Tang Wee Teo
Aik-Ling Tan
Yann Shiou Ong *Editors*

Science Education in the 21st Century

Re-searching Issues that Matter from Different Lenses

Springer

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Introduction

Theme of the Book

Many problems in science teaching, learning and assessment are not new but they can be looked through new lenses to identify unique strategies and solutions, particularly as societies change with disruptions by technologies and the demands made by the fourth industrial revolution. This book marks the beginning of the third decade into the twenty-first century. Hence, it is time for scholars to reflect on the Discourses of science education in the last 20 years before as they plan their journey forward. As scholars in science education, we are often asked the question, "What kind of work do you do as an academic?" More often than not, we will sum up our work with the word, "research". According to the Merriam-Webster Dictionary (n. d.), "research" is defined as an "investigation or experimentation aimed at the discovery and interpretation of facts, revision of accepted theories or laws in the light of new facts, or practical application of such new or revised theories or laws." This simplified definition does not accurately reflect the continual and reiterative process of re-framing a study, refining research questions, collecting more data to strengthen the conclusions, revising interpretations and discussions to generate new insights. This constant and complex process of reworking processes and products of an inquiry study to look for better solutions to address issues and challenges in science education is more aptly termed as *research*.

We have invited colleagues, who have presented their work at the International Science Education Conference (ISEC) 2018, to submit articles to this book. Invited contributions are aligned with the ISEC 2018 theme on "Re-searching Science Education: Same Issues from Different Lenses". This theme aims to evoke intellectual dialogue on issues in science education through alternative lenses. The word "research" is purposefully hyphenated to underscore the importance of constantly re-looking and re-examining longstanding issues to gain new insights into familiar problems that confront diverse stakeholders in science education and policy. It is through such a process that practitioners develop praxis and the field of science education research continually be enlivened.

The book chapters are aligned to the theme of *research* in three key areas of science education research: (1) science curriculum and teaching; (2) science learners and learning; and (3) science teachers and teacher education. In the first section on “Re-searching Science Curriculum and Teaching”, the authors present familiar ideas such as the nature of science (NOS), scientific literacy, team-based learning and informal science learning from different theoretical and practice lenses. The different ways to understand and implement science teaching and learning is a response to changing societal demands both locally and globally. Science curriculum and teaching is complex as it needs to be agile and responsive to rapidly changing educational landscape (Chaps. 1 and 4), but at the same time, there is a need to preserve the fundamental principles of good science curriculum and teaching (Chaps. 2, 5 and 6). Readers could ponder about the agency that science curriculum developers have when designing a new curriculum—do science curriculum developers lead or merely respond to societal needs and demands? In this era of the fourth industrial revolution, will the science education community “be pushed” or “self-initiate” a radical remake of science curriculum and teaching?

In Sophia (Sun Kyung) Jeong, Gretchen King, David Pauli, Cary Sell and David Steele’s *Conceptualizing Multiplicities of Scientific Literacy From Five Theoretical Perspectives* (Chap. 1), they re-examined the issue of the mistrust and misunderstanding of science from the new lens of dialogic meta-theorizing as a methodological inquiry. Seungran Yang, Wonyong Park and Jinwoong Song’s *Representations of Nature of Science in New Korean Science Textbooks: The Case of ‘Scientific Inquiry and Experimentation* (Chap. 2) discussed recent curricular initiatives in Korea in introducing the nature of science (NOS). They examined how newly published textbooks presented NOS to offer insights on Korea’s effort in the implementation of NOS using historical episodes. Lishan Yang, Emmanuel Tan and Preman Rajalingam’s *Pedagogical and Content Expertise in Team-Based Learning: Re-aligning Two Teaching Perspectives in an Undergraduate Medical School* (Chap. 3) offers perspectives on how two distinct domain experts—content and process—worked together in a constructivist flipped classroom setting at higher education to optimize the learning experiences of undergraduate medical students. Kai Ming Kiang and Klaus Colanero’s *A Classics Reading Approach to Nurture Epistemic Insight in a Multidisciplinary and Higher Education Context* (Chap. 4) integrated classics reading as a tool for nurturing scientific literacy. Miguel Ison and Sharon Bramwell-Lalor’s *Opportunistic Science Teaching and Learning “Outside” the Classroom* (Chap. 5) underscored the importance of leveraging on out-of-classroom settings to provide engaging and enriching learning experiences for students.

The second section on “Re-searching Science Learners and Learning” pays attention to the learners of science. The ideas presented range from understanding of students’ ideas of scientific concepts (Chaps. 6, 7, 10, 12 and 13) to questioning the opportunities presented to students to learn science (Chap. 11) and assessing students’ understanding (Chaps. 8 and 9). The seminal publication, *How Students Learn: History, Mathematics and Science in Classroom* (Donovan, & Bransford, 2005), detailed two fundamental important assumptions about students for teachers and researchers to consider—(1) students attend classes with preconceptions about how the world works and these preconceptions can serve as starting points for learning, and (2) development of competences in an area of inquiry requires deep foundational knowledge, ability to understand facts and ideas in the context of a conceptual framework, and having systems to enable retrieval of knowledge. Readers of ideas presented in this section could negotiate the ideas presented in the various chapters using the familiar assumptions by Donovan and Bransford.

