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Complexity and Simplicity in Science Education

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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 Julius Ajayi Eyitayo 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 they provide targeted and detailed support for the enactment of specific classroom practices" (p. 2).

Consistent with the above, Roblin et al. (2018) stated that "science education has been the focus of recent reforms around the world; and curriculum reforms are very instructive in this regard". For example, Carlson et al. (2014) stated that new curriculum materials can provide a critical fulcrum for meeting the Framework for K–12 Science Education and the Next Generation Science Standards vision for science learning in the United States of America (USA). This is because research suggests that curriculum resources provide a good background for the development of teachers' science content knowledge (SCK) (Donna & Hick, 2017) and teachers' pedagogical content knowledge (PCK). Shulman (cited in Roblin et al. 2018), described PCK as the knowledge that teachers use in transforming subject matter knowledge into forms that are comprehensible for students. A relevant question may be that, "Does the knowledge referred to include teacher's knowledge of the curriculum or teacher's SCK (in case of science subjects) only?" Similar to a reformed curriculum-driven educational agenda of the USA, England also "introduced a revised national curriculum with an ostensibly more rigorous focus on specific content knowledge in 2014 […]" (Timberlake et al., 2017, p. 46).

Further to the above, the basic education curriculum in China has experienced several major waves of transformations since the People's Republic of China was founded in 1949 (Cui & Zhu, 2014). According to Law (2014), "curriculum reform is China's main human capital development strategy for coping with the challenges of the 21st century, and […] the state plays an important role in the reform of curriculum making mechanisms and in the social distribution of knowledge, skills and dispositions through curriculum making" (p. 1). Also, in its bid to entrench extraordinary technological change, the National Innovation and Science Agenda forms part of the Australian school curriculum. Notwithstanding, Dilkes et al. (2014) reported that certain factors shape Australian teachers' reactions to curriculum reforms which include "lack of support during implementation or how ideologically aligned the rationale of the reform is with a teacher's values and practices" (p. 49).

In view of the above, it is arguable that the curriculum reforms in the above nations reviewed, and elsewhere, may not have been without sociopolitical and sociocultural considerations. Cunningham (2018) believed that curriculum reforms are "largely politically driven (p. 2) [so much that] insufficient attention is paid to the underlying context and culture in which education is delivered, resulting in an aspirational rather than feasible curriculum" (p. 7). Without any doubt, curriculum reforms are often accompanied by complexities (Cunningham, 2018). Priority seems to be given to teachers' SCK and PCK, as far as curriculum is concerned. But I ask 'how much attention is given to 'teachers' curriculum knowledge' (TCuK)'? Law (2014) reported that the realization of the proposed curriculum changes at the school and classroom levels are "constrained by both curricular and extracurricular factors" (p. 16) of which the teacher's understanding of the curriculum is important. The manner in which curricula are "handed down from on high" (Hildebrand, 2007, p. 48) to teachers may seem to suggest that stakeholders within educational contexts assume that teachers fully understand, comprehend and correctly interpret the basic principles, goals and aims of curriculum. This calls to question how fundamental TCuK is to stakeholders within educational contexts. I consider that the lack of support during curriculum implementation, mentioned above may also result from the ‘handing down’ syndrome which tends to put TCuK in an exclusive list. In their study, Yates and Collins (2010) interviewed senior curriculum actors and noted “how rarely ‘knowledge’ came into the frame of their talk about curriculum, compared with a focus on outcomes, politics and management of resources” (p. 89). In line with global trends, and against the backdrop of a colonial and apartheid past, curriculum transformations have also taken a central stage in the educational reforms in South Africa.

2.5 Curriculum Reforms in South Africa – The NCS, Grades R-12

In South Africa, the period 1994–2011 witnessed major curriculum transformations which took place as part of post-apartheid reforms in the educational sector of South Africa. Moreover, educational reforms and curriculum transformations have been a major concern since the establishment of democratic governance in South Africa (Gumede & Biyase, 2016). The introduction of the Outcome-based Education (OBE) in 1994 was to “move away from the apartheid curriculum and to address […] skills, knowledge and values […]” (Mouton et al., 2012, p. 1211). Nonetheless, the OBE initiative suffered some set-backs as a result of various shortcomings including implementation problems; and was eventually scrapped. The first post-apartheid curriculum known as Curriculum 2005 (C2005) was introduced. One of the most important criticisms against this curriculum was that it lacked specific guidelines for its implementation in the classroom by teachers. The review of the C2005 gave birth to the Revised National Curriculum Statement (RNCS). Maringe (2014) reported that “unlike C2005, the RNCS clarified the distinction between outcomes and assessment standards, making the selection of teaching content and assessment criteria a lot easier for educators” (p. 44). Yet, the RNCS was subjected to review partly resulting from implementation issues coupled with poor performance of South African learners in the regional Southern and Eastern Africa Consortium for Monitoring Educational Quality (SACMEQ) tests. From the Revised National Curriculum Statement, the Curriculum Assessment Policy Statement was introduced, resulting into the policy statement, the NCS, Grades R-12, currently used for teaching and learning in South African schools.

