkit of teaching strategies to achieve scientific literacy in their students. It was emphasized in these standards that they were not a curriculum, instead they provide the criteria which schools can use to assess whether their students are attaining scientific literacy. To fully implement these standards, much of science education in the U.S. would need to change.

Again, no mandates required states to adopt these standards. Instead, they were to be used as guidelines for states to develop their own set of science standards. However, there was a consensus among scientists and science educators that these standards reflected quality science education. By 2006, all states except one had used these standards, and other publications such as the *Benchmarks for Science Literacy* (American Association for the Advancement of Science, 1994), to establish their own state science standards (Labov, 2006).

The establishment of state standards was further accelerated by the passing of the *No Child Left Behind Act* (NCLB) in 2001, when it was signed into law by President George W. Bush. NCLB was one of the most comprehensive and contested educational reform acts ever enacted (Goertz, 2005; Simpson et al., 2004; Van Heertum & Torres, 2011). The stated goal of

NCLB is to “ensure that all children have fair, equal, and significant opportunity to obtain a high quality education, and reach, at a minimum, proficiency on challenging state academic achievement standards and state academic assessments.”(p. 68; Simpson et al., 2004). There were 5 major themes in NCLB Act: 1) Accountability through Adequate Yearly Progress (AYP); 2) accountability through Highly Qualified Teachers; 3) the Use of Scientifically Based Research (SBR) practices in the classroom and school; 4) expanded educational options for parents; and 5) increased local school and school district control. Because of these, especially the first theme of accountability, schools needed to prove that their students were proficient in English & Language Arts (ELA) and Mathematics through yearly state level standardized assessments. This led all states, except one, to adopt state standards, including in the sciences, by 2006. The consequences to inquiry-based teaching and learning were manifested in how the accountability assessments were undertaken and funded. States assessed their schools through student progress on standardized tests. Schools that did well on these tests received good ‘grades’ for the AYP and received public recognition and rewards. Schools that did poorly were often sanctioned and could be taken over by the state. Also, the mandates associated with NCLB were poorly funded by the federal government, causing additional financial strain on the states. Originally, the only scores that mattered were those in reading and mathematics. It, therefore, quickly became apparent that scoring well on these tests was the thing that mattered to the detriment of all other subjects. Right or wrong, teaching methodologies and practices not focusing on the skills and content material necessary to pass these tests were quickly reduced or abandoned. This was exacerbated by extreme teacher shortages in the early 2000s, leading to many unqualified or less qualified teachers in classroom subjects they did not know well, and promoting many teachers to ‘teach to the test’ (Dee et al., 2013; Goertz, 2005; Knudson, 2011; Simpson et al., 2004; Van Heertum & Torres, 2011).

In the sciences, this was even more puzzling because the science standards being developed by nearly all the states are based on the NSES, which focused heavily on inquiry. There seemed to be a large disconnect between what was written into the science standards and what students were being tested on. And, regardless of whether state science standards incorporated inquiry-based teaching and learning, no one was watching. Although NCLB required science standards to be in place by the 2005-2006 school year, science was not part of the standardized testing at the beginning of NCLB. The first standardized science exams as part of the AYP were given in 2007-2008 school year (Judson, 2010; Labov, 2006), and therefore could be ignored up to this point for the more important assessment goals in ELA and mathematics. And, in reality, science could continue to be ignored because, although schools were required to administer tests in science, the scores were not used to calculate the schools’ AYP (Judson, 2010). So, ignoring or shortening the amount of science instruction is exactly what happened in many classrooms, especially at the elementary level (Anderson, 2012; Griffith & Scharmann, 2008; Marx & Harris, 2006). And, in those states or districts where the science tests mattered, teachers reported increasing pressure to ‘teach-to-the-test’ which fostered more teaching to facts and less doing science in the form of inquiry-based activities and other active learning strategies (Anderson, 2012). Interestingly, in the literature review by Anderson (2012), studies looking at teacher methodologies in science classes not associated with specific tests or student test years showed an increase in the use of inquiry-based strategies. Therefore, it appears that when the pressure is off, teachers implement more active learning methods.

