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Complexity and Simplicity in Science Education

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Contents

Chapter 1
Complexity and Simplicity: Framing the Work

David Geelan, Kim Nichols, and Christine V. McDonald

H G Wells said "Civilization is in a race between education and catastrophe". As we write this introductory chapter, much of the eastern seaboard of Australia, where the editors and several contributors to this volume live, is on fire. Sydney is enveloped in smoke that may last for several additional weeks. The bushfire season has arrived unseasonably early and is unusually severe. Experienced emergency service professionals have called the situation 'unprecedented'. And yet, in this context, the leaders of both of Australia's major political parties are actively promoting the mining and export of more thermal coal. One key task of science education, surely, is to support citizens in being able to understand sufficient science and to develop sufficient critical thinking skills to be able to vote and actively participate in society in evidence-based ways that lead to human flourishing and reduce the potential for harm?

Climate change, of course, is only one of the many 'wicked problems' facing our students, who are the citizens of the future. Automation and machine intelligence are already displacing human workers in many industries and will continue to do so. Clean fresh water will be much more difficult to obtain, partly a consequence of climate change and partly due to growing human population and pollution. Disease pandemics are a persistent feature of human life that will challenge most generations.

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These are not simple problems, and they have social and political dimensions as well as scientific ones. A clear and simple delineation between science, technology, other school disciplines and society may only occur in academic discourses: real life is complex and messy. Certainly the efforts of science education researchers to prepare, retain and develop effective science teachers in primary and secondary school settings partake of these complexities. This book seeks to bring some clarity and simplicity, where possible, to a range of issues with potential impact on science education in Australia and internationally. It also seeks to reveal complexities in teaching and learning in the science classroom that are critical to shedding light on how to ensure that students have sufficient conceptual understanding to make informed decisions about complex issues facing them (Hilton et al., 2011).

When speaking about 'science education for citizenship', national citizenship is important, but many of these problems, including water and energy shortages, disease pandemics and particularly climate change, are no respecters of national borders, and require coordinated global action to address them. As such, to some extent we can educate our students as global citizens who have a vision of humanity as a whole as both the recipient and the provider of solutions to those global-scale issues.

It is interesting to draw from the field of complexity science when speaking of the complexity of science education, and educational contexts in general. It seems to us as though complexity is defined in the literature discussing it by ostension rather than explicitly: an inductive process of pointing out multiple instances of complex phenomena or processes. A distinction can be drawn between processes that are described as 'complicated' and those described as 'complex': a *complicated* process can meaningfully be reductively analysed into simpler systems and processes and understood in terms of those subunits and their interactions. A *complex* system, on the other hand, is considered to be in-principle irreducible; to have its essential properties by virtue of some sort of emergence or other process that is not amenable to reductive analysis.

This distinction has problems, of course: without the ability to throw infinite analytical and computing resources at a problem, it is difficult or impossible to decide in a definitive way whether a particular system is complex or merely very complicated. It could be that what appears to be an emergent process is in fact amenable to reductive analysis, if sufficient analytical resources are applied. For most purposes, however, it is not necessary to determine whether a system is complex in a final sense: if it appears so with the current level of resources we can apply to it, then it may as well be for our purposes. (And we can leave aside for the moment the question of whether, with truly infinite computational resources available, every apparently-complex system would be revealed to be merely very complicated.)

In thinking about complexity (and simplicity) in relation to science education, it is helpful to think about several layers at which complexity arises: the individual, the classroom, the school and society more broadly.

1.1 Individual Complexity

While there is a strong intuitive attraction to the idea that human action/cognition constitutes a complex system, we can conceive of an experiment that applies sufficient lifelong surveillance and processing power to render an individual comprehensible in a reductionist way.

In the absence of confirming evidence in either direction, however, we would argue that there is value in treating teachers and students as though they – or at least the things they do, say and think in the classroom – are complex.