The current curriculum enacted for use in schools in South Africa is a culmination of efforts “to transform the curriculum bequeathed to [the nation] by apartheid [and colonialism]” (DBE, 2011b, p. i). It may not be misplaced, therefore, to conclude that curriculum transformations in the South African education context are fraught with complexities. This may not be unconnected with the “inherited racist, divisionary and conservative curriculum” (Cunningham, 2018, p. 5), prior to 1994 before the country's independence. The NCS, Grades R-12 includes the CAPS (Curriculum and Assessment Policy Statements) and contain the relevant topics for all approved subjects in all the phases of the educational trajectory in South Africa. These policy documents direct curriculum and assessment within the primary (grades R – 3), intermediate (grades 4–6) and high schools (Senior (grades 7–9) and Further Education and Training (FET) (grades 10–12)) phases (DBE, 2011a, b). As a developing country, the government of South Africa in overcoming the deficiencies of the previous apartheid regime emphasized the importance of teaching and learning of mathematics and science, Hence, the NCS/CAPS makes natural sciences compulsory for all learners at the Senior Phase (grades 7–9) level (DBE, 2011a, b). The transition from grade 9 to grade 10 is also important for the learners in South African schools because it is in grade 9 that they decide which subjects to study in the FET phase. The Guidelines for Inclusive Teaching and Learning (DBE, 2010) and the Guidelines for Responding to Learner Diversity in the Classroom through the CAPS (DBE, 2011a, b) are also part of NCS initiatives written to enhance teaching and learning in all phases of schooling in South Africa.

Curriculum is *sine qua non* for teachers considering that they are facilitators (Morrison, 2014) or activators (Goodyear & Dudley, 2015) of teaching and learning in the classroom. As 'custodians' of curriculum, teachers' implementation of curriculum in the classroom most likely underpins teacher-learners'[1] engagement (TLE) as well as their (teachers and learners) performance. Alsubaie (2016) stated that "without doubt, the most important person in the curriculum implementation process is the teacher [hence] with their knowledge, experiences and competencies, teachers are central to any curriculum development effort" (p. 106). Yet, little attention may have been drawn to teachers' understanding of the nature, contents, aspirations, principles and purposes of curriculum. This seeming gap can hardly be ignored. It remains in the realm of conjecture how curriculum reform agenda of any nation may be devoid of how the teacher implements the document in the classroom. Hence, according to Doyle (1992) the "translation from institutional and programmatic curricula into actual classroom curriculum can be difficult because the latter is often shaped by teachers' curriculum perspectives and factors shaping classroom context and events". According to Young (2013) it is important to examine limitations of teachers' curriculum choices; and the implications of such on their pedagogies. Considering this, teachers' understanding of curriculum may determine the relevance of the document to them. Hence, teachers' curriculum knowledge selection and subsequent pedagogic implications may be impacted by their understanding of the resource material. It is very doubtful that a consideration for teachers as well as the curriculum may be excluded with respect to educational reforms in any part of the world. However, as influential as curriculum and teachers may be within educational contexts, teachers' knowledge, comprehension; and interpretation of curriculum is vital for both implemented and intended curriculum outcomes.

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[1] In South Africa, the term 'learner' is mostly used rather than 'students' in the primary and secondary schools while the term 'educator' is also used to refer to their teachers.

2.6 Research Background

As part of a larger study which adopted a case study research design (Creswell, 2008), six grade 9 natural sciences teachers were purposively selected from two peri-urban townships schools in a metropolitan school district in South Africa. A qualitative method of data collection using semi-structured conversational interviews (Currivan, 2008) was employed. This allowed the teachers to answer the questions regarding their experience, meaning and perspective from their points of view. I gave unscripted feedback to clarify questions which were not well-understood by the teacher (Currivan, 2008); and the conversational interviews were transcribed verbatim. Document analysis involved content and thematic analyses (Bowen, 2009) of the NCS, Grades R-12/CAPS for grade 9 natural sciences. In order to foreground findings which emerged through excerpts derived during analysis of the NCS, Grades R-12 document, “skimming (superficial examination)” (Bowen, 2009, p. 32) was done for two curriculum documents, namely: (i) ‘Guidelines for inclusive teaching and learning’ (DBE, 2010); and ‘Guidelines for responding to learner diversity in the classroom through curriculum and assessment policy statements’ (DBE, 2011a, b). These guidelines are a “critical and integral component of all NCS initiatives (DBE, 2011a, b, p. 2). Another curriculum-related document known as the ‘pacesetter’ which was mentioned during the interviews was ‘skimmed’ as well. The document analysis was done to have an insight of the underpinnings, with respect to the ‘nature and character’ of the NCS, grades R-12. This provided a platform upon which an exploration and examination of the teachers’ understanding of the policy statement was done. Data analysis was conducted using the framework for thematic analysis proposed by Maguire & Delahunt (2017). The transcripts were scanned thoroughly in the first instance in order to achieve some familiarity. Afterwards, initial codes were generated through a coding process while the themes which emerged were described. The emergent themes form the basis of my discussions to theorize around the goals and aims of my study.

2.7 Findings and Discussions

In this section, I present the findings with respect to the two research

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?

