

The Nature of Climate Science: Challenges for the Development of Climate Change Science Literacy in Education

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The Nature of Climate Science: Challenges for the Development of Climate Change Science Literacy in Education

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Abstract

Despite raising awareness and promoting knowledge and skills-development for education about climate change, efforts by the education sector to promote the development of climate change science literacy in schools is challenged by the nature of climate science. We illuminated the nature of climate science by analysing literature on the nature of science that foregrounds discussions in climate science, and found that climate science

involves mostly complex systems and problems; the scope of climate science is vast and interdisciplinary; most issues and problems in climate science are geographic in nature; climate science is characterised by uncertainty and disagreement; and, it is highly politicised. Unless education policymakers and curriculum designers consider these factors when formulating pedagogical intervention frameworks for a more effective and efficient climate change education; nurturing climate change science literacy in schools will be ever more elusive.

Introduction

The most recent report (the Fifth Assessment Report) of the Intergovernmental Panel on Climate Change (IPCC, 2013) reveals that global climate change is of the most devastating environmental crises in the Earth's history. It affects everyone anywhere on our planet, but the most vulnerable are populations in the developing countries owing to their limited fiscal and physical resources to initiate effective and efficient responses to the impacts of climate change. Unless pragmatic measures are taken now to reduce global warming, continued climate change will undermine some of the progress already attained by developing countries towards the Millennium Development Goals (MDGs) of eradicating extreme poverty and hunger, achieving universal primary education, and ensuring environmental sustainability (United Nations, 2000). Whenever society is confronted by environmental and social crises it turns to education for solution, notwithstanding that education has some challenges implicit in climate change. The idea of education about climate change was first hatched at the United Nations (UN)-sponsored World Conference on Education for Sustainable Development (WCESD) held in Bonn, Germany, in April 2009. Climate change education, as

described by (UNESCO, 2009a:2), is not merely about increasing people's environmental awareness but also helping people to understand and address the impact of global warming today, while at the same time encouraging a change in the attitudes and behaviour required to act on climate change. Thus, the ultimate goal of climate change education is to promote the development of climate change literacy. Supporting the climate change education initiative is the assumption that education can help to promote climate change science literacy and, by doing so, contribute to building a more resilient society. To translate policy into action, many countries have reviewed and revised existing school curricula to integrate new climate change concepts and content (UNITAR, 2013; UNESCO, 2010a, 2009a, 2009b).

Climate change education is an integral component science education. Science is a catchword of our time, yet it conveys different meanings to different people and in different contexts. The goal of science education varies by level of education. At the basic education level the purpose of science education is to produce individuals capable of understanding and evaluating information that is, or purports to be, scientific in nature and of making decisions that incorporate that

information appropriately; and, to produce a sufficient number and diversity of skilled and motivated future scientists, engineers, and other science-based professionals. Good science education requires those involved with science teaching to have a common, accurate view of the nature of science (National Science Teachers Association, 2018; National Academy of Sciences, 2018a, 2018b). Since climate change education is an integral part of science education, those teaching climate change concepts and content in schools should also understand the nature of science, so that they will be able to organise and present the climate change content and concepts as simple and clearly as possible to the learners. The main objective of climate change education is to promote the development of climate change science literacy, which is the capacity to understand and respond to climate changes. People who are climate change science literate demonstrate a basic knowledge and understanding of climate change science: climate processes, causes, impacts and solutions of climate change (Anyanwu and Le Grange, 2017).

Research shows that implementing climate change education in basic education is one of the most tricky projects the field of education has ever witnessed (Leal Filho, 2009; Pruneau, Khattabi and Demers, 2010). Some researchers (e.g. Dupigny-Giroux, 2010; Moser, 2010) explored the factors that make climate change education tricky and none focused specifically on the nature of climate science. The purpose of this paper is to explain how the nature of climate science poses a challenge to the development of climate change science literacy in education. To thoroughly illuminate the nature of climate science, an analysis of literature on the nature of science that foregrounds discussions on climate science and climate change was conducted. It is anticipated that the outcomes will not only reveal some characteristics of climate science that challenge efforts to promote the development of climate change science literacy in education, but also provide a theoretical framework that may be considered by prospective researchers to examine how the nature of climate science challenges effort to promote climate change science in schools.