Yann Shiou Ong, Richard Duschl and Julia Plummer's *Scientific Argumentation as an Epistemic Practice: Secondary Students' Critique of Science Research Posters* (Chap. 6) built upon the productive disciplinary engagement framework to inform a critique task design that makes students' thinking visible, which in turn enables robust feedback from teacher and peers. Bernadette Ebele Ozoji's *Effects of Concept Mapping Technique on Nigerian Junior Secondary School Students' Cognitive Development and Achievement in Basic Science and Technology (Integrated Science)* (Chap. 7) showed how activity-based instructional strategies, such as concept mapping technique, similarly improved male and female students' performances on science reasoning tasks (of the Piagetian tradition) and science content knowledge test. The author concludes the use of concept mapping technique might be one promising solution in the search for strategies to improve Nigerian students' science performance. Readers are invited to consider how new theories of cognitive development could account for the findings. Nilavathi Balasundram and Mageswary Karpudewan's *Embedding Multiple Modes of Representations in Open-Ended Tests on Learning Transition Elements* (Chap. 8) demonstrated the effectiveness of integrating application-based graphic organizers in teaching transition elements on students' use of multiple modes of representations (besides writing). Mijung Kim and Suzanna So Har Wong's *Trustworthiness Challenge in Children's Environmental Problem Solving in the Digital Era* (Chap. 9) discussed a persistent and on-going challenge of critical thinking and problem solving in science classrooms with a different dimension, that is, critical literacy practice in digital space. Caroline Ho and Fei Victor Lim's *Assessing Conceptual Understanding in Primary Science Through Students' Multimodal Representations in Science Notebooks* (Chap. 10) proposed a framework for assessing the extent to which students' understanding, specific content vocabulary and relationships between concepts are made explicit through analysis of students' multimodal representations in written artefacts. Tang Wee Teo's *An Analysis of Power Play in the Subculture of Lower Track Science Classrooms* (Chap. 11) interrogated common understanding of cultures and emphasized the possibility of subcultures in the science classroom formed through power play. Kim Chwee Daniel Tan's *Facilitating the use of Research in Practice: Teaching Students to Plan Experiments* (Chap. 12) offered an example of how the research and practice gap can be bridged. Chang Fui Seng and Mageswary Karpudewan's *Working Memory Capacity and Teaching and Learning of Stoichiometry* (Chap. 13) showed the applications of cognitive neuroscience in science education.

In the last section, we present research in the area of science teachers and teacher education. According to the McKinsey report (2007), the world's best performing school systems hired the right people to become teachers and developed them to be effective instructors. As such, it is not surprising that many education systems pay attention to science teacher education and development since it is essential to the success of science education reforms and quality science teaching and learning. However, researching science teachers and teacher education is problematic. Lee (2016) argued that the construct of teacher knowledge is elusive and hence the tenets of teacher knowledge are difficult to pinpoint. He highlighted the range of theories that aimed at helping scholars make sense of teaching and learning. These theories range from "…pinpointing necessary certifications or personal psychological traits to a host of competencies or bodies of knowledge that enable one to be recognised as a successful teacher. Teacher effectiveness as a board field has therefore evolved from searching from more atomistic, within-person attributes to examining excellence in professionalism from more holistic, person-in-context theories." (Lee, 2016, p. 71). As readers peruse the seven chapters in this section, they are invited to think about the methods that the various researchers employed to better understand science teacher learning and education.

Sharon Bramwell-Lalor, Marcia Rainford and Miguel Ison's *Pre-service Science Teachers' Reflections on the Field Experience: Does Context Matter?* (Chap. 14) reconceptualized school context as comprising institutional, physical, professional, social and personal components. Through this analytic lens, the authors gained insights on how various components of school context shaped pre-service science teachers' conceptions of teaching during field experience. Yvonne Kulandaisamy and Mageswary Karpudewan's *Teachers' View on Replacing Traditional Chemistry Experiments with Green Chemistry (GC) Experiments* (Chap. 15) presented teachers' viewpoints on the possibilities of implementing green chemistry experiments. Marjee Chmiel and Rodrigo Tapia Seaman's *Preliminary Results on the Value of Investing in Training for Practicing Chilean Life Science Teachers* (Chap. 16) examined how an international collaboration between the U.S. and Chile provided professional development for practicing life science teachers. Thasaneeya Ratanaroutai Nopparatjamjomras and Suchai Nopparatjamjomras' *Teaching Integration of 5E Instructional Model and Flower Components* (Chap. 17) illustrated how the 5E model which originated in the U.S. was adapted for teaching a biology education course for higher degree education students from developing countries. The approach of integrating science content (i.e. flower components) to teach a pedagogical approach (i.e. the 5E model), while not new to the science education community at large, is a relatively novel approach for the local education community of the authors and their students. Chorng Shin Wee and Gah Hung Lee's *Crafting Literature-Based Task—Our Journey on Viva Voca and Thought Processes* shared the personal journeys of the co-authors in curriculum innovation to develop students' thought processes as science learners. Cassander Tan and Aik-Ling Tan's *Learning Trajectory of a Science Undergraduate Working as an Intern in a Research Laboratory: A Science Practice Lens* (Chap. 19) carefully traced the learning growth of a science undergraduate working in a laboratory. Umesh Ramnarain's *The Role of Empowerment Evaluation in the Professional Development of Science Teachers in the Enactment of an Inquiry-Based Pedagogy* (Chap. 20) infused evaluation theory into this study about science teacher professional development.