Moreover, I discuss these findings based on two major themes: (a) The nature/character of the NCS, Grades R-12; and (b) teachers’ understanding of the NCS, Grades R-12. These themes are expounded using subthemes to interrogate excerpts (italicized) from the NCS, Grades R-12 policy statement; and responses of the teachers during the conversational interviews. In discussing the themes, I examine the nature/character of the NCS, Grades R-12 in relation to curriculum documents which underpin teaching and learning (of sciences) in other parts of the world. Consequently, I take note of issues related to teachers' understanding of these curriculum policy documents. Firstly, I expatiate on the theme which emerged from the document analysis; and later juxtapose this with my discussions on the theme which emerged from the conversational interviews.

2.8 Research Question 1: The Nature/Character of the NCS, Grades R-12

I present the analysis related to the first question and discuss two subthemes.

2.8.1 Subtheme 1: The NCS, Grades R-12 as a Policy Statement Undergirded by the Constitution of South Africa

The establishment of the NCS, Grades R-12 as an underpinning educational policy statement/document for curriculum and assessment in South African schools is spelt out in the South African Schools Acts, 1996 (Act No. 84 of 1996, as amended) under the sub-heading "Curriculum and Assessment" as stated in the Excerpt 2.1 below:

Excerpt 2.1
The Minister establishes the national curriculum statement [NCS] indicating the minimum outcomes or standards and the process and procedures for the assessment (or examination) of a learner. These apply to both public and independent schools.

Moreover, the Schools Act is established under 'Education', an item (No 29) in the Bill of Rights enshrined in Chapter 2 (Nos. 7–39) of the constitution of the South Africa (1996, as amended) (www.gov.za). Section 7 (Titled 'Rights') under the Bill of Rights declares that:

Excerpt 2.2
This Bill of Rights is a cornerstone of democracy in South Africa. It enshrines the rights of all people in our country and affirms the democratic values of human dignity, equality and freedom.

Fundamentally, the NCS, Grades, R-12 is enshrined in the constitution of South Africa. This constitution is an embodiment of the different sociocultural affinities in South Africa as reflected, for example, in Chapter 1 (Founding provisions), item 6 (languages) of the 1996 constitution (as amended), which recognizes 11 official languages in South Africa.

Considering the above, I regard the NCS, grades R-12 as the ‘grundnorm’ for all curriculum resources used for teaching and learning in South African schools. According to Kelsen (1967), grundnorm is the “basic norm […] which is presupposed in the creation of a constitution [and] can be called the constitution in a logical sense in contrast to the one in the sense of positive law [however] the basic norm is not a positive law itself as it is not created by some legal organ or custom; it is a presupposed starting-point for the legislative procedure” (p. 198–199). I view the NCS, grades R-12 as a ‘constitution’ which informs and guides not only teachers, but all stakeholders in the educational sector; and directs teaching and learning of all school subjects in South Africa. Specifically, I consider section (1) of the NCS, grades R-12, which encompasses the policy statement that undergirds all the approved school subjects in South Africa, as the ‘spirit’ of the law; while the section (2) which addresses teaching and learning pertaining to topics of specific school subjects in South African schools constitutes the ‘letter’ of the law Garcia et al. (2014) refer to the “letter of the law [as] its literal meaning [and] the spirit of the law is its perceived intention” (p. 479) what Penuel et al. (2014) referred to this as “curricular goals and principles undergirding the structures of curriculum” (p. 752). The insight of the teachers with respect to the ‘spirit’ of the NCS, grades R-12 is a focus in this chapter.

In view of the above, and unlike what pertains to South Africa, the Australian curriculum is not located in a Bill of Rights as the Australian constitution has no Bill of Rights (Commonwealth of Australia, 2010). The Australian curriculum emanated from the Melbourne declaration on educational goals for young Australians (Ministerial Council on Education, Employment, Training and Youth Affairs, 2008). The Australian Curriculum, Assessment and Reporting Authority (ACARA), similar to the Department of Basic Education (DBE) in South Africa, developed and administer the Australian curriculum. According to the ACARA (2012), “promoting world-class curriculum and assessment is one of eight interrelated areas for action designed to achieve the Melbourne Declaration goals (p. 5). Although, the American constitution possesses a Bill of Rights (Constitution of the United States), however unlike the South African constitution, neither is the issue of education nor the K-12 curriculum (the curriculum in use in the USA) enshrined in the US Bill of Rights or the US constitution. This is because the “US Supreme Court specifically declared that education, though important,” is not among the rights afforded explicit protection under our Federal Constitution” (Boaz, 2006).

Nonetheless, the Every Student Succeed Act (ESSA) (US Department of Education, 2019), seemingly similar to the South African Schools’ Act, is in place in the USA. The ESSA ensures that every child in the USA is offered the same standard of education regardless of race, income, background, the zip code, or where they live. Education is explicitly enshrined in the constitution of the People’s Republic of China. Yet, neither the issue of education in China nor the curriculum is located in a Bill of Rights. However, unlike what operates in the countries mentioned earlier, the Organization for Economic Co-operation and Development (OECD, 2016) stated that China utilizes a “three-level curriculum model consisting of curricula developed at the national level, regional level and school level [with] the central government, local authorities and schools developing the most suitable curriculum for the local context [while] at the national level, the Ministry of Education produces the curriculum plan for elementary and secondary education […]" (p.). In the next section, I consider the second sub-theme regarding the nature/character of the NCS, Grades R-12; and later connect my discussions on the two subthemes.