None the less, by at least 2007 it was clear to most educational stakeholders that an improvement to the ELA, mathematics, and science educational standards was needed. ELA and mathematics came first with the development of the *Common Core Standards in English and Mathematics*. The state-led effort to develop the Common Core State Standards was launched in 2009 by state education leaders. State governors and educational leaders recognized the value of consistent, real-world learning goals and launched this effort to ensure all students are graduating high school prepared for a fruitful and purposeful life. Forty-one states had officially adopted the standards by 2010-2011 school year, and full implementation was achieved by most states between 2012 and 2015. By this time, only nine states had opted to develop their own standards and did not adopt the Common Core. Although inquiry is not explicitly a part of these standards; problem-solving, collaboration, communication, and critical-thinking skills are woven into the standards and from this you can infer that some active learning strategies must be suggested by the standards to fully realize these skills (Common Core State Standards Initiative, 2021).

The quest for standards reform in the sciences was a two-step process. It began with the development of *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* (National Academies Press, 2012) and followed by the development of a new set of science standards the *Next Generation Science Standards (NGSS)* (National Academies Press, 2013), which were released in 2013. As of 2014, twenty states and the District of Colombia have adopted the NGSS and 24 other states have developed their own standards using the *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* as a template. Only five states chose not to adopt the NGSS (National Science Teaching Association, 2014). A prime reason for developing the new standards was because the current science education practices lacked opportunities for students to engage in experiences of how science is done (National Academies Press, 2012). This is a direct link to inquiry-based teaching and learning.

NGSS is built around 3 dimensions of learning: science and engineering practices; crosscutting concepts that apply across all fields of science and unify the scientific realm; and, core ideas in four disciplinary areas: life sciences, earth and space sciences, physical sciences, and engineering, technology, and application of science (National Academies Press, 2012, 2013). *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* clearly lays out the importance of scientific inquiry in the science and engineering practices. The emphasis is no longer only on content knowledge, and the authors of the Framework are careful to point out that the terms scientific and engineering practices were specifically used to recognize that for engaging scientific inquiry there must be a combination of knowledge and skills used simultaneously, not just practical skill usage. We have reached the present era in our narrative. The next section will examine where we are today with inquiry in education, particularly the sciences.

**An Inquiry Definition for Today's Classrooms**

The ideas about how science is actually performed must be translated to the science classroom so that students have a clear idea of how scientific knowledge is constructed (Alberts, 2000). Aspects and products of scientific thinking are important to consider if the point of education is to teach for a scientifically literate society. Especially since inquiry-based teaching and learning has been touted as one of the ways to convey this information to today's youth, so that they become tomorrow's scientifically literate citizens.

Additionally, in the teaching of science, we must acknowledge how science and the intellectual and cultural traditions in which it is embedded, interact. Science is not static. It has a history through which one can see the development of the relationship between the wider world and science ideas and therefore can shed light on contemporary issues and how to address them (Matthews, 1994). This aspect of science must be incorporated into the classroom. Also, the nature of scientific investigation makes it almost a necessity for using inquiry-based teaching and learning in the classroom. This is especially important if one is going to teach the processes of science (i.e., how science is done) since it itself is an inquiry process.

As we have seen, the terms inquiry teaching, and inquiry learning have multiple, and elastic, definitions in the literature and there is no general agreement to a common meaning in the science education field (Barrow, 2006). However, to implement inquiry teaching and learning in the K-12 classroom, teachers need a clear understanding of inquiry and what it looks like in the classroom. I think it can be agreed upon that to be considered 'scientific inquiry' certain components are necessary, and these need to align well with the new NGSS standards. Therefore, the following educational concept of inquiry is suggested as a framework for the establishment of scientific inquiry in the science classroom. Inquiry in the science classroom should encompass (1) the pursuit of answers to scientific questions; (2) planning, designing, and conducting investigations; (3) analyzing, evaluating, and interpreting data; (4) explaining phenomena from observations or evidence; (5) using evidence to advance a claim or conclusion; (6) communicating scientific information in written or spoken form; (7) constructing and using scientific models; and (8) engaging in these activities within a community of science. This definition clearly reflects those same 21$^{st}$ century skills deemed necessary for survival in today's world (Binkley et al., 2012; Jukes & Schaaf, 2019): critical thinking, problem solving, decision making, communication, and collaboration skills.