The Nature of Science

Science is the catchword of our time; yet it is tricky to explain. A Google search for and analysis of literature on the meaning of science provided a vast amount of information and multiple perspectives which make understanding of the concept even more problematic. Nonetheless, sifting the bits and pieces of information and perspectives provide insight into the nature of science, culminating in definitions such as 'science as a field of discipline' and 'science as a method of inquiry', as discussed below.

As a discipline, science comprises formal sciences such as mathematics and logic; and natural sciences such as biology, physics, chemistry, earth science, health and medical sciences and social sciences. These

disciplines vary by the questions they ask about the world, their perspectives and worldview about nature, and the set of assumptions and methods they employ when exploring phenomena. Decision about what problems to investigate in any discipline is mostly determined by the charisma and personalities of individuals in that discipline (Casadevall and Fang, 2015). There are also some sciences whose content and methods are drawn from two or more disciplines. Supporting the idea of interdiscipline or interdisciplinary integration is the assumption that some important but complex problems, phenomena and concepts resist explanation or resolution when approached from single discipline perspective. A good example is climate science. Coping with knowledge construction and research in interdisciplinary fields requires tremendous investment of time and intellectual energy. It also requires the convergence of professional communities whereby each professional community brings on board their own language, frameworks, methods and tools into the analysis. Sometime this convergence could have insalubrious consequences such that some essential features of the problem may be missed out in the analysis and discussions may become stale (Webb, Smith and Worsfold, 2011; Golding, 2009; Krishnan, 2009). This could be the case when freelance scientists are involved in the analysis of climate issues.

Aside from being a discipline or field of study, science is also a method of inquiry about the natural world. The natural world is composed of matter. Some of its components are known and others are not yet known. Science is a human effort to know the unknown and extend knowledge of the known. Knowing is not an arbitrary activity rather it follows a set of guidelines. When scientists undertake inquiry they employ the scientific method, which encompasses activities such as observation and experimentation; inductive and deductive reasoning; formulation and testing of hypotheses and theories; engaging in argument driven by evidence; and obtaining, evaluating and communicating information. The outcomes of these activities are expressed in the language of science comprising theories and hypotheses, data and evidence, and argument. Language of science enables scientists to explain phenomena and concepts in ways different, and often more restrictive, ways than their everyday usage. Scientists employ the language of science to pursue three primary objectives: providing valid, holistic and intelligible explanations of the nature of phenomena; discovering solutions to real-world problems; and applying principles and theories from one or multiple domains of science (National Science Teachers Association, 2018; National Academy of Sciences, 2018a; Stanford Encyclopedia of Philosophy, 2016; Halai, 2010). Since science has its own language, it is pertinent that science educators to understand this language and be aware of the confusion or controversies that often arise from

multiple viewpoints on a single issue and different usages of familiar concepts.

One of the important debates in the philosophy of science is the nature of knowledge. Discussions about the nature of knowledge are dominated by two competing worldviews: traditionalism and constructivism. Traditionalism avers that knowledge is objective or fixed and can be transmitted by the one who knows (the repertoire of knowledge) to another who does not know (the tabula rasa). In the past three decades traditionalism has come under intense criticism for providing minimal opportunity for individual construction and social negotiation of meaning and for being ineffective to develop problem-solving skills. In his essay entitled 'Scientific Revolution' Kuhn contends that when substantial disapproval arises against paradigm practitioners should embrace a new paradigm. Usually when a new paradigm comes into focus, an epistemological rift ensues between those holding on to the old paradigm and the supporters of the new paradigm (Kuhn, 1970). The rift also applies to the waning of traditionalism and the rising of constructivism. As a philosophy of knowledge, constructivism claims that knowledge is constructed by individuals through experience. People experience the natural world through exposure to and reflection about phenomena. Both exposure and reflection involve thinking, manipulating, gathering evidence, analysing, decision-making, problem solving (Amineh and Asl, 2015; Wilson, 2010). Considering that science is about searching for new knowledge, scientific inquiry should not only be concerned with individual construction of knowledge but also social negotiation of meaning. At times social negotiation of meaning on a single phenomenon can be a source of controversy. In the event of controversy or disagreement on a topic, scientists should leave the subject of controversy open to further inquiry. Inquiry, the search for truth, is a rational process of settling doubt to build further theory..