2.8.2 Subtheme 2: The NCS, Grades R-12 as a Culturally-Oriented Value-Driven Policy Statement/ Document

The NCS, Grades R-12 is a culturally-oriented, value-driven document underscored by the values inherent in the Constitution of South Africa. This view is underscored by Excerpt 2.3 stated under section 1.3(c) of the NCS, Grades R-12 (DBE, 2011a, b).

Excerpt 2.3

The National Curriculum Statement, Grades R-12 is based on the […] principle of valuing indigenous knowledge systems: acknowledging the rich history and heritage of this country [South Africa] as important contributors to nurturing the values contained in the constitution.

Congruent with Excerpt 2.3 above, Motshekga (2011) asserted in Excerpt 2.4 below that:

Excerpt 2.4

From the start of democracy, we have built our curriculum on the values that inspired our constitution (Act 108 of 1996).

The excerpts below (Grouped as Excerpt 2.5) derived from the NCS, Grades R-12 under sections 1.3 (a), (b), (c) and (e) (General aims of the South African curriculum) (DBE, 2011a, b, p. 4) further affirms the value-driven nature of the policy statement.

Excerpt 2.5

(a) *[Giving] expression to the knowledge, skills and values worth learning in South African schools (Emphasis author's)* (DBE, 2011a, b, p. 4).

(b) *[Serving] the purpose of: equipping learners, irrespective of their socio-economic background, race, gender, physical ability or intellectual ability with the knowledge, skills, and values necessary for self-fulfillment and meaningful participation in society as citizens of a free country* (DBE, 2011a, b, p. 4).

(c) *[…] human rights, environmental and social justice: infusing the principles of social and environmental justice and human rights as defined in the Constitution of the Republic of South Africa.*

As indicated in (b) above, I particularly note that the NCS, Grades R-12 requires that South African teachers 'equip' learners with values inherent in the constitution through the teaching and learning of the approved subjects (sciences as in this chapter).

From the above excerpts, I consider the NCS, Grades R-12 as a value-driven cultural acquisition. The injustices resulting from the introduction of Bantu education within the South African educational sociocultural context during colonial and apartheid regimes have been reported (Ndimande, 2013). Hence, considerations for a culturally responsive (Gay, 2002) and culturally relevant (Aikenhead & Jegede, 1999) value-driven science teaching and learning are pertinent for a South African society. Handa and Tippins (2012) reported that this kind of science teaching and learning takes into consideration the “creation of practicing culture of science, socially mediated knowledge and the inclusion of indigenous science or local knowledge in science classrooms” (p. 1202). In the same vein, Bryan and Atwater (2002) expressed the need for culturally sensitive curriculum resources that may be locally sourced. Breidlid (2009) argued that when the nature/character, with respect of the “languages and the culture of the majority of the people are more or less excluded from the curriculum in the country, it does something to the self-confidence and self-esteem of those people besides the obvious learning challenges it creates in school” (p. 147).

Congruent with the above views, I consider that the Australian curriculum also values a culturally-oriented value-driven curriculum. The Melbourne declaration on educational goals for young Australians, cited earlier, stated that “as a nation Australia values the central role of education in building a democratic, equitable and just society— a society that is prosperous, cohesive and culturally diverse, and that values Australia’s Indigenous cultures as a key part of the nation’s history, present and future” (Ministerial Council on Education, Employment, Training and Youth Affairs, Melbourne Declaration on Educational Goals for Young Australians, 2008, p. 4). The perspective of the importance of a culturally sensitive and culturally relevant curriculum resonates all through the Australian curriculum. The ACARA (2012) stated that, as contained in the Melbourne Declaration, one of the three key areas prioritized by the Australian curriculum is the “the Aboriginal and Torres Strait Islander histories and cultures [which] provides opportunities for all learners to deepen their knowledge of Australia by engaging with the world’s oldest continuous living cultures” (p. 18).

Similarly in China, the basic education reform prioritizes the cultivation of culture; and also emphasizes on value and skills development as key components of the curriculum (OCED, 2016). Bernard (1991) stated that “in traditional China, culture was an unself-conscious experience [and] traditional schooling had no subject,” Chinese culture, “but, rather, those cultural components that the literati considered the most important constituted the entire curriculum” (p. 650). Wang (2006) had also argued that for a successful Chinese culture curriculum planning, factors such as cultural milieu of the students, character of culture; and sociocultural context within which the curriculum is applied, are very vital. It has also been reported that attempts have been made to integrate Chinese culture into Chinese curriculum (Nord Angelia Education, 2018). In the US, attempts had been made to introduce the African-American curriculum into the school curriculum throughout the grade levels. The report of one of the task forces appointed in a school district to investigate this problem stated, in the Evaluation Document (cited in Soudien, 1996, p. 45) released, that African and African-American history are a must in terms of their educational, social and moral value for all students. Such course offerings should span the entire curriculum and not be limited to social studies and language arts classes. Barnhardt (2007) reported on the Philadelphia Parkway program otherwise known as the "school without walls" (p. 24). This program implies that students and teachers engage in a process of creating their own curriculum considering the framework of the culture of the school district. In this way, a synchronization of the school and community culture of the school district is achieved.