This definition assumed that inquiry-based teaching and learning should involve and/or incorporate teaching of these dimensions, and to accomplish this, students need to be an active part of the learning. In an inquiry-based classroom, the teacher's role is to guide and facilitate student learning. However, keep in mind, there is no standard single approach. Attaining the elements in this definition cannot be achieved by a single learning experience or teaching strategy. If done correctly, inquiry-based teaching strategies provide students with various activities and investigations initiated by the student, which allows for the development of understanding of scientific inquiry, while also learning content material (Bybee, 2000). Notice, that this definition does not include 'cookbook' laboratories, because in practice inquiry-based teaching and learning should include less defined, open-ended, student driven science questions, discussions, or laboratories.

From this definition, we see that inquiry-based learning should be an active process of learning. Inquiry-based learning should reflect the way scientists conduct inquiry in the scientific context. According to Anderson (2006), inquiry-based learning is understood to carry with it the following four elements: (1) Learning is an active process of individuals constructing meaning for themselves; (2) The meaning each individual constructs depends on prior conceptions and knowledge this individual already has; (3) The understandings each individual develops are dependent upon the contexts in which these meanings are engaged. The more abundant and varied these contexts are, the richer are the understandings acquired; and (4) Meanings and understandings are socially constructed. Which means that the process needs to encompass a range of different activities and methods of inquiry. So, are these practices happening in the science (or any) classroom?

## Implementation of Inquiry in Today's Classrooms

Barrow (2006) and Yager (2000) stated three crucial ingredients that were needed if inquiry was to be implemented: (1) teachers must understand what scientific inquiry is; (2) they must have ample understanding of the content material; and (3) they must become skilled in inquiry teaching methodologies. The evidence today suggests that there is a wide range in the degree of instructor and student involvement in teaching as inquiry, from very little involvement to a great deal of control depending on the model used (Table 1; Bevins & Price, 2016). In general, evidence does not support open or 'discovery' inquiry as an adequate learning method (Alfieri et al., 2011; Kirschner et al., 2006). However, there are many studies that indicate guided inquiry does have a significant positive impact on learning and retention in the sciences (Alfieri et al., 2011; Blanchard et al., 2010; Deslauriers et al., 2019; Marshall et al., 2017; Udovic et al., 2002; Vilardi, 2013; Wilson et al., 2009), although results can be mixed because of the numerous factors that go into quality science teaching and learning (Schuster et al., 2018).

Along with what the student does in an inquiry-based classroom, instruction in inquiry classrooms also reflects a variety of methodologies (Matthews, 1994). Teachers serve as role models in deliberating issues, in examining values, in admitting error, and in confronting areas of their own ignorance. The classroom atmosphere needs to be favorable to inquiry. Students should feel encouraged to ask questions. They need to know that risk-taking is encouraged and safe, and that student responses are listened to, clarified, and deliberated upon seriously by others. Classroom climate should stimulate a thoughtful exploration of ideas, objects, and events. However, as Anderson (2006) said, if we want to transform science education to a fully inquiry-based educational paradigm, something needs to be done to change the current school structural patterns.

So, the question becomes, has school structure changed enough since the advent of inquiry in the science education standards (both the NSES and the NGSS) to see the full implementation of inquiry into the science classroom? Unfortunately, few studies have specifically looked at the progress of implementing inquiry nor the quality of implementation that has happened since inquiry was incorporated into the science curriculum.