Biggiero (2001) claims that human systems do fall under the requirements for complexity:

> Human systems are affected by several sources of complexity, belonging to three classes, in order of descending restrictivity. Systems belonging to the first class are not predictable at all, those belonging to the second class are predictable only through an infinite computational capacity, and those belonging to the third class are predictable only through a trans-computational capacity. The first class has two sources of complexity: logical complexity, directly deriving from self-reference and Gödel's incompleteness theorems, and relational complexity, resulting in a sort of indeterminacy principle occurring in social systems. The second class has three sources of complexity: gnosiological complexity, which consists of the variety of possible perceptions; semiotic complexity, which represents the infinite possible interpretations of signs and facts; and chaotic complexity, which characterizes phenomena of nonlinear dynamic systems. The third class coincides with computational complexity, which basically coincides with the mathematical concept of intractability. Artificial, natural, biological and human systems are characterized by the influence of different sources of complexity, and the latter appear to be the most complex. (p. 3)

Biggiero claims that human systems are the most complex systems with which we attempt to come to grips, in terms of all six of the forms of complexity he enumerates.

1.2 Classroom Complexity

Beyond the complexity of each individual, of course, there is the complication of the classroom as a social environment. This consists at first in the two-dimensional complication of the possible interactions and relationships between 20 and 40 people: if we imagine a diagram of a classroom, with a single, simple line joining each person in the room to each other person, the image is already one of a very complex spiderweb of connections and interactions—one in which some threads are much stronger and more structurally important than others, and one that is in constant flux. In the past one of us (Geelan, 2001) used the image of a spiderweb.

The web is complex, and as well as the potential to trap prey it must support the spider's movement and convey information about what is going on at a distance. If the spider wishes to move the 'centre' at which it sits to catch or avoid the sun, it cannot simply move but must re-weave much of the web. Similarly, if teachers wish to change what happens in the classroom, they cannot simply implement new practices, but must re-weave the set of student actions and expectations to fit the new approach. This is a negotiation with students rather than a simple imposition upon them.

The web is not so much of communication as of expectations and beliefs. Complexity arises at the technical, practical and emancipatory (Habermas, 1971) levels. The technical level is the cause-and-effect level of actions, the practical level of meaning, emotion and art, and the emancipatory level is where harmful assumptions, beliefs and stereotypes are dismantled and replaced with new beliefs more effective in promoting human flourishing.

1.3 School Complexity

A classroom is part of a school, and each school has multiple dimensions of complexity – it draws its students and teachers from a particular area with a particular socioeconomic status and demographic mix (though teachers and students may hail from different suburbs), it has its own school culture, history and set of expectations, its own leadership culture and group. Each school has a story that it tells about itself, mostly to itself but also to its community. As Nigerian poet Ben Okri said:

> Stories are the secret reservoir of values: change the stories individuals and nations live by and tell themselves, and you change the individuals and nations.

There may be discontinuities between the story the school wishes to tell about itself and the stories experienced by teachers and students: Clandinin and Connelly (1995) talk about ‘secret’, ‘sacred’ and ‘cover’ stories. Sacred stories are the official narrative of the school, secret stories are those lived out by teachers in classrooms, and cover stories are the ones teachers tell as they seek to bridge the gap between secret and sacred stories. Science teachers, especially those new to the profession and those teaching ‘out of field’ (without formal preparation as science teachers) work within these complexities and constraints.

1.4 Social Complexity

The agenda for schools and schooling is very much set by society more broadly, in terms of the assumptions and expectations parents bring to their children’s schooling and of the imperatives of politicians and bureaucrats charged with organising how education is funded and delivered. On the one hand science education is championed as being crucial to future prosperity and economic and technological development, on the other the findings of scientists are often ignored when they are inconvenient.

Dr. Tom Beer is an Australian scientist who studied climate change and bushfire risk in the 1980s and warned of exactly the conditions we are currently experiencing four decades ago (Guardian Australia, November 2019). In a recent interview he asked "What else could I have done?" besides publishing the research and publicly advocating for change. He felt that the efforts of scientists had been overwhelmed and made ineffective by industry-funded lobbyists.

Society partakes of all the different levels and kinds of complexity that apply at the other levels discussed here, with the additional complexities of politics, religion, traditional and social media, economics and a huge range of other pressures and imperatives. Science education, with the aspirations of its teachers and researchers, seeks to swim in these complex oceans... arguably full of both nutrients and predators!