In view of the above, I conclude on theme 1 that the NCS, grades R-12 as a policy statement located in the Bill of rights of the constitution of the RSA, itself is a value-driven document, is value-driven. . Besides, the first point on the preamble of the constitution of the RSA states that the document is adopted so as to "heal the divisions of the past and establish a society based on democratic values, social justice and fundamental human rights" (Constitution of the RSA, 1996, as amended). Deacon (2018) stated that "'culture represents aspirational values and principles that underlie the Bill of Rights and the new system of devolved, democratic governance" (p. 171). Hence, I consider that the NCS, Grades R-12, in similar circumstance like curricula of nations considered above, as a cultural; acquisition which reflects the value-driven cultural affiliations of the South African society. Consequently, since "values infuse all perspectives on the curriculum […] (Hildebrand, 2007, p. 58), the NCS, grades R--12, as an educational resource, is value-driven. Hildebrand (2007) stated that "values have always been explicitly and/or implicitly taught through the science curriculum because the curriculum is ever a value-free zone" (p. 16). The NCS, grades R-12, CAPS for grade 9 natural sciences, as a cultural acquisition, is diversified in the sources of values embedded in it, with the community, science and education acting as contributing domains.

I argue that the strength of the NCS, grades R-12, lies in its purpose of 'equipping' learners with values (DBE, 2011a, b, p. 4) enshrined in the constitution of the RSA, through teaching and learning of all the approved subjects (natural sciences in this chapter). I contend that the policy document may not have explained what this meant or how teachers may achieve the purpose through teaching and learning of the sciences. Therefore, teachers may have been left to use their discretion in understanding and interpreting this requirement of the policy statement. Maringe (2014) observed that, regarding curriculum use within the South African educational context, "[…] space was opened up among educators and administrators to interpret it in a variety of ways" (p. 44). Although, a thorough analysis of the curricula documents of the nations mentioned above may not have been achieved in the study leading to this chapter, a challenge of how teachers understand and interpret their curricula may be implicitly inherent. I regard a central focus of the NCS, Grades R-12 of 'equipping' learners with value to mean that teachers are to teach the recommended topics in all school subjects (grade 9 natural sciences in this chapter) in a way that imbues the learners with values enshrined in the constitution of the RSA.

I argue that, through this process of ‘equipping with value’ “learners [are] expected to demonstrate the values of a democratic society; the sanctity of life; equality; human rights; and social justice [including] values of independence, life-long learning, respect for the environment, and critical and active citizenship …” (Maringe, 2014, p. 43–44). These values serve as key indicators of the type of learners, intended through curriculum, who could participate meaningfully “in [the South African] society as citizens of a free country” (DBE, 2011a, b, p. 4). By this, the NCS, Grades R-12 reflects what South Africa wants to pass on to the next generation. I consider the teachers’ understanding of the purpose of the NCS, grades R-12 with respect to ‘equipping’ learners with values (DBE, 2011a, b) as a central focus of the NCS, Grades R-12. In the next section, I use these deductions to explore teachers’ understanding of the NCS, grades R-12.

2.9 Research Question 2: Teachers’ Understanding of the NCS, Grades R-12

I discuss this the findings related to this research question under two subthemes.

2.9.1 Subtheme 1: Teachers Conversance with the NCS, Grades R-12

The teachers’ responses regarding their use of the NCS, Grades R-12 suggest that they were not conversant with the policy statement going by the quotes below.

> Hmm (humming and trying to figure what to say), Yes, I can say I have gone thru the curriculum because you can’t use just the textbook and other materials, you first have to go through the curriculum to see what must be taught otherwise you end up giving information which not relevant to learners …. I deal majorly with the pace setter
> I am not very familiar with what could be the contents
> Yes, mostly last year during my studies but I still do go back to it ….
> We do use the CAPS but not that much. I cannot do everything in the document.
> I use both [the CAPS and pace setter].
> Basically we use the pacesetter and the exam guidelines … I deal majorly with the pace setter.

However, from the above responses, I deduce that the teachers may not have been conversant with the NCS, Grades R-12 document but rather familiar with another document referred to as the ‘pacesetter’. This is an abridged form of the NCS, Grades R-12 but which contains only the topics for grade 9 natural sciences, including the specified dates during the term for teachers to start and complete teaching the topics. The contents of the ‘pacesetter’ for grade 9 natural sciences indicated that it gave priority to the topics; and how they have been scheduled for teaching within specified periods during the term. Thus, the ‘pacesetter’ was more agreeable with section (2) of the NCS, Grades R-12; and may not be seen as in full consonance with the intricate details of section (1). The pacesetter paid less attention to the underlying principles of the NCS, Grades R-12 on how it directs that the topics in natural sciences be taught in the classroom. I consider that the pacesetter paid more attention to teacher's SCK through emphasis on the science topics to be taught; and teacher's PCK on how the topics may be taught. That the pacesetter may have been 'handed down from on high' for teachers must-use resonated in the responses of all the teachers. However, one of such more resounding responses, in this regard, is reflected in the quote below:

> The department places much emphasis on the pacesetter and how the curriculum can be covered. ….So maybe it's because these directors are political appointees and they do not really care about what is going on in the classroom. All they are interested in are the results which they are going to give them political mileage.