From the preceding narrative, it can be deduced that science is a field of study as well as a method of inquiry. Both contexts depict science as a human endeavour that seeks understanding of the natural world. Characteristically, science has its own content, problems, concepts, language, approach; method, and tools. It is against this backdrop that the nature of climate science and climate change is discussed below.

The Nature of Climate Science

Climate science is a field of study concerned with analysis of the Earth's climate including the changes occurring in it. Analysis of global climate change an aspect of climate science referred to as climate change science, which focuses on the processes and the probable causes and impacts of climate change, and the responses to it (Anyanwu and Le Grange, 2017). A broader account of the scope of climate change science is provided UNESCO. According to UNESCO

(2009b:2), climate change science involves making clear distinctions between different scientific concepts and processes associated with climate change, knowledge of, and abilities to distinguish between certainties, uncertainties, projections and risks associated with climate change; knowledge of the history and interrelated causes of climate change, including the economic and political dimensions; knowledge of mitigation and adaptation practices that can contribute to wider social transformation towards sustainability; knowledge of consequences and time-space dynamics of climate change including the delayed consequences that current greenhouse gas (GHG) emissions hold in store for the quality of life, security and development options for future generations. It also includes understanding of different interests that shape different responses to climate change (e.g. business interests, consumer interests, farmers' interests, political interests, future generations' interests, etc.) and abilities to critically judge the validity of these interests in relation to the public good; and critical media literacy to address the causes of overconsumption and develop capacity to make better lifestyle choices as well as to participate in climate change solutions. Looking closely at the UNESCO-prescribed content of climate change science, one would notice that the climate change science incorporates the content and concepts of formal and natural sciences which connote interdisciplinarity. Usually the scope of interdisciplinary subjects is vast. Following that the scope of an interdisciplinary subject is vast, no person in our time can claim to know everything about the content. It is against this background the National Academy of Sciences' (2012a:2) describes 'climate science' as "a process of collective learning" whereby professionals from diverse disciplines work as a team to provide valid, holistic explanations about a problem. Since the content of climate change science is vast, it is expected that people who studied climate science and related disciplines in higher education may have better knowledge and understanding of climate change than those who studied 'non-science' disciplines. Since climate change is geographic, teaching climate change topics and concepts may be easier for Geography teachers than teachers of other subjects. In the same vein Physics teachers may be more conversant with the physics of the atmosphere and not conversant with the spatial dimensions of climate change. Ordinarily a teacher would prefer to teach the topics he or she is conversant with. Teaching multidisciplinary issues including those associated with climate change such as drought, outbreaks of disease, biodiversity degradation, resource conflict and sustainable development could be challenging particularly for teachers who did not study climate change science during their education/training. Like teachers, learners also may find interdisciplinary concepts challenging owing to the cognitive demand involved in making

conceptual connections. When learners do not understand the explanation of concepts they form misconceptions, and once formed, they are resistant to change. Misconception occurs in all subjects but more in subjects with complex concepts and contradictory explanations (Ergul, 2013; Gooding and Metz, 2011); of which climate change science is among them. Studies (for example, Anyanwu and Le Grange, 2015; Boon, 2010) show that teachers and learners hold conceptions about climate change that are distanced from the explanations by scientists. Therefore, the prospect for achieving a climate change science literate generation in the foreseeable future may be unrealistic, except with pedagogical interventions that will help to facilitate understanding of climate change content and concepts.