In essence, this book offers new insights into old topics of science education research and injects new ideas from other domains of research into science education. We are reminded that the "old" is never dated and the "new" is never unfamiliar.

Tang Wee Teo
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About the Editors

Tang Wee Teo is an associate professor at the National Institute of Education, Nanyang Technological University, Singapore. She is an equity scholar in science education. Her recent research work focuses on students who have been streamed into the lower track classrooms and science learners with special education needs. She adopts critical theories in her research work including feminist, cultural and sociological theories to interrogate often-taken-for-granted assumptions and norms.

Aik-Ling Tan is an associate professor at the National Institute of Education, Nanyang Technological University, Singapore. Her research delves into how students and teachers interact in the primary science and biology classrooms. The data analytical methods used to illumine classroom interactions in her studies include discourse analysis, conversation analysis as well as content analysis. Her more recent work includes examining how physiological measures such as heart rate and skin conductance can be used to reveal more insights into student–teacher interactions in the classrooms. Besides physiological measures, she is also interested in the noticing patterns of teachers as they interact with students to jointly construct knowledge in science.

Yann Shiou Ong is a postdoctoral fellow at the National Institute of Education, Nanyang Technological University, Singapore. Her current research focuses on secondary students' epistemic practices in scientific inquiry, specifically how students engage in group critique and construction activities. She adopts the Productive Disciplinary Engagement framework and its guiding principles to analyse classroom/group discourses and instructional designs. While she takes a pragmatic approach to data analysis, her research questions have mostly landed themselves to qualitative methods, especially discourse analysis. Her other research interests include scientific models and modelling, social metacognition and learning progressions.

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Part I
Re-searching Science Curriculum and Teaching

Chapter 1
Conceptualizing Multiplicities of Scientific Literacy from Five Theoretical Perspectives

Sophia Jeong, Gretchen King, David Pauli, Cary Sell, and David Steele

Abstract As science education researchers, sometimes we encounter those in our classrooms or our personal lives who mistrust and misunderstand the scientific information we hold dear. In this theoretical piece, we propose an amelioration of the current climate of mistrust and misunderstandings of science by embracing different epistemological stands. The authors of this chapter will discuss the goals and applications of scientific literacy from five different epistemological stands (positivism, pragmatism, constructivism, critical theory, and poststructuralism). In doing so, we provide lenses through which science educators can frame their perspectives on scientific literacy and employ them in their research and classrooms.

Introduction

"***I always loved science because there's always a right or wrong answer***."

The original version of this chapter was revised: The chapter author's "Sophia (Sun Kyung) Jeong" first and last name have been corrected. The correction to this chapter is available at https://doi.org/10.1007/978-981-15-5155-0_21

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These words were spoken by a Congressional District representative of the state of Georgia at the annual Science Day in 2017 Spring. The deterministic tone we heard in the representative's comment generally rings true with the American public view of science. The phrase *science is a way of learning about the natural world through observations and logical reasoning* is the classic, textbook definition of science, which is repeated in various secondary science classes. It further reflects the notion that "science and technology have their own objective logic and reasoning to which society must adapt as best it can" (Irwin & Wynne, 1996). The dissonance between the general public's consensus regarding the objective nature of science, and the misunderstanding and mistrust of science is nothing new (historically, this is the case because of the threat to religious faith), and thus, still needs to be addressed with different philosophical lenses.

Shawn Otto, the co-founder of the U.S. Presidential Science Debates and author of The War on Science, gave a keynote address that emphasized the "erosion of the understanding of science and engineering among the public. According to Otto, people seem much more inclined to reject facts and evidence today than in the recent past. *Why could that be?*" (The National Academies Press, 2017). Otto's rhetorical question is an important problem that needs to be addressed in the science education community. To this end, we posit that the pervasive assumptions about science stemming from positivism contribute to deepening the public's misunderstanding and mistrust in science. Such tensions are contributing factors to inadequate communication and misrepresentation of the *nature of science*.

The concept of *scientific literacy* is intimately entwined with the public's misunderstanding and mistrust of science. Since Paul Hurd coined the term *scientific literacy* in 1958, scholars have been trying to define, refine, and explore this term. For example, a notable work by Norris and Phillips (2003) conceptualized various components of scientific literacy. However, a consensus definition of *scientific literacy* still remains elusive (Holbrook & Rannikmae, 2009). Scholars do agree, however, that the term *scientific literacy* portrays a complex idea that goes beyond the simple acquisition of science content, or simply reading and writing. In this vein, Holbrook and Rannikmae (2009) argue that the emphasis on *scientific literacy* should be placed "on the appreciation of the *nature of science*, the development of personal attributes and the acquisition of socioscientific skills and values (p. 276)." However, questions such as what are the characteristics of scientific literacy and how do we identify and assess scientific literacy still are far from being settled.