2.9.2 Subtheme 2: Teachers' Understanding of the Value-Driven Nature of the NCS, Grades R-12

The teachers' responses to questions related to value as it relates to the NCS, Grades R-12, especially with respect to 'equipping' learners with values inherent in the South African constitution, are as shown in the following excerpts of quotes below:

> Can't remember, but I know it [value] does exist there.
> …would find it a bit of a challenge when we talk of value in line with the curriculum.
> I can't remember.
> It is not stated in the pacesetter……
> Since we use the pacesetter most times, I have not come across such……
> I am not sure that I once saw it in the pacesetter

The responses above may be taken as a confirmation that the teachers hardly or never used the NCS, Grades R-12 policy statement as professional teachers. The issue of the concept of value is prominently expressed in the policy document and may not have been missed, if the teachers were conversant with the document. Moreover the document specifically directs that learners should be "…equipped with values […]" (DBE, 2011a, b, p. 4). None of the teachers were aware of this requirement of the NCS, Grades R-12. However, for further confirmation on the teachers' conversance or non-conversance with the policy statement, their engagement with the NCS, Grades R-12 during pre-service training was explored. The responses below, in this regard, suffice:

> I did not specialize in curriculum studies hence it was not our basic priority…
> We majorly dealt with the contents…. as in the topics in the curriculum…
> As a student in the science division, I was taught how to teach the science topics
> May be a deeper insight into the curriculum may have been valuable
> My basic training in education was not in South Africa…

The above responses are suggestive of the possibilities of a non-engagement or superficial exploration of the NCS document, during the pre-service training of the teachers. As science-inclined pre-service teaches, their pre-service training may have involved only PCK of sciences and not a detailed in-depth exploration on the philosophy, nature and character of the curriculum. That three of the teachers did not have their basic preservice training in varsities in South Africa may have also contributed to this seeming gap. As professionals, the teachers may therefore not see any need of the NCS, Grades R-12 especially when they are provided with an abridged and of-not-much-detail version of the policy statement. This view may confirm why/that the teachers were more familiar with the 'pacesetter' document; and may not have come across or understood 'equipping with values" as specified by the NCS, Grades R-12 document.

Therefore, the teachers may seem to understand the 'letter' of the NCS, grades R-12, through their constant use of the 'pacesetter' but not the 'spirit' of the policy document, as earlier expounded under theme (1). Congruent with the 3 layers of curriculum expounded by Khoza (2016), I argue that the teachers may not have understood the first layer which is the "intended/planned/prescribed/official/formal curriculum, which is a written policy of ideas that are framed by educational vision with goal/s and intentions of the teaching/learning curriculum (belongs to managers/developers)" (p. 1). However, I view that the teachers may be placed on the second layer of curriculum which is "implemented, enacted, or practiced curriculum (also known as curriculum in action), which is the interpretation of the intended curriculum as perceived by teachers and the actual process of teaching in operation (belongs to teachers)" (Khoza, 2016, p. 1). In essence, there may inevitably be a "gap between the intended and enacted curriculum that is, between how designers intend for teachers to use curriculum materials to plan and lead instruction, and what teachers in fact do" (Penuel et al., 2014, p. 752). Similarly, Shilling (2013), reported that there is a "significant difference between the official, written curriculum developed by experts and the actual curriculum taught in the classroom because teachers, working autonomously, make different choices regarding curriculum and instruction based on their knowledge, experiences, and the realities of their classrooms" (p. 20). Moreover, none of the teachers in my study was aware of the availability of any guidelines on diversity and inclusivity, mentioned earlier. These guidelines contain certain information which may guide teachers with respect to understanding the basis of the NCS, grades R-12.

Pantic and Wubbels (2012) argued that, there has not been sufficient attention paid to the issue of value during teacher education. Pantić (2008) showed that the issue of value is not dealt with in a clear and detailed manner in teacher preparation programs.

O'Flaherty et al. (2018) not only reported on the concerns for incorporation of societal value in curriculum documents but also on how it is taught within teacher education. Teachers' understanding and knowledge of the curriculum (Shulman, 1986; Davis & Varma, 2008) has been found to impact learners' performance. 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). I argue that the teachers' non-familiarity with the NCS, grades R-12 suggests that they may not have understood the policy statement *ab initio*. I contend that as science teachers, their pre-service training may have not considered a proper and thorough exploration of the NCS, Grades R-12. Efforts towards professional teacher development programs for in-service teachers may not have also included TCuK. Mouton et al. (2012) posit that curriculum implementation problems may be a result of limited curriculum development for teachers. As germane as the teachers' responses may have been, I presume they may not totally resonate with the intention of the NCS, grades R-12 concerning 'equipping' learners with values. As such, learners are expected to be imbued or instilled with the values inherent in the constitution through teaching and learning of the approved school subjects. As previously argued, I reiterate that the NCS, document may not have explicitly explained how teachers should 'equip' learners with values through teaching and learning of natural sciences. In addition, the teachers' non-familiarity with the NCS, Grades R-12, as previously argued may have further diminished their understanding of this vital purpose of the policy document.