The Earth's climate system is composed of the atmosphere, land surface, snow and ice, oceans and other bodies of water, and living things as well as their subsystems. These elements and subsystems interact and affect each other in a very complex way (IPCC, 2013; Peilke, 2008). A system is complex if its components or structures interact and affect each other in ways that makes it difficult to analyse the entire system accurately when the individual components and processes of the system have not been understood. Complex systems often present complex problems. Problems associated with complex systems are often unique, extremely threatening and very difficult to solve or manipulate. Ignoring them (business-as-usual) may result in more serious consequences; and, solving them might necessitate broader social transformations that may evoke other problems. In most cases, controversy ensues as to the best approach to tackle the problem. Sometimes problems originating from complex systems evade solutions, particularly when the systems and their components are approached as though they are complicated. In complex systems small inputs produce disproportionate effects, whereas in complicated systems input into the system produces equivalent output (Hasan, 2014). One of most widely used approaches to understand complex problems is functional analysis: analysing the activities exerted by the problem. For climate changes, functional analysis should be concerned with variations and trends within the world and its earthly systems, across space and time. Specifically, functional analysis of climate change should offer holistic explanation of climate change. To achieve this, the analysis must be driven by questions such as where does the change occur, when, and for how long? Answers to these questions may offer some rationale for further analysis into why change has occurred, the potential knock-on effects of the changes, and a framework to address the problems. At times climate natural variability occurs on temporal scales too trivial to be explained quantitatively. Quantitative analysis, an offshoot of positivism, is based on the assumption that phenomena can be understood through judgement made on the basis of facts gathered through sense experience. Positivism,

according to Higgs and Smith (2006:3) seeks facts or 'truth' through logic and empiricism. While logic seeks 'true' knowledge by drawing inferences from valid argument; empiricism weighs true knowledge by the extent to which the phenomenon in question purports to tell us something about real objective facts. At times climatic processes such as changes within the climatic systems do not represent the features of the entire system and therefore cannot be experienced and described with exactness. In situations like this, scientists resort to models such as the Atmosphere–Ocean General Circulation Models (AOGCMs), Earth System Models (ESMs) and Regional Climate Models (RCMs) to enable analyse the response of the climate system to natural and anthropogenic forcings, predict seasonal to decadal time scales and project future climate patterns. But, where climate variability is still too trivial for modelling, scientists opt for the parameterization technique wherein they average the known properties of the system elements and their processes on far larger scales (Edwards, 2011). Yet some aspects of climate change cannot be fully understood using the positivist methodology. For example, the effects of climate change on livelihoods is better analysed qualitatively or with the use of mixed methods. Climate analysis requires people who understand scientific research methods and process – scientific method literacy. Employing inappropriate or flawed methodology may result in inaccurate conceptualization of the problem and illogical results. Climate change is a geographic problem that requires a geographic solution. This is because climate change results from interactions between the Earth's complex natural systems and anthropogenic influences. Understanding climate change therefore will involve the organisation of knowledge around the concept of place, spatial processes, spatial distribution and humans and the environment (Coelho, Ferro, Stephenson and Steinskog, 2008). Under the circumstance of the visible impacts of climate change on natural and human systems, mere ability to encode and decode text information, which is the standard for distinguishing the literate from the illiterate, may not be adequate to understanding, and responding to, climate change; rather, it may require literacy in the contemporary sense - a flexible group of competencies needed to succeed in today's rapidly changing world. Part of the literacy is the ability to use Geographic Information Systems (GIS) to better understand a complex situation and offer some tangible solutions. Thus, technological literacy offers the means to assess, plan, and implement sustainable programs that can affect us many years into the future (Holbrook and Rannikmae, 2009). This paper takes the perspective that promoting climate change science literacy in schools will require teachers who are not only geographically literate but also technologically literate. Climate science has made many important advances in the past four decades. The Fifth Assessment Report of the Intergovernmental Panel on Climate Change

(IPCC) (IPCC, 2013) attribute the advances to that direct measurements and remote sensing from satellites and other platforms as well as paleoclimate reconstructions recording as far back to millions of years. These advances provide a more comprehensive view of the variability and long-term changes in the atmosphere, the ocean, the cryosphere, and the land surface. Yet, general consensus still evades climate scientists on some aspects of the Earth's climate and the changes occurring therein. However, there is still a range of plausible projections for future global and regional climate that are specific to some climatic variables and their spatial and temporal scales. When scientists make projection about the climate, they make choices about data and models, and the processes to include and those to omit in the analysis. However, some of the choices scientists make become sources of disagreement and uncertainty, which are usually resolved through further scientific inquiry into the subject of the disagreement (IPCC, 2013). In some cases scientists could not reach a consensus view on some issues in climate change science, as discussed below.