Dividing out these levels for our own analytical purposes by no means implies that there are not complex interactions within and across the levels as well. The metaphor of an ecosystem might be almost cliched in this context, but studies like those reporting the elimination and then re-introduction of wolves in Yellowstone National Park and the impact up and down the food chain, so dramatic that it changed the courses of rivers, seems appropriate. A change at any level of the schooling system in relation to the teaching of science propagates upward and downward through the layers, in ways that are often unpredictable and surprising. At the time of writing the 2019 PISA results have just been released. Most of the media attention in Australia has been on a perceived fall in Australia's mathematics ranking, but there is also dissatisfaction with Australia's scores on international comparisons in relation to science education. The moves made by governments to seek to address these metrics are often not informed by the best available evidence, and often echo through the complexities of science education in unforeseen ways that can yield further challenges in need of solution.

The chapters in this book focus in on various levels of complexity transcending these broader fields, and attempt to bring some simplicity and clarity, using the tools of research, to some of the complex vexed problems of twenty-first century science education for global citizenship. The book is organised into four parts that progress from the broader social complexities to the classroom and individual complexities of science education.

In the first part, Chaps. 2 and 3 explore broader social complexities of science education including curriculum enactment, teacher retention and out-of-field teaching. In Chap. 2 the philosophy, goals and objectives underpinning the South African National Curriculum Statement are considered by Eyitayo Julius Ajayi who explores aspects pertaining to Grade 9 Natural Science, and teachers' understandings of the policy documents. Due to the impact of colonial and apartheid history on South African education, in concert with transformations of the curriculum, teachers' understanding of the current curriculum, underpinned by its values, are considered to be non-negotiable. In Chap. 3 Merryn Dawborn-Gundlach explores the transition experiences of 15 Australian early career science teachers by interrogating the features of their post-graduate initial teacher education (ITE) programs that support this transition. In Chap. 4 Linda Hobbs and Frances Quinn, using metaphor as a research tool, examine longitudinal data to explore the learning journeys of nine Australian out-of-field teachers over time. In Australia, out-of-field teaching of science and mathematics in secondary schools has become a significant concern due to an under supply of qualified teachers. Given this, it is vital to understand and support the learning of out-of-field teachers to ensure students are provided with high quality learning experiences.

In the second part of the book, Chaps. 5 and 6 focus on the perceptions, teaching and learning of socio-scientific issues in diverse school contexts. In Chap. 5 Keith Skamp, Edward Boyes and Martin Stanisstreet report on a large cross-national study which explored the beliefs held by more than 12,000 secondary school students in 11 countries about actions with the potential to mitigate global climate change. Some of these actions related to personal choices about transport and energy usage, others to collective action through voting. Addressing the causes and consequences of climate change is an urgent global challenge for educators, but simply informing students about the issues seems to be insufficient to prompt action, at least in some cases. In Chap. 6 Vaille Dawson and Grady Venville developed two case studies on gene technology and two on climate change and used them with Year 10 students in four diverse Western Australian secondary schools in order to develop their critical thinking skills through argumentation. Argumentation is the attempt to persuade another person to adopt a view or share a perspective. It is a critical thinking skill that can be effectively learned and taught as part of science education and draws on engagement with socio-scientific issues to develop skills and dispositions.

In the third part Chaps. 7, 8 and 9 explore the development of scientific literacy through teaching academic vocabulary explicitly, using collaborative inquiry and investigating children's self-created representations of scientific phenomena. In Chap. 7 Chris Nielsen seeks to add to the body of knowledge on integrating literacy instruction in the science classroom by investigating student and teacher perspectives on the effectiveness of specific pedagogical techniques designed for teaching vocabulary: in this case, the six-step approach developed by Marzano and colleagues in 2015. The author argues that a greater understanding of the usefulness of specific pedagogical approaches might be gained from this study, through comparing and reflecting upon student and teacher perceptions of the strategies taught. In Chap. 8, in their study of a collaborative STEM inquiry learning project conducted in Western Australia, Debra Panizzon, Bruce White, Katrina Elliott and Alex Semmens explore beliefs about students' own ability to succeed in science education in academic terms and to understand scientific concepts, along with the ability to imagine themselves as having a role and place in science. Surveys and focus group discussions were conducted to explore students' self-efficacy and self-concept in relationship to science and STEM knowledge given these factors strongly influence student engagement in science and their interest in continuing to study science in senior secondary school and university. In Chap. 9 Christine Preston, Jennifer Way and Eleni Smyrnis explore the premise that children's self-created representations of physical phenomena reveal their emerging conceptions in science and mathematics and provide rich data for investigating the complexities of their representational systems. The authors draw on research that focused on how 7 to 12-year-old children represent scientific and mathematical concepts and processes by creating drawings of dynamic phenomena encountered during simple physical experiments, to reveal layers of complexity in seemingly simple situations. Through task-based interviews, using digital data-gathering devices, the authors interpret the signs, symbols, diagrammatic structures, gestures and verbalisations that children created to represent observed changes, movement and relationships.