2.10 Conclusions and Recommendations

This chapter seeks to provoke awareness towards the need for stakeholders within educational contexts globally to focus attention on the extent to which teachers understand, comprehend and interpret curriculum materials. Despite the inherent complexities and simplicities, the importance and global attention on science and science education, mostly in the face of the sustainability 2030 agenda, may be instructive in this regard. Against the backdrop of curricula reforms, which in themselves are fraught with complexities, nations need to be informed that teachers' disposition towards reforms is influenced by their willingness to effect such changes; and most importantly their capacity to do so. It is plausible that teachers' ability to carry out or implement curricula reforms depends on how knowledgeable they are with respect to 'deeper' underpinnings of the curricula within the context in which they are operated. A seeming misconception may be that teachers only need to have content knowledge of topics spelt out in curriculum documents. However, curriculum documents, usually accompanied with simplicities, may be more complexities of the contexts within which they are utilized, seem to entail more underlying complex details, than 'meets the eye', with respect to their nature/character, philosophy, purposes and aims. In this respect, for example, the NCS, Grades R-12 emerged as a result of efforts geared towards ameliorating the injustices meted on, especially 'blacks', during apartheid and colonial rules in South Africa. Hence, the policy statement requires that teachers 'equip' learners, through teaching and learning, with values enshrined in the post-apartheid constitution of a country referred to as the 'rainbow nation'. According to Buga (2015), the "Rainbow Nation was described by [Archbishop Desmond] Tutu to encapsulate the unity of multi-culturalism and diversity of South African people" (p. 1). This term was further reechoed by Nelson Mandela when he became the first democratically elected President of South Africa in 1994. Similarly, the Melbourne Declaration, which undergirds the Australian curriculum, prioritizes students' knowledge about Aboriginal and Torres Strait Islander histories and cultures. An important question, however, is "To what extent do teachers within these mentioned educational contexts understand or are knowledgeable about these 'knitty-gritties'? The urgent need for global attention to interrogate this puzzle is corroborated and proposed by the arguments and summations in this chapter. Penuel et al. stated that there are differences in "teachers' adaptations with respect to their consistency with the purposes and structures of curriculum materials as construed by designers [while] teachers different approaches to interpreting the goals and structures of the curriculum unit partly account for patterns in their enactment in ways that can inform refinements to materials and the design of professional development supports for teachers" (p. 751).

I suggest that efforts should be geared towards bridging the seeming gap between intended and implemented curriculum through better teacher understanding of curricula documents. Notwithstanding reports which have implicated teachers' curriculum implementation with respect to learners' poor performance in the sciences, in South Africa and other parts of the world, I argue that understanding the curriculum precedes its implementation. Teachers draw inspiration, for curriculum implementation when they understand, comprehend and interpret its principles correctly. Considering its colonial and apartheid history which negatively impacted education, including science education, coupled with curriculum transformations, teachers' understanding of the NCS, Grades R-12 is non-negotiable within the South African educational context. This is because as a policy statement entrenched in the country's value-driven constitution, the correct implementation of the NCS, Grades R-12 is premised upon teachers' understanding of its value-driven underpinnings. Khoza (2016) corroborated this view by stating 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). Through curriculum alignment, teaching and learning outcomes may be realized when learners' experiences are impacted by teachers' knowledge of curriculum structure and content (Leoniek & Merx, 2018).

Congruent with the above, I consider that the strength of the NCS, Grades R-12, just like curricula globally is hinged on certain value-driven philosophies which are not disconnected from the sociopolitical and sociocultural underpinnings of such contexts. As a policy document which is enshrined in the value-driven Bill of Rights entrenched in the value-driven constitution of South Africa, the NCS, Grades R-12 requests that learners be equipped with values inherent in the constitution. This is fundamental against the backdrop of the country's history of a tortuous journey of colonial and apartheid rules prior to democratic governance which now intends to heal the divisions of the past to establish a society based on democratic values, social justice and fundamental human rights" (RSA constitution, 1996, preambles). One of the most important ways to achieve this is, is for teachers to understand how to 'equip' learners with values through the teaching and learning of natural sciences (as in this chapter). Through this, learners who are embodiments of 'constitutional values' necessary for "self-fulfillment, and meaningful participation in society as citizens of a free country" (DBE, 2011a, b, p. 4) may have been trained. Although the teachers in the study responded in manners which suggest that they had ideas on what 'equipping' with value might mean, the NCS, Grades R-12 seem not to have clearly stated what this meant or how teachers may achieve this essential purpose of the policy statement.