Issues about Climate Change

Since the middle of the eighteenth century global climatic changes has emerged as one of the critical environmental issues for scientists and policymakers. Extensive research on climate change has been conducted by internationally-accredited institutions, groups, freelance scientists and academics. The upshots of those studies have intensified controversies among climate scientists on the definition of climate, the definition of climate change, climatic processes and actual causes of climate change, impacts of climate change, and possible solutions to climate change. Some of the controversies are discussed in this section.

Definitions of climate and climate change

The meanings of climate and climate change are among the contentious topics in climate science. The debate has resulted in multiple explanations of the concepts. Pertaining to climate, the IPCC provides two different definitions: the first definition is narrow and the second definition is more rigorous. In a narrow sense, climate refers to the average weather (IPCC, 2013). This view is consistent with the National Aeronautics and Space Administration (2017) definition of the concept. In a broader sense, climate refers to the statistical description in terms of the mean and variability of relevant quantities over a period of time, ranging from months to thousands or millions of years. The classical period for averaging these variables is thirty years, as defined by the World Meteorological Organization. The relevant quantities are most often surface variables, such as temperature, precipitation and wind. A common feature of climate (local, regional or global), is changes but the nature of the changes is still a subject of debate. While NASA believes that climate changes occur slowly; be local,

regional or global); Rial et al (2004:11) describes it as greatly nonlinear such that inputs and outputs are not proportional, but rather outputs are episodic and abrupt. However, the different types of nonlinearities, how they manifest under various conditions, and whether they reflect a climate system driven by astronomical forcings or by internal feedbacks or a combination of both, is relatively poorly understood. Wernd (2014) criticizes current definitions of climate for being endorsed where the external conditions are held constant. He argues that some climate scientists analyze the climate of a certain region by concentrating on the distribution of the climate variables of that region, particularly those variables describing the state of the atmosphere, such as the surface air temperature or the surface pressure. Others incorporate variables describing the state of the ocean and sometimes other variables such as those describing glaciers and ice sheets, in addition to dynamic meteorological variables. Controversy arises as to which of these perspectives offers a more scientific explanation of the nature of climate. Until this controversy is resolved and a common definition of climate is offered, climate will be defined in different ways by different scholars.

Like climate, there is also controversy among scientists on the definition of climate change. A study of related literature and policy/mission statements illuminates broadly differing perspectives on the phenomenon of climate change. In IPCC terminology, climate change refers to a change in the state of the climate that can be identified (e.g. based on using statistical tests) by changes in the mean and/or the variability of its properties persisting for an extended period; decades or longer. Climate change may be due to natural internal processes or external forcings such as modulations of the solar cycles, volcanic eruptions, and persistent anthropogenic changes in the composition of the atmosphere or in land use (IPCC, 2014). In the UNFCCC terminology, climate change means a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods (United Nations, 2011). Both the IPCC and UNFCCC recognise the role of internal and external forcings on the global climate but the UNFCCC is concerned with making a distinction between climate change attributable to human activities that are altering the atmospheric composition and climate variability attributable to natural causes. The crux of the argument between the definitions lies on the criterion for differentiating between 'change' and 'variability'. It is pertinent to note that the main obligation of the IPCC is to prepare assessments based on available scientific information on all aspects of climate change and its impacts and to formulate realistic solutions on climate change. The UNFCCC, on the other hand, is a United Nation's environmental framework aimed to stabilise greenhouse gas concentrations in the atmosphere at a level that will

prevent dangerous human interference with the climate system. These two different obligations have yielded two different perspectives which might introduce controversy in defining the phenomenon of climate change. Unless this controversy is resolved, educators will continue to experience confusion in defining climate change.