In this chapter, we ground our answers to these challenging questions in literature, theory, and philosophy of science education. We aim to conceptualize *scientific literacy* as a vehicle that can help ease the tensions and confront the issue of *science mistrust and misunderstanding,* by examining the multiplicities of *scientific literacy* from the following theoretical perspectives: (1) Positivism, (2) Constructivism, (3) Pragmatism, (4) Critical Theory, and (5) Poststructuralism. These theoretical frameworks (constructivism, pragmatism, critical theory, and poststructuralism) ground each author's scholarly work, and thus were selected to represent a range of postpositivist paradigmatic inquiry. In doing so, we provide lenses through which science educators can frame their perspectives on scientific literacy and employ them in their research and classrooms.

Theorizing *Scientific Literacy*

To foster a dialog on the issue of *science mistrust and misunderstanding* and mediate its various contributing factors (such as the polarization of science, and media influence,), we posit that understanding the nature of science is critical, especially the aspects of tentativeness, uncertainty and subjective objectivity of science, theory-ladenness of data, etc. Thus, we theoretically draw from the work of Thomas Kuhn to conceptualize *scientific literacy* as a vehicle that can help ease the tensions and confront the issue of *science mistrust and misunderstanding*.

Thomas Kuhn conceptualized *scientific revolutions* as periods during which existing scientific ideas are replaced with radically new ones. In the aftermath of each of these revolutions was a fundamental change in the scientific world-view. Kuhn, then, coined the term *paradigm.* According to Kuhn (2012), a *paradigm* consists of a set of fundamental theoretical assumptions which all members of a scientific community accept, and a set of scientific problems that have been solved by means of those theoretical assumptions. Though the *paradigm* itself is non-negotiable, the change of a *paradigm* occurs when the existing one can no longer support the *anomalies* found in nature. The malfunctioning of an old/existing *paradigm* catapults a revolution or crisis at which point a new institutional *paradigm* emerges (Kuhn, 2012). This does not mean that the old *paradigm* was *wrong;* however, the need for a *paradigm shift* speaks to the tentative and uncertain nature of science. Kuhn also argued that data is theory-laden and that science is *value-laden*. Acknowledging the social–cultural process of science can mediate the deconstruction of *objectivism* and help one understand the nature of science as having *subjective objectivity.*

Here, we embark on a *philosophical* and *theoretical* journey to bring together insights about *scientific literacy* that emerge from the empirical studies operating under each of the five perspectives. Drawing on Bakhtin's (1981/1975) notion of *dialog*, the authors engage in a *dialogic process* to juxtapose the different theoretical perspectives in the context of their work. We synthesize the tensions emerging from the five theoretical perspectives and thus refine understandings of what it means to conduct research that explores different aspects of scientific literacy in educational contexts.

Overview of the Chapter

Grounded in our own scholarly work, we discuss the selected theoretical perspectives (Constructivism, Pragmatism, Critical Theory, and Poststructuralism), which we use to theorize, analyze, and understand the *nature of science* and the multi-faceted meaning of *scientific literacy.* First, the assumptions of Positivism and its historical perspective on knowledge and science are discussed. Second, the assumptions of Constructivism are elaborated in the context of a research study investigating the secondary high school science teachers' understanding of the *nature of science* as it pertains to the teaching and learning of science (Sell, 2018). Third, the tenets of Pragmatism are explained in the context of a study examining written argumentation to enhance middle school students' scientific literacy in the classroom (Pauli, 2017). Fourth, the assumptions of Critical Theory are described in the context of a study that conceptualizes science as a mechanism of reproducing norms and practices of science as a culture (Steele, 2018). Lastly, the perspective of Poststructuralism is shared in the context of a study that explores subject positions of teachers, students, and material entities in relation to pushing the boundaries of how we should understand subjective objectivity of science and thus deconstruct the notion of objective *truth* (Jeong, 2018). We present the important theoretical assumptions and tenets of each perspective with respect to conceptualizing *scientific literacy*. In doing so, we use these perspectives to promote a better understanding of the multiplicities of scientific literacy by elaborating on its epistemological and ontological complexities.

Positivism and Scientific Literacy: Setting up an Argument

From a historical perspective, it was once widely accepted that knowledge could only be generated through the church and via morally worthy men of God (St. Pierre, 2012). However, by introducing the idea of rational thought, Descartes created a path of knowledge production through verification using "scientific practices in order to know truth" (St. Pierre, 2012). His belief in the ability of humans to produce *objective knowledge* spread throughout Europe in the teachings of Comte, becoming the cornerstone of modern-day Western science. The production of *objective results* and knowledge, free from the bias of values and beliefs of the scientist, is the cornerstone of the scientific community. Objectivism insists that there is a real world that exists, and its meaning exists independently of human thought (Jonassen, 1999). Further, *objectivism* assumes that there is one correct understanding of any given topic, and therefore education is the transfer of this objective knowledge into the mind of the learner (Lakoff, 1987). These teachings and beliefs are the foundations of what we refer to as positivism.