This might be because the evaluation of implementation of any type of program in a classroom can be problematic and complex. Implementation is often examined across three factors: adherence (the extent to which procedures of a program are delivered as intended), exposure (the frequency units of the program are presented), and quality (how well the program implements the methods of the program). Of these three, quality is the least measured because it is the most difficult to measure. It is best measured qualitatively, through classroom observation of teachers' instructional strategies (Brandon et al., 2008, 2009). Only six studies were found that give us insight into the amount and quality of inquiry that is actually going on in the classroom (Blanchard et al., 2010; Capps et al., 2016; Capps & Crawford, 2013; Gaylor, 2017; Gejda, 2006; Marshall et al., 2009). Each of these studies, except Capps & Crawford (2013), used data from teacher self-report surveys.

The studies indicate that teachers are indeed reporting implementation of inquiry-based teaching and learning in their classrooms. They also found significant relationships between the comfort a teacher had in their own content knowledge and knowledge of inquiry-based teaching practices and their implementation of inquiry-based teaching and learning in their classrooms. Those teachers with more experience and more professional development related to inquiry practices were more comfortable implementing inquiry into their classrooms. In two studies (Blanchard et al., 2010; Marshall et al., 2009), it was found that elementary teachers implemented more inquiry-based learning activities in their classrooms than did middle or high school teachers, although they taught less science overall than the higher grade levels.

Two studies (Capps et al., 2016; Capps & Crawford, 2013) expanded beyond the survey and interviewed teachers about actual practices they implemented within the classroom, to see if what the teachers reported about inquiry and what they actually did in their classrooms corresponded. What they found showed two things: 1) teachers think they understand what inquiry-based teaching and learning is but have rather poor understandings of inquiry and the nature of science in general; and 2) teachers report enacting inquiry-based activities in their classroom much more than actual inquiry is being done. This is partially because the teachers lack understanding of what inquiry is and partially because the teachers are labeling activities that have inquiry-like aspects (hands-on, manipulative, discovery learning) but do not meet the full criteria for inquiry as stated in the standards documents.

This, unfortunately, gives us a rather dismal view of the implementation status of inquiry-based teaching and learning in science classrooms. It has been almost 8 years since the release of NGSS. No studies on the implementation of NGSS related inquiry could be found by this author, and although two of the studies used teacher information from post NGSS release, neither directly connected their results to NGSS. It would be important to know if implementation is happening at the classroom level post NGSS release.

It should, however, be kept in mind that if we fail in implementing the current concepts of inquiry-based teaching and learning using the standards that are currently mandated,

**Table 1**

*Models of inquiry-based education, associated inquiry skills, and the extent of involvement of the learner in that skill.*

| | Inquiry Skills | | | | |
|---|---|---|---|---|---|
| Inquiry Level | Scientifically orientated questions | Priority to evidence | Explanations from evidence | Explanations connected to knowledge | Communicate and justify |
| 3: Open Inquiry ('discovery') | Learner poses question. | Learner determines what is evidence & collects it. | Learner summarizes evidence & formulates explanations. | Learner independently examines other resources & forms links to explanations. | Learner forms reasonable & logical argument to communicate explanations. |
| 2: Guided Inquiry | Learner selects among given questions, poses new questions. | Learner directed to collect certain data. | Learner guided in process of formulating explanations from evidence | Learner directed towards areas & sources of scientific knowledge. | Learner coached in development of communication. |
| 1: Structured Inquiry | Learner sharpens/clarifies questions provided by others. | Learner given data & asked to analyze. | Learner given possible ways to use evidence to formulate explanation. | Learner given possible connections to scientific knowledge. | Learner provides broad guidelines to use to sharpen communication. |
| 0: Confirmation/ verification exercises | Learner engages in question provided by others. | Learner given & told how to analyze data. | Learner provided with evidence. | Learner provided with precise connections. | Learner given steps and procedures for communication. |