Actual causes of climate change

Besides the nuanced disagreement over the meaning of climate change, climate scientists also differ on the actual cause of climate change. At the core of this controversy is the IPCC Anthropogenic Global Warming Theory (AGWT) published in the Fourth Assessment Report (AR4) in 2007. The AGWT attributes the observed warming of the Earth's atmosphere over the past century to enhanced GHGs mostly carbon dioxide (CO₂) and methane. The theory claims that the increase in greenhouse gases that occurred in recent decades were due to the decline in the efficacy of natural carbon sinks and enhanced anthropogenic activities such as energy supply and demand, industry, agriculture, transportation, construction of commercial and residential buildings, and waste and waste water (IPCC, 2014, 2013). Leading international scientific organisations with interests on global climates including the National Ocean and Atmospheric Administration endorse the AGWT's claim that anthropogenic causes account for over ninety percent of global warming that occurred since 1900 and virtually all of the warming that occurred since 1970 (National Ocean and Atmospheric Administration, 2011); nonetheless, independent climate scientists still question the validity of the AGWT.

Critics of the AGWT contend that current amounts of CO₂ are far higher than they were in the mid-20th century but maintain that the cause of global climate change in this century may have little or nothing to do with anthropogenic burning of fossil fuels but far more to do with sunspot cycles and other natural phenomena not affected by GHGs. They criticise the AGWT for projecting monotonic warming and for excluding some mechanisms that could affect climate related natural temperature oscillations that are not directly linked with humans such as the El Niño-Southern Oscillation (ENSO). They argue that the AGWT fails to reproduce the temperature patterns and the temperature oscillations at multiple time scales, ignores the distortions of temperature up through the stratosphere; overestimates the positive temperature feedbacks, and underestimates the responses of other GHGs like water vapour to increased temperature. For the AGWT critics, the Earth's climate had experienced radical shifts in the Earth's history before humans appeared hence, substantial and continuing anthropogenic impact on climate is not particular to this century. At a methodological level, they condemn the IPCC's coloured reading of the scientific literature to justify its own political stance, which of course favours human-

induced climate change (Weart, 2011; Carter, 2010). Despite these criticisms the IPCC maintains that their climate analysis models have high resolutions and their observations and claims are well within the range of the extent of the previous projections. Against this background, one would infer that there is yet no consensus among climate scientists on the main cause of global climate change. Since knowledge and understanding of the cause of climate change is crucial in responding to climate change, lack of a consensus view about the main cause of climate change may seriously affect effort to promote the development of climate change science literacy in education.

Impacts of climate change

Globally, people are experiencing both the subtle and stark effects of climate change. Some of the effects include rising seas and increased coastal flooding; longer and more damaging wildfire seasons; more destructive hurricanes; more frequent and intense heat waves; an increase in extreme weather events; heavier precipitation and flooding; more severe droughts in some areas; increased pressure on groundwater supplies; changing seasons; melting ice; disruptions to food supplies; destruction of coral reefs; and plant and animal range shifts (Union of Concerned Scientists, 2018). Although some climate changes are mostly trivial, but over a long time they may reach a tipping point that could dislodge natural and human systems, patterns and processes on a global scale that can put millions of people at risk. Risk is a measure of the probability and the weight of undesirable consequences (Sotic and Rajic, 2015). Several indicators are used to measure the level of risks of the impacts of climate change on society, namely vulnerability and resilience of the population. While vulnerability is a measure of a population's exposure to risk; resilience is a measure of the persistence of systems and of their ability to absorb change and disturbance and still maintain relationships. Risk, vulnerability, and resilience have become very popular concepts in environmental, health, and sustainability sciences, and as well in many other disciplines dealing with endangerments, threats, or other agents, which may cause adverse effects in certain systems (Scholz, Blumer and Brand, 2011).