Positivism has been widely critiqued for being intolerant of other paradigms of understanding and explaining the world. St. Pierre (2012) wrote, "we thought we'd sufficiently demonstrated decades ago the inadequacy of positivist knowledge in addressing many complex social problems, and we'd moved on…but the positivist…is tenacious" (p. 483). Positivists seek to remove *subjectiveness* in order to understand the world through certain knowledge, which is an argument made based on observations and measurements of the natural world. In a positivist viewpoint, data representing truth should be "uncontaminated, un-biased, and value free" (St. Pierre, 2012). Because of the notion that science must be un-biased and expertly measured, science has come to be portrayed in popular culture as something that an expert does that is inaccessible to a layperson. As such, for more than 60 years, science educators have been calling for an increase in science content in K-12 classrooms. Hurd (1958) wrote, "Science instruction can no longer be regarded as an intellectual luxury for the select few. If education is regarded as a sharing of experiences of the culture, then science must have a significant place in the modern curriculum from the first through twelfth grade" (p. 13). Hurd (1958) argued for teaching students to adapt to this new "space age." Forty years later, Hurd (1998) continued his argument for incorporating more science into the curriculum, but this time argued for more scientific skills taught in school, skills that would help students in all areas of their lives. He suggested steering "science instruction toward modes of social inquiry beyond the traditional discipline-bound notions of scientific inquiry" (p. 412). These goals included the idea that students should be able to tell experts from non-experts, to know when they lack sufficient evidence to make a rational judgment, and to recognize when it is appropriate to reach outside of science and use knowledge from other disciplines for making a decision. These goals represent an advancement of thinking beyond science as a list of facts that students must memorize; however, Hurd (1958) noted that "a failure to recognize changes in either the practice of science or shifts in our culture continues" (p. 411). One only needs to read the numerous headlines about anti-vaxxers and flat earthers to recognize this failure.

We believe that the lack of scientific literacy is intimately tied to the *nature of science*. In part, the skepticism of science could be related to the language that scientists use. For example, the misunderstanding of the word "*theory*," and others like it, in the scientific context could be one explanation as to why the American public mistrusts scientific information. Scientists place a different value on the word "*theory"* when discussing it as a scientific theory than the general public does when they use the word. This contradiction suggests that positivism remains pervasive in our culture, particularly in the way scientific information is viewed and understood. Assumptions about the *nature of science* stemming from objectivism can continue to deepen the public's misunderstanding and mistrust through inadequate communication and misrepresentation of the *nature of science*.

Constructivism on the Nature of Science and Scientific Literacy

If we were to arrange the paradigms on a continuum, the opposite of positivism would be constructivism (Charalambos, 2000). Objectivism insists that there is a real world that exists, and its meaning exists independently of human thought (Jonassen, 1999; Lakoff, 1987). Further, *objectivism* assumes that there is one correct understanding of any given topic, and therefore education is the transfer of this objective knowledge into the mind of the learner (Lakoff, 1987). In contrast, the overarching assumption of *constructivism* is that knowledge does not exist independently of the learner

(Piaget & Duckworth, 1970; Kuhn, 1996; Vygotsky, 1978). Additionally, constructivist educators understand that learners who construct meaning as new experiences are filtered through the prior experiences and prior knowledge of the learner. For science education, the nature of science itself presents a constructivist view of science. The *nature of science* constitutes, "the values and assumptions inherent to the development of scientific knowledge" (Lederman, 1992). In order to understand the *nature of science*, one has to understand that scientific knowledge is *tentative* and *empirically based*; scientific knowledge is *theory-laden*; it is partly the product of human *inference*, *imagination*, and *creativity*; and it is *socially* and *culturally* influenced (Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002). Additionally, the *nature of science* illustrates the distinction between theories and laws.

The *nature of science* provides a framework to examine scientific literacy, thereby easing tensions that have occurred in society as a result of misunderstandings of science by the general population. According to Quigley and Che (2018), the public often leans on the media as a major source of information and opinions about science, and thus media's representations of scientific knowledge influence public perceptions of science. Much of education and media presents an *objectivist* view of phenomena (i.e., there is one correct answer). This creates misunderstanding and misconceptions of scientific validity when there is not complete agreement on all aspects of issues such as evolution, anthropogenic climate change, or medical treatments. Therefore, Quigley and Che (2018) urge science educators to recognize the influences such as the media's role on students' and communities' knowledge construction.

Constructivists hold that learning is about making meaning within experiences (Piaget and Duckworth 1970). In this vein, the nature of science is the embodiment of how we understand scientific knowledge and how it is constructed. In terms of education, teaching the *nature of science* through explicit and reflective means can address scientific literacy, thereby promoting a more sophisticated view of the *nature of science* and supporting learners who are better prepared to interpret scientific information that they will be exposed to on a daily basis (Lederman, Lederman, & Antink, 2013). Sell's (2018) study designed a professional development (PD) program to provide the necessary structure for science teachers to gain knowledge of the *nature of science* and the pedagogical content knowledge necessary to teach NOS. Through the lens of constructivism, the PD program in his study supported a learning environment for the science teachers to engage in a community of practice through peer coaching that became an effective support strategy to aid in the development of a more informed conception of the *nature of science*. Thus, building scientific literacy through teaching and learning the *nature of science* would allow science educators to address misconceptions and mistrust of science that persists today.