*Note*. Table adapted from Bevins & Price (2016) NGSS. No studies on the no educational reform will occur, no matter how necessary. What needs to go forward in terms of inquiry-based teaching and learning today is dedication to providing better professional development for teachers. Professional development should address not only the pedagogy of inquiry-based teaching but also the advancement of more comprehensive content knowledge within a discipline for teachers. Currently, most professional development, unless it is offered during a scheduled school day, is voluntary and often unpaid. This needs to change. If we truly want our science teachers, or any teacher, to adopt inquiry as a pedagogy, we need to ensure them an educational setting where they can learn about inquiry and how to teach it well. This signifies that administrations at the local, state, and federal level need to work together to either fund such professional development or work it into the scheduled school calendar without making it a hardship on the teachers. Inquiry-based teaching and the subsequent skills and knowledge learned by the students is achievable, if we are willing to put the time, effort, and money into it.

## Discussion

Inquiry, as the ancient Greek philosophers envisioned it, was the tool used to seek out truths about the world. In our post-truth world, this is a skill that is sorely needed.

Inquiry has a long, and often chaotic, history in education, but was not really a state mandated part of science education until the advent of standards in the late 1990s. The philosophical concepts of inquiry as laid out in the educational standards in many ways matches the early progressive educators' ideas of inquiry, both in general and in particular in the sciences. Additionally, the concepts of inquiry in education somewhat match the original (ancient Greek philosophers) concepts of critical inquiry, especially if one includes Socratic discussion as part of their inquiry teaching practices in the classroom. However, some aspects of inquiry in education do not match the original concepts of classical critical inquiry. This could be because scientific inquiry, which inquiry in education is supposed to address, is itself only partially reflective of the classical inquiry concepts and practices. It is probably unrealistic to mesh the true characteristics of philosophical inquiry with those of scientific inquiry, completely. There will never be a complete meshing of the two, because scientific inquiry is a subset of philosophical inquiry (Burgh & Nichols, 2012).

The history of inquiry in the science classroom indicates that the rationale behind including inquiry-teaching and learning into the classroom is to develop the students' scientific literacy. Although content is important, one main aim of inquiry-based teaching and learning is to promote understanding of the process by which science is done so that students can make critical decisions regarding science issues in their daily lives. Skills that, coincidentally are learned along with learning to act and think like a scientist, are being able to think critically, ask questions, use evidence in their argumentation, and be able to communicate complex information with some skill. These are life skills and are important habits of mind that encourage and equip students with the tools to use inquiry beyond the classroom. Indeed, if these skills are learned, students will exit their K-12 education as scientifically literate citizens.

The authors of *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* contend that science, in the form of information, technology, and engineering, infuse every part of modern life. Indicating that this way of thinking holds the key to all current and future challenges we will face. So, the authors goal is to ensure every high school senior leaves school with the knowledge that makes them careful consumers of scientific and engineering information related to their lives, possess enough knowledge on science and engineering to contribute to public discussions on science related issues, and to be able to enter careers in fields related to science and engineering (National Academies Press, 2012). The Framework authors maintain that students need to understand how science is done (the nature of scientific inquiry) to accomplish these goals.

Education needs to change to confront the onslaught of fake news and mistrust in science. We need a more scientifically literate populace. This paper proposes that inquiry as a pedagogical method is a way to achieve this goal.

Yet, no clear consensus on what inquiry means in the classroom exists. As educators and educational researchers, we know what components inquiry teaching and learning should include, but the translation of these to classroom practices is lacking. So, we are now at a crossroads as to where to go in science education. We need a populace that trusts the products of science, not because they are told to, but because they know and understand that the process of science is a systematic procedure based on evidence and not public opinion. We need this for the health and safety of our population. Individuals need to be able to make trusted, evidence-based decisions every day. The post-truth world in which we are rapidly finding ourselves must be turned around. In the new horizon of educational possibilities, inquiry-based teaching and learning, if implemented well, has the potential to be one of the best pedagogical methods to produce a populace of scientifically literate individuals.

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