The level at which individuals and the society perceive and rank risks and potential benefits at any given time and space is determined by their worldviews, values and goals. Where risks are perceptible on geographical scales (spatial and temporal), delayed action or inaction may expose millions of people to danger particularly in countries with limited technologies to respond climatic disasters. The level of confidence in these claims varies (IPCC, 2014; National Academy of Sciences, 2012b; Skoufias, Rabassa, Olivieri, and Brahmabhatt, 2011). Predicting with accuracy the direction and dimension of the climate changes and their impacts a decade or less in advance is tricky, owing to uncertainties that characterize the timing,

magnitude, and precise location of the risk Good predictions are valuable in formulating other possible courses of action, and choosing among the options by anticipating how things will turn out.

The IPCC Fifth Assessment Report (AR5) (IPCC, 2013) notes with high confidence that the impacts from recent climate-related extremes, such as heat waves, droughts, floods, cyclones, and wildfires, reveal significant vulnerability and exposure of some ecosystems and many human systems to current climate variability. With less confidence, the IPCC notes that the global burden of human ill-health from climate change is relatively small compared with the effects of other stressors. An analysis of the impacts of climate change by Ackerly, Loarie, Cornwell, Weiss, Hamilton, Branciforte and Kraft (2010) reveals that the biological impacts of climate change are likely to be greater where the rate and/or magnitude of climate change is greater, and faster rates are increasingly likely to out-pace some types of biological responses. Where greater imbalance exists between climate and ecological systems, there is possibility that the impacts may cross critical ecological thresholds culminating in regime shifts. Besides, climate change imposes psychological stress on humans either directly in the form of mental health injuries following climate-related crises; or indirectly as a result of intense emotions prompted by the experiences of other individuals struck by the crises; or anxiety and uncertainty about future risks (Doherty and Clayton, 2011). The way climate change risks and impacts are perceived and ranked by societies that may influence political decisions on how to respond to them, including investment in climate change education.

Possible solutions to climate change

The scientific evidence for climate change as an environmental crisis for which urgent solution is needed to curtail the impacts is unequivocal. Curtailing the scale, speed and intensity of the impacts of climate change requires sustainable managing risks. When discussing risk in the context of climate change it is pertinent to consider the probability of its occurrence and the possible impacts on livelihood and quality of life. A livelihood comprises the capabilities, assets (including both material and social resources) and activities for a means of living. A livelihood is sustainable when it can cope with and recover from stresses and shocks, maintain or enhance its capabilities and assets, while not undermining the natural resource base (Scoones, 2009). On the other hand, quality of life refers to the well-being of individuals (Theofilou, 2013). The Millennium Development Goals (MDGs) were formulated to enhance people's livelihoods and quality of life. Considering that there is an inextricable connection between people, environment and development, achieving the MDGs goals may help to reduce the scale, speed and intensity of the impacts of climate

change on society even though the MDGs were not intended specifically for climate change.

A two-pronged approach to address climate change was proposed by the IPCC, namely mitigation and adaptation. Whereas mitigation involves cutting down carbon emissions rate; adaptation involves adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects (IPCC, 2014). Two additional approaches are proposed by the Australian Academy of Sciences: sequestrations (removing carbon dioxide (CO₂) from the atmosphere into permanent geological, biological or oceanic reservoirs); and solar geoengineering (large-scale engineered modifications to limit the amount of sunlight reaching the earth, in an attempt to offset the effects of ongoing greenhouse gas emissions (Australian Academy of Sciences, 2015). Each of these approaches embodies a collection of specific strategies with associated risks, costs and benefits. Supporting these proposed solutions to climate change is the assumption that global warming and the resultant climate change may not stop anytime soon considering current concentration of CO₂ in the atmosphere. In other words, there is a high probability that even if CO₂ concentrations were to drop considerably today, the Earth's climate will continue to change for many centuries to come and several other climatic impacts will become more visible. This projection foreshadows pessimism for education about climate change as a possible solution to climate change, at least in the meantime.