In the fourth and final part Chaps. 10 and 11 focus on making the complexities of science curriculum content and concepts more accessible to learners. In Chap. 10 William Palmer pays tribute to an important historical figure in the field of chemistry education by providing a historical account of Edgar Fahs Smith; a researcher and teacher. The history of various fields of science is captured in our Australian Curriculum strand referred to as ‘Science as a Human Endeavour’. This strand also includes the nature of science and it is expected that teachers integrate the history and nature of science into the content of the curriculum subject areas. This strand is deemed to have particular complexities as each subject area has a rich, complex and detailed history. In Chap. 11 Peter Hubber and Christine Preston describe the implementation of a guided inquiry approach for teaching the topic of electricity to Year 6 students. A case study that incorporated a design-based research method was applied to explore the challenges in teaching and learning electricity adopting a Representation Construction Approach (RCA). The project involved collaboration with classroom teachers over 2 years to develop and refine a sequence of lessons. The lessons involved students constructing multi-modal representations in response to hands-on challenges with strategic, teacher-led discussions supporting the development of conceptual understanding. The chapter considers the teachers’ perspectives as they negotiated changes in their classroom practice necessary to adopt the RCA.

As a group of science education researchers, editors and authors we would like to thank our families and colleagues who support our research and share our values toward science, education and global citizenship. We would like to thank the teachers and students who were willing to participate in the research studies here, without whom the work would be impossible. We would like, in particular, to thank our editors at Springer and the anonymous reviewers whose careful and insightful work definitely made this book much better.

We hope that these ideas, perspectives and approaches and the evidence shared in our descriptions of these studies will provide an occasion for reflection on your part as reader, and help to further inform the learning, teaching and research work you do. Together, we and you are seeking to make our world a better place and one better able to survive novel challenges and wicked problems and to promote progress and human flourishing.

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Part I
Exploring the Broader Social Complexities of Science Education

Chapter 2
Exploring the Nature, and Teachers' Understanding, of the National Curriculum Statement (NCS, Grades R – 12): Navigating the Changing Landscape of Science Education Through the Curriculum Assessment and Policy Statement (CAPS) in Post-Apartheid South Africa

Julius Ajayi Eyitayo

2.1 Introduction

> Science education has been the focus of recent reform efforts around the world [hence] large investments are made in curriculum materials with the goal of supporting science education reforms […] Roblin et al. (2018, p. 1).

According to Penuel et al. (2014), "curriculum materials and knowledge about curriculum purposes and structures are valuable tools that teachers often draw upon to organize instruction and facilitate student learning […]" (p. 751). Despite the emphasis of the post-apartheid government of South Africa on the significance of science and mathematics education as key areas of knowledge competence and human development (Reddy et al., 2012, p. 620); poor performance of South African learners in the sciences has been reported (TIMSS, 2016; Reddy et al., 2016) The South African Department of Education (DoE, 2009; DBE, 2011a, b) and the South African Department of Basic Education (DBE, 2018) has partly linked the under-achievement of South African learners in the sciences to/with issues bordering on the curriculum. The issue of challenges pertaining to curriculum is not peculiar to South Africa. Erstad and Voogt (2018) examined global issues and challenges with respect to the twenty-first century curriculum. In like manner, the Levine Institute (2016) reported about difficulties implementing a Global Ed K12 Curriculum in the United States of America (USA).