Through the lens of constructivism, scholars have come to a greater awareness of the learner and there has been an innovative methodology for the pedagogy of science (Tobin and Tippins 1993). On the other hand, as a theoretical referent, constructivism has "a flawed instrumental epistemology" which misrepresents "the views and practice of science and scientists". In this vein, it overemphasizes the construction of concepts and fails to distinguish the manner in which "new knowledge is made with the manner in which old knowledge is learned," thereby "assuming that the two are one and the same thing" (Osborne, 1996). Constructivism has been seminal in exploring learning outcomes resulting from "knowledge that is acquired through sensorimotor interaction… and knowledge that this is acquired through cultural transmission, be it through the popular media or specialized institutions such as schools" (Osborne,1996). However, how the idea of science might be represented or shown is often ignored in constructivism research; ergo, it is critiqued as a weak theoretical referent. "For constructivism would appear to hold the belief that an objective view of knowledge inevitably requires a didactic pedagogy and by inference, to advance any role for transmitting knowledge would be to present it as objective. There is no logical justification to this premise and the two are not inextricably linked" (Osborne, 1996). As we re-visit the issue of the misunderstanding of science, scientific literacy grounded in theoretical constructs of science is critical in allowing common experiences to be interpreted. These science's theoretical constructs, however, are not self-evident. According to Wolpert (1992), science is fundamentally unnatural. Therefore, understanding the world is not commonsensical (Cromer 1993). In order to explicate the epistemological complexities of learning science, a constructivist approach to *teaching science* should offer a view of science as a process of constructing and manipulating representations that bear the necessary relations to the ontological reality, and most importantly a pluralist pedagogy.

Pragmatism on Argumentation and Scientific Literacy

The idea of what makes a scientifically literate person varies greatly (Lederman et al., 2013). Cavagnetto (2010) defines scientific literacy as "the ability to accurately and effectively interpret and construct science-based ideas in the popular media and everyday contexts" and used this definition in research that focused on argumentation interventions as a means to promote scientific literacy (p. 352). Although DeBoer (2000) states that *multiple definitions of scientific literacy are appropriate*, Cavagnetto's (2010) definition relates science knowledge to *everyday experiences* and therefore can be viewed through a lens of pragmatism.

Pragmatism holds that a reality exists outside of the learner and that it is constructed by the learner (Johnson & Onwuegbuzie, 2004). John Dewey posits pragmatism as *transactional realism* that allows for both *subjective* and *objective* views of reality (Biesta & Burbules, 2003). "What is constructed—over and over again—is the dynamic balance of organism and environment" (Biesta & Burbules, 2003). In this vein, argumentation fosters such construction by allowing learners to make sense of the world around them through a scientific process, thereby enhancing their science literacy. Science is fundamentally unnatural (Wolpert, 1992) and understanding the world is not commonsensical (Cromer, 1993). Osborne (1996) asserts that "children must be shown and introduced to ideas that are not palpable and to the advantages that such concepts bring in understanding our world" (p. 77). Similarly, from the perspective of pragmatism, Pauli (2017) posits that students do not come to teachers scientifically literate. They must be taught how to navigate the world as a scientifically literate person. As such, a critical question here is *how do students come to understand science through argumentation?*

Science is *constantly changing* and *adapting* based on new evidence (Lederman, 2007). *Knowledge can change or be adapted based on new evidence*. Learners must have a *vehicle* to sort through the abundance of daily information if they are to become literate in the world they live, and argumentation is one vehicle. Argumentation is grounded in supporting a claim with warranted evidence. For argumentation in the classroom to be effective, students need to assess different evidence to help explain science content (Osborne, Erduran, & Simon, 2004). For instance, different pieces of information need to be considered, their value weighed, and either accepted or dismissed as warranted evidence supporting explanations; these are the hallmarks of a scientifically literate person (Cavagnetto, 2010). One of the earlier critiques of constructivism was that it misrepresents how science is practiced and fails to examine how one idea could be more *viable* (Osborne. 1996). Argumentation theorized from the perspective of pragmatism addresses this limitation. Osborne (1996) articulated:

> For science does have a well established methodology and acts of reference for deciding between competing theoretical descriptions and rejecting those which are clearly fallible, incomplete, or simply false. Furthermore, the content of the scientific knowledge that forms the substance of science education is not some transient, uncertain representation, where one theory is replaced by another that is incommensurable. (p. 58)

Following this, Pauli's (2017) work operated largely on pragmatism as a philosophical basis for research where a scientific practice of argumentation was adapted and taught to students. In doing so, the process of argumentation allowed students to understand that the goal of science is to generate the best explanation given the evidence at hand in the context of Pauli's (2017) study. The process of argumentation provided students with the opportunity to make claims, support with evidence, reason, and participate in a process that is at the heart of the scientific community and what scientists actually *do*. Through a scientific process like argumentation, students were taught to know that "there are entities for which we have well-established arguments for their existence and reliable theories that have superior explanatory power than those of common-sense reasoning" (Osborne, 1996). By using the process of science to learn the content of science, students have a tool to address misconceptions in the media as well as with themselves about science, thereby learning to evaluate ideas in science that can be considered more *viable* than others.