The relationship between humans and environment is an important topic in climate change discourses. Different people have explained the pattern that this relationship should take in many different ways, giving rise to camps of perspectives and worldviews on the topic (Rae, 2014; UNESCO, 2010a; McShane, 2009). On one camp is anthropocentrism, which is the belief that humans are the exclusive bearers of intrinsic value and all other species are there to sustain and advance people's well-being. This philosophical position overlooks the medium- and long-term consequences of unsustainable exploitation of ecological resource. It is unlikely that anthropocentrism enthusiasts would accept that current global warming is down to anthropogenic causes. Ultimately they would support business-as-usual, which is antithetical to mitigation and adaptation. In contrast, ecocentrism is the belief that no organism, even humans, is the sole source of existence. Followers of this ecocentrism argue that since humans are now the most consuming of all species, they should also take greater responsibility to preserve other species, at least for the fact that humans are the only species with the ability to make rational choices. Thus, ecocentrism enthusiasts would support stringent action on climate change, a position that may sound idealistic to regions and countries that are opposed to carbon emissions reduction. The third camp, the deep ecologists, takes the middle ground, claiming that humans and all other species have

identity only in their relationships within the environment and as such it is unfair to segregate between species in terms of who should have greater right over ecological resources and survival. They are likely to oppose any options that would dispossess people of access to ecological resources. These worldviews may have some influences on public opinion and political decisions on climate change education.

Geography of global CO₂ emissions shows that over sixty percent of global emissions come from power and industry sectors concentrated in four regions which account for over 90% of global emissions. The regions are: Asia (30%), North America (24%), the transitional economies (13%), and OECD West (12%). The rest of the regions collectively account for less than 6% of the global emissions from the power and industry sectors (IPCC, 2014, Union of Concerned Scientists, 2010). Despite several international instruments, including the Kyoto and Paris Agreements to persuade countries to support emission reduction, some countries have not shown remarkable commitment. Some of them give explanation for their low commitment to the agreements. For example, China describes her emissions as ‘emissions for survival’, insisting that all of her mitigation initiatives must support her domestic sustainable development policies. India supports mostly carbon friendly policies that will help to promote and sustain her domestic economy. In contrast, the European Union particularly Germany and the United Kingdom are committed to developing and delivering technologies to lower CO₂ emissions while at the same time assisting other countries and regions to explore new and more efficient mitigation options (World Energy Council, 2009). Although Africa’s CO₂ emissions are minimal compared with other regions, Africa is the most vulnerable to climate change compared with other regions in the world. Climate justice demands that the cost of climate change solutions should be shouldered in proportion to CO₂ production, so that the countries that produce more should take greater responsibility of providing funds and technologies required to tackle climate change (Kennedy, 2017; Johnston, 2016). Till now, climate justice is poorly enforced, resulting in political divides on how climate change education should be funded.

Without a strong political will, it will be difficult to provide the resources for an effective and efficient climate change education in schools.

Conclusion

Through this study we found that climate science is concerned with developing an understanding of Earth’s climate systems, the processes that occur within the system, their impacts on human and physical systems, and ways of responding to the impacts. Characteristically, climate science involves mostly complex systems and problems that often evade solutions; the scope of climate science is vast and interdisciplinary in nature such that no person is expected to know everything in climate science; most problems in climate science are geographic in nature owing to their spatial and temporal characteristics; climate science is characterised by disagreement due to uncertainty about the processes, causes, impacts and solutions of climate changes; and, climate science is greatly politicised because of the social, economic, environmental, legal, scientific, psychological issues that affect political decisions. These factors could make effort to promote the development of climate science literacy in education problematic.

This study is significant in a number of ways. It closes some conceptual gaps in previous studies and provides a framework for understanding the nature of climate science and the challenges it poses to efforts to promote the development of climate change science literacy in education. Although the study did not exhaust all that should be known about the nature of climate science; it provides an insight into the nature of climate science. To guarantee effective and efficient climate change education in schools, it is pertinent that education policymakers and curriculum designers reflect on the nature of climate science when formulating intervention frameworks for climate change education. Prospective researchers should extend this study’s conceptual framework to investigate the nature of climate science and the challenges it poses to the development of climate change science literacy in education, not only to corroborate the findings of this study but also to identify additional characteristics of climate science.

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