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In this chapter, I explore the 'nature/character' in relation to South African teachers' understanding, of the National Curriculum Statement (NCS) Grades R-12, which "represents a policy statement for learning and teaching in South African schools" (DBE, 2011a, b, p. 3). By nature and character, I mean the philosophy, goals and objectives which underpin the NCS, Grades R-12. The policy statement comprises the Curriculum and Assessment Policy Statements (CAPS) for each approved school subject taught in South African schools. This chapter focuses on the NCS, Grades R-12 policy statement which incorporates the CAPS for Grade 9 natural sciences. Venville et al. (2013) reported that "over the last decades, a plethora of reports and position papers have been released arguing the importance of science education not only because a continuing supply of science, mathematics, engineering and technology (STEM) workers are required to fill positions in research and industry but because there is an increasing need for citizens to have sufficient understanding of the science-related complexities of their everyday lives, to participate in decision-making about various local and global issues" (p. 2208). In line with this global trend and phenomenon, the post-apartheid government of South Africa emphasized the significance of "…science and mathematics education as key areas of knowledge competence and human development" (Reddy et al., 2012, p. 620).

Hence, in its effort to redress the inequality of the past, the post-apartheid and colonial government explored various transformations in the educational system in South Africa. This included curriculum transformations in line with "…changing fashions in curriculum policy…." witnessed in many countries (Priestley & Biesta, 2013, p. 92). One major reform in the post-apartheid South African educational context included four transformations in curriculum culminating in the currently used policy statement (NCS, Grades R-12). Notwithstanding, teachers' challenges relating to curriculum are still on the front burner of education in South Africa. Consequently, the curriculum policy, support and monitoring programme was intended to develop "curriculum and assessment policy and support; and to monitor and evaluate curriculum implementation [as] the primary vehicle for ensuring quality delivery of the curriculum in the Basic Education Sector" (DBE, 2018, p. 63). Despite emphasizing challenges regarding curriculum, reports within the South African educational context and other studies may have confined teachers' understanding of the principles which underpin the aims, goals, purposes and aspirations of curriculum to a back seat. Moreover, studies with respect to South African teachers' understanding of the 'nature/character' of the NCS, Grades R-12.are scarce in the literature.

It has been argued that teachers should understand how to incorporate the curriculum (for sciences, as in this chapter) into classroom practice (Sexton, 2017). I view that in incorporating the curriculum into classroom practice, teachers must first understand the aims and objectives or what I call the 'nitty-gritty' of the document. Thus, teachers must understand and be knowledgeable, *ab initio*, about the curriculum they utilize; in order to enable them to implement the document in the classroom. I adopt the Merriam-Webster online dictionary (2019) meaning of the word 'understand' to mean being able to grasp, comprehend or interpret the meaning of something. Hence, the science teacher needs to comprehend the 'foundation' and be able to correctly interpret what the goals and aspirations of the curriculum are, as well as what value it serves, not only for the teacher and learners but to the society where the curriculum emanates from and is located. Barradell et al. (2018) proposed ways of thinking and practicing (WTP) that may "assist educators to think about curriculum in broader ways:" (p. 266). Although teachers' use of curriculum has been a focus of research in science education (Drake & Sherin, 2006), there is a dearth of studies on the 'character' of the NCS, R-12; and importantly in this regard, South African teachers' understanding of their policy document.

Consequently, I ask the following questions:

1. What is the nature of the National Curriculum Statement (NCS), Grades R – 12 used in South African schools?
2. To what extent do natural sciences teachers understand the NCS, Grades, R-12 curriculum and assessment policy statement for grade 9 natural sciences?

2.2 Science and Science Education as Cultural Acquisitions

Science/education is a "complex power/knowledge system that is shaped by the people who form the discourse communities [culture] of education, of science and, more closely, of science education" (Hilderbrand, 2007, p. 45). Science and science education may not therefore be exclusive of the culture within which they are practiced. The DBE (2011b) recognizes that science (and thus science education) is embedded in the cultural matrix; and "has evolved to become part of the cultural heritage of all nations' (p. 8). Each culture thus has its own ways of acquiring knowledge and exploring the 'world of the unknown'. But, what is culture? Culture has been variously described in the literature (Keith, 2011; Gill, 2013), however, the term still "causes much confusion and suffers from its misuse" (SAHO, 2019) notwithstanding a pattern of notable relatedness among the descriptions. The array of conceptions of culture may have arisen from its complexity resulting from the nature and dynamics of social interactions among humans. This is because "each cultural world operates according to its own internal dynamic, its own principles and its own laws – written and unwritten" (SAHO, 2019). The SAHO describes culture as the ways of life of a specific group of people, including various ways of behaving, belief systems, values, customs, dress, personal decoration, social, relationships, religion, symbols and codes.