Critical Theory on Power and Science

The aim of a positivist approach is to establish general laws, which can serve as instruments for systematic explanation and dependable prediction (Nagel, 1979). Critical theory is a multi-faceted response to such a positivist approach. Critical theorists' critique of positivism includes the inherent lack of focus on important issues such as power, class, conflict, politics, and ideology (Steffy & Grimes, 1986).

Devetak (1996) writes that positivists epistemologically believe that the *subject* and *object* are strictly separated in order to theorize, and that there is an external world out there to study; that the subject can study this world in a balanced and objective manner by leaving behind any ideological beliefs, values, or opinions which would invalidate the inquiry. By contrast, critical conceptions deny the possibility of a value-free social analysis and instead posit that all research should be seen as potentially *laden with socially-constructed values* and structures (Devetak, 1996). As a means to examine concerns such as the relationship between method, theory, and the social consequences of theory, critical theory reveals both obvious and subtle forms of injustice and domination in society (Devetak, 1996; Steffy & Grimes, 1986). In practice, critical theory employs researchers to search out and use tools that enable the examination and transformation of inequalities from multiple perspectives; in particular from the perspective of the oppressed (Barton, 2001).

Science, with its formulaic assumptions and rigid expectations of knowledge production, acts as its own gatekeeper. As the gatekeeper, access has continually been limited to those who meet the public perception of who can be a scientist; a White, heterosexual, and middle-class male (Yoder & Mattheis, 2016). By limiting access, science itself has determined who among the populace will be scientifically literate and who will continue to mistrust and misunderstand science concepts and ideas. To this end, critical theory exposes, critiques, and transforms inequalities associated with social structures that act as barriers of exclusion so that all individuals may become scientifically literate for community and individual reasons (Barton, 2001). In Steele's (2018) study on the experience of gay men in STEM classrooms, these barriers include the genderized culture present in these classrooms. From heteronormative assumptions to rigid gender expectations, STEM fields have placed increased pressure on gay men to downplay the importance of gender and sexual orientation in their personal lives and to hide their queer identities altogether (Yoder & Mattheis, 2016). These pressures along with the indifference of the field to an individual's identity, personal life, and experiences may increase the level of discomfort for gay men (Bilimoria & Stewart, 2009) and thus have a silencing effect on gay-identified male students (Dalley & Campbell, 2006).

Research suggests that STEM cultures in the United States are distinctly heteronormative due to the attempt to maintain a sharp distinction between the two sexes while legitimating only heterosexual attractions and relationships as natural or acceptable (Cech & Waidzunas, 2011). It follows then that a hyper-genderized environment could have negative effects on any student who does not identify strongly with the hegemonic masculine identity pervasive in these fields, while individuals who break gender rules often experience backlash and increased pressure to conform to gendered expectations (Moss-Racusin, Phelan, & Rudman, 2010). Students, who wish to study in fields gendered as masculine but do not exhibit strictly masculine characteristics due to identifying as female, women, or gay, are continually sent messages by the dominant groups that they do not belong (Nassar-McMillan, Wyer, Oliver-Hoyo, & Schneider, 2011).

Power shapes the everyday life of schools and school science at all levels. In this respect, school is a social practice that operates within a society characterized by unequal power relations. However, that discussion is often missing from the public discourse due to a positivist approach to understanding and teaching science. Positivism would lead one to believe that any individual who wants to pursue science and has the mental capacity to understand the broad concepts, as well as the minute details, is able to do so. The majoritarian stories, or grand narratives, create stories about meritocracy and equal opportunity (Yosso, 2005) while ignoring the significance of racial, sexual, and gender norms prevalent in STEM (Steele, 2018). Following this critique, we call for new narratives that: (1) eliminate binary thinking such as trust and mistrust, (2) eliminate binaries of differences which marginalize anyone who might not fit the categories such as White, straight, wealthy, and male, and (3) encourage openness on the part of scientists about their work. Perceptions of scientific uncertainty are highly correlated with judgments about the *value* of science. As such, we can communicate with diverse communities about science and help the public understand the uncertainty of science.

From a critical theory standpoint, researchers not only need to expose the structures and processes that have been used to oppress certain individuals from minority groups, but should also be involved in generating a kind of science education that values both excellence and equity (Barton, 2001; Steffy & Grimes, 1986). The solutions reside in documenting, critically analyzing, and acting on the discriminatory practices found in science classrooms (Barton, 2001). In doing so, future teachers can be prepared with the ability to recognize and critique hegemonic practices in STEM classrooms; science education researchers become an activist; a change agent responsible for establishing conditions to increase scientific literacy and access to science for all individuals.