According to Idang (2015), culture is "often seen as the sum total of the peculiarities shared by a people, a people's values can be seen as part of their culture" (2015, p. 97). Going by this view, one may consider the way science is being practiced within a culture as part of their shared peculiarities. Science is part of people's culture (Iaccarino, 2003) and science is thus influenced by the cultural context within which it is practiced. Invariably, science is imbued with values. Matas (2018) stated that "science as a human activity relates to different human values, and therefore it is capable of ethic valuation, both for its consequences, as for its process and its action". Moreover, Kovac (2006) argued that science is an integral part of human culture and that must not be ignored especially in solving humanity problems.. Ultimately, science teaching and learning (science education) are cultural acquisitions or heritage rooted in the heritage bequeathed to the people (Keith, 2011). Ogunniyi (2015) opined that any educational endeavor or process, including science teaching and learning, is a cultural heritage and a reflection of value systems, beliefs and practices. However, Rosenberg et al. (2010) stated that culture has significant influence on beliefs underlying education, the value ascribed to education, and manner in which people participae in the endeavor. I view that educational endeavors are part and parcel of what forms the culture of the people while educational enterprises also influence cultural developments. In both ways, culture and education impact each other; and construct individuals, families and societies through social transformations.

Furthermore, each culture has its own value system; and hence is value-driven. By being value-driven, I mean each culture is permeated with certain value(s) through social interactions among the people within that culture. Accordingly, the people within such a culture hold the values in high esteem. Essentially, an individual within a 'cultural space' is an embodiment (value-driven) of the value system of that culture. The value system of a particular culture may 'confer' a cultural identity on the people within such culture. Altugan (2015) reported that "learners' [and teachers"] cultural identity plays a significant role in transmission of [certain] values" (p. 1159). Science and science education as social endeavors are value-driven cultural acquisitions through which the value system of a culture may be transmitted. Ultimately, an understanding of the concept of culture; and most importantly how value underpins science and science education; and other related socio-cultural enterprises and endeavors, are fundamental to my discussions in this chapter. Invariably, curriculum, as an educational resource material, which underpins formal science and science education endeavors may be considered to be a value-driven cultural acquisition, as well.

2.3 Curriculum

Curriculum is an "amorphous term, characterized by lack of consensus about its exact meaning" (Maringe, 2014, p. 40). Against the backdrop of "unpacking curriculum controversies" (Cochran-Smith & Demers, 2008, p. 261), curriculum has been described in several ways in the literature (Shulman, 1986; Shillings, 2013; Young, 2014; Penuel et al., 2014; Leoniek & Merx, 2018). Penuel et al. (2014) may have corroborated Shulman's description of curriculum mentioned previously in the introduction of this chapter by stating that, "curriculum materials and knowledge about curriculum purposes and structures are valuable tools that teachers often draw upon to organize instruction and facilitate student learning […]" (p. 751). Hildebrand (2007) viewed the science curriculum as the "bequeathing of a set of cultural practice from one generation to the next" (p. 46). Furthermore, Shilling (2013) posited that curriculum is "central to all the processes and experiences occurring in school settings" (p. 20). These processes and experiences are not devoid of how the teacher is able to use the curriculum in order to meet educational outcomes. It is arguable that a successful usage of the curriculum depends on how knowledgeable the teacher is about the document to achieve teaching outcomes; and this may be used as a measure of the teacher's performance as well.

Curriculum is a "complex phenomenon" (Johnson-Mardones, 2015, p. 125). Pacheco (2012) (cited in Johnson-Mardones, 2015) stated that the complexity of curriculum makes the curriculum a complex as well as controversial endeavor. Hence, curriculum, an essential resource which drives the process of science education, just like the process itself, has its own complexities. While describing curriculum as a phenomenon, an academic field and a design process, Johnson-Mardones (2015) argued that curriculum is actually a multi-dimensional concept. Thus, considering the complexity, controversial and seeming inexhaustibility of its descriptions, I examine curriculum as social facts (Young, 2014) structured in a plan or blue print which contains learning objectives and assessment procedures that inform what guides teachers for the transmission of knowledge in order to achieve an overall educational outcome. Penuel et al. (2014) suggested three important aspects regarding curriculum namely:

(i) The contents, with respect to the 'letter and spirit' of curriculum (Krajcik et al., 2008). This is similar to what obtains in the Law profession where the "letter of the law" is the literal meaning while the "spirit" of the law is its perceived intention Garcia et al., (2014). Penuel et al. (2014) referred to the 'letter and spirit' of curriculum as "curriculum goals and principles undergirding the structures of curriculum" (p. 752).
(ii) The teachers' understanding and knowledge of the curriculum (Shulman, 1986; Davis & Varma, 2008).
(iii) The teacher's implementation of the document (Davis & Varma, 2008). According to Penuel et al. (2014), this is the "integrity of implementation [which is] the degree to which teachers' adaptations of materials is congruent with the curriculum goals and principles undergirding the structures of curriculum" (p. 752).

Different curriculum types have been named, for example, hidden curriculum (Jackson, 1968); ideal, formal, perceived, operational, exponential curriculum (Goodlad, 1979); and explicit, implicit curriculum (Eisner, 1979). Kanbir (2016) posited that "curriculum theorists have identified three different aspects of curriculum [which are] the intended curriculum as represented in local, state-or national-level curriculum standards [..], the implemented curriculum as interpreted and delivered by classroom teachers; and, the attained curriculum, as learned by students" (p. 1). Hildebrand (2007) regarded enacted curriculum as implemented curriculum while he reckoned that realized curriculum is a subset of the attained curriculum. Nonetheless, considering the "contested notion of curriculum" (Hilderbrand, 2007, p. 46), this author teased out two additional 'perspectives' of null curriculum and hidden curriculum. According to Joseph et al. (2000) the null curriculum is "what is systematically excluded, neglected, or not considered (p. 4). Glatthorn et al. (2019) stated that the "hidden curriculum might be seen as those aspects of the learned curriculum that lie outside the boundaries of the school's intentional efforts" (p. 25). Regardless of how curriculum is classified, teachers are the 'end users' in the classroom, hence, their understanding and interpretation of contents of the curriculum becomes paramount. On one hand, a challenge may be teachers' knowledge, understanding or interpretation of what drafters of the curriculum intends in the document (intended curriculum). A successful outcome of this process, on the other hand, may impact how teachers' implement curriculum in the classroom (implemented curriculum).

Congruent with the above discussions, the literature reported problems and challenges associated with the use of the curriculum by teachers. For example, Khoza (2016) stated that "teachers' lack of understanding of the curriculum/teaching visions (teaching rationale/reasons) and goals in teaching a curriculum is becoming a worldwide challenge that needs to be addressed in order to promote quality teaching and critical thinking" (p. 104). In their study, Penuel et al. (2014) concluded that there were differences in "teachers' adaptations with respect to their consistency with the purposes and structures of curriculum materials as construed by designers" (p. 1). Similarly, Penuel et al. found that the teachers had different perspectives of "interpreting the goals and structures of the curriculum" (p. 1); which partly accounted for the way they enacted or implemented the curriculum in the classroom. Moreover, the South African Guidelines for responding to learner diversity in the classroom through curriculum policy statements (DBE, 2011a, b) also recognizes that "one of the significant barriers to learning [and teaching] is the school curriculum" (p. 2). The role of the teacher, as the facilitator of teaching and learning; and 'implementer' of the curriculum in the classroom is very pertinent in this regard. Perhaps in line with this position, curriculum reforms take central stage within educational contexts of many nations of the world, including South Africa.

2.4 Global Efforts on Curriculum Transformations

The International Bureau of Education-UNESCO partnership (IBE-UNESCO, 2017) on global education 2030 agenda stated that "an escalating number of countries have undertaken or are in the process of curricula reforms toward competence-based approaches" (p. 16). This move is paramount as countries world over may have realized, according to Bas (as cited in Baskan & Özcan, 2011), that "three main elements of instruction process [namely] student, teacher and curriculum are the most important cases which guide and shape instruction process in the classroom". Accordingly, a concordant relationship among these three elements impacts the quality of education, including science education. Roblin et al. (2018) reported that "curriculum materials have long been put forward as a vehicle of reform since