Poststructuralism and Knowing Science as Becoming

The relationship between *science* (and relatedly, technology), humans, and nonhumans in the Anthropocene emerges with new meaning in a time of unprecedented human impact on the Earth. This relationship is contested, troubled, and its traditional role of science within it resisted, but pushing the boundaries of its nuanced understandings and moving beyond the rhetoric of *science* or *scientific literacy* still remains as an imperative task in science education. Irwin and Wynne (1996) elaborated:

> One of the most routine observations about modern life concerns the rapid pace of technical change and the consequences of this for every aspect of society… The social impact of ceaselessly changing science and technology has been a classical theme of writers, social scientists and scientists since the Industrial Revolution. Generally, the tone has been deterministic, suggesting that science and technology have their own objective logic to which society must adapt as best it can. (p. 1)

Drawing on a poststructural perspective, actor-network theory (ANT), Jeong's (2018) study of re-thinking gender and race in the science classroom engages the readers with concepts and emerging tensions influencing the fields of both science education and science. Stemming from the sociology of science and technology, ANT became the conceptual framework for exploring collective sociotechnical processes and viewing *science* as a *social process*, just like any other social activity (Latour & Woolgar, 1979). Through the perspective of actor-network theory, social scientists and researchers began to grapple with the processes, which characterized socioscientific concerns and contributed to the analytic approaches and suggestions that "rupture certain central assumptions about knowledge, subjectivity, the real, and the social" (Fenwick & Edwards, 2011).

Poststructuralist perspectives aim to decenter "the Enlightenment and positivist model of an evolutionary superior, rational human subject that can be understood in itself and from which the world can be understood by and in relation to it" (Jeong et al., 2017). To reframe human beings as part of a flat ontology, and sometimes not even distinct from other animal-beings and other material-beings, all of whom are ethically bound to care for one another, is a step in the process of pushing the boundaries of how we should understand subjective objectivity of science (Jeong et al., 2017). When we consider the nature of *flat ontology*, we find ourselves in the midst of chaos and messiness and we come to realize that the *subject* (not just a human subject) is *entangled* across webs of other *becomings* and subjectivities and overlaid across newly conceived *space-time* matterings (Jeong et al., 2017). When we focus on the *socio-material* aspect of how minute relations among the actors/entities/subjects create their world, we can begin to understand these entities, as they are "performed in, by, and through" the relations that are formed among the actors and other entities (Law & Hassard, 1999). For example, Jeong's (2018) study demonstrates the performativities of gender and race as they are manifested through socio-material relations among the human and non-human actors in the actor-network of high school biology classrooms. Furthermore, Malone, Truong, and Gray (2017) discuss how teachers (especially science teachers) can help children make connections to the natural world by **becoming** the natural world. Similarly, we would argue that the new vision of science education with respect to developing *scientific literacy* is to guide the learners to **become** *enacted* such that the inclusion of non-traditional, non-western conceptions of *science* can occur. Such a notion of *inclusion* would then lead to a more mindful direction for teaching and learning science, which would allow for the inclusion of different perspectives and *subjectivities.* In doing so, learners would understand the notion of **becoming** something respectful and inclusive in the search for understanding *science.* This would be a step toward developing *scientific literacy* as a *vehicle* that can help ease the tensions and the issue of *science mistrust and misunderstanding*—our overarching thesis of this chapter.

When the very notion of *science* deeply rooted within the assumptions of positivism becomes *re*-composed, *re*-structured, and *re*-conceptualized, the *social domains* of *science* and its relations between humans and various nonhumans/entities can better be understood. Understanding the complex ontological and epistemological complexity of *science* and thus accepting the very notion of multiplicities of *scientific literacy* is the very first step that will open up infinite possibilities to theorize and examine not only environmental, public health issues in science, but also social justice and equity issues in science education.

Discussion and Conclusion

Since the days of Thomas Kuhn and Karl Popper, it is evident that the scientific community at large has moved beyond the *paradigm wars*. Given the current global and political climate, both the scientific community and science education community seem to be at *war* with the general public, in what appears to be a dichotomy of the *scientifically literate* versus *the scientifically illiterate.* The dissonance between the general public's consensus regarding the objective nature of science and the misunderstanding and mistrust of science, is nothing new, and thus, this issue still needs to be addressed with different philosophical lenses. In alignment with the focus of the book, "*Re-searching science education: Same issues from different lenses*," we aim to promote intellectual dialog on the issue in science education from multiple perspectives in order to *re*-examine previous issues toward gaining new insights into familiar problems that still confront the stakeholders in science education. Cultivating scientific literacy is a major goal for science education, and thus we have *re*-defined scientific literacy. In doing so, in this chapter, not only do we propose to move beyond the rhetoric of *scientific literacy* but most importantly, to create a dialogic process to theorize the very notion of *multiplicity* of conceptions in *science*. Furthermore, we outline how, as science educators, we can use multiple perspectives to achieve this goal with our students in the science classrooms. In truth, we all are actors entangled in a large web of our own cultures within our subsumed society. Nonetheless, we acknowledge the issue of *science mistrust and misunderstanding* in the Anthropocene as tensions continue to rise among different populations such as scientists, science educators, policy makers, and the general public. As such, we hope to contribute to our communities of interest by *re*-examining and thus *re*-conceptualizing *scientific literacy* as a *vehicle* that can help ease the tensions and the issue of *science mistrust and misunderstanding*. This, we believe, is a profound ideological transformation in thinking about how we *do* science and *think* about science education not only in schools, but also within the specific contexts within which we live, and we hope to make our first step in sharing our perspectives with our own science education community both at home and abroad.

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