In this chapter, I examined the culturally-oriented value-driven nature or character of three international educational contexts. Through curriculum resources students are enculturated with values inherent within social contexts in which such resources are utilized. This process has its own simplicities and complexities regarding curricula. However, Pantić and Wubbels (2012) reported concerns regarding less attention that is paid to the issue of value during teacher education. Pantić (2008) showed that the issue of value is not dealt with in a clear and detailed manner in teacher preparation programs. The concern for incorporation of societal value in curriculum documents; and also on how it is taught within teacher education has been a concern within educational circles. I propose that teachers' understanding of how to equip learners with values through teaching and learning of science is sacrosanct within all educational contexts since each society has its own complex value system. I suggest that an insightful exploration of curricula is considered as part and parcel of the syllabus of teacher training institutions globally. It is arguable that non-familiarity or non-knowledgeability of teachers about curricula may be traceable to gaps with respect to non-engagement with curricula or its superficiality during preservice training. I propose that for proper understanding of the NCS, Grades R-12 or any curricula, professional development for in-service teachers in South African schools and around the world should be pursed vigorously. I conclude with the words of Barradell et al. (2018) below:

> Curriculum is more than content to be covered. It is more than learning outcomes, constructive alignment, assessment or the technical aspects of how academics teach. It involves the students' experience of learning, but it is more than that too. Curriculum should be understood in a broad and dynamic sense to include purpose, content, alignment, scale, learning activities, assessment, physical environments and learning collaborators (p. 266).

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Chapter 3
Teacher Retention: Supporting Early-Career Science Teachers

Merryn Dawborn-Gundlach

3.1 Introduction

The practices and approaches presented in Initial Teacher Education (ITE) programs which support a positive transition and adjustment are important in ensuring that early-career teachers are not part of the increasing number of teachers leaving the profession. The transition phase from pre-service to early-career teacher can be difficult and the support that is provided both in their Initial Teacher Education program and in the school in the early months of teaching, is crucial in assisting a positive adjustment. This study investigated how the teaching and learning approaches presented in an ITE program in a large university in Australia supported early-career teachers in their first months teaching science subjects in secondary schools.

There has been significant research considering the effectiveness of ITE programs; however, the success of the programs as indicated by the quality of the transition from pre-service to early-career teacher has been less widely studied (Luft, 2007). This small-scale study of 15 early-career teachers investigated the support identified by participants as aiding a positive transition and successful adjustment to teaching.

In the context of education, transition has been defined as a period of significant adjustment, development and change, affecting all spheres of students' lives (Kantanis, 2002). A positive transition has implications for new teachers as they make the adjustment to become confident, independent and able to accept the challenges of the teaching experience. Failure to make the adjustment can have financial consequences for teachers and a loss of investment to schools and ITE providers. It may also have devastating effects on self-esteem and leave teachers unprepared for the job of teaching. Teacher shortages, due to attrition, particularly in difficult to

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staff areas such as science and STEM are a further implication of an unsuccessful adjustment to teaching.

The formal and informal support processes provided to early-career teachers in their first months of teaching are instrumental in the quality of their transition. Buchanan et al. (2013) identified collegiality and support as making "a substantial difference to their ability to manage their teaching" (Buchanan et al., 2013, p. 118). The conflict between expectations and the reality of teaching, the quality of initial teacher education programs (Mason & Matas, 2015), and the continuing nature of teacher education, post ITE programs, have also been shown to affect the quality of adjustment and subsequent teacher retention (Mason & Matas, 2015; McLean-Davies et al., 2013). In addition, the requirement to teach 'out of field', due to teacher shortages in some subjects, has caused early-career teachers additional anxiety in the requirement to prepare and teach content with which they are unfamiliar (Mason & Matas, 2015).

While many schools have induction programs in place which enable familiarisation with the school culture, early-career teachers also require an induction to teaching practice and how to establish a professional presence in their schools and classrooms. The first weeks of the school year are crucial in setting the tone and establishing a professional identity in a school (Buchanan et al., 2013). Early experiences can significantly affect new teachers' attitudes and self–confidence in their ability to manage the complexities and difficulties of adjusting to teaching, including lesson-planning, classroom management, professional development and integration into the school community. The ability to cope "with the clash between expectations and the realities" (Buchanan et al., 2013) and apply the pedagogy learned to classroom practice, can be overlooked in the urgency of the new school year. Challenges such as being required to teach 'out of field' to meet teacher shortages, especially in mathematics and science subjects, can further complicate the adjustment process (Kenny & Hobbs, 2015), lead to difficulties with teacher identity (Hobbs, 2013), and other intrinsic issues such as motivation, satisfaction, and commitment (Beswick et al., 2016; Cinkir & Kurum, 2015).

Research has questioned the relationship between a teacher's early work experience and a positive and future-focused career outlook. With evidence that much of their learning occurs in the first two years of teaching, teacher professional development is a shared and ongoing responsibility between ITE providers and the school, as the impacts of learning are experienced not only by early-career teachers but also their students (McLean Davies et al., 2013).

Opportunities for developing professional skills and competencies, such as microteaching (Koross, 2016) provide ongoing support and enhance teaching confidence (Wangchuk, 2019), while formal and informal mentoring can establish best practice, especially if modelled by proficient and experienced teachers (Mason & Matas, 2015). In addition, providing release time to observe experienced teachers can assist early-career teachers to find their professional identity (Buchanan et al., 2013; Mason & Matas, 2015). New science teachers are "quick to discard the pedagogy and professional practice they learn in teacher education" (Hutner & Markman, 2017, p. 10) and the processes and methodologies of teaching once in their own science classes (Hsu, 2016; Hutner & Markman, 2017). The limited time pre-service teachers spend in front of a class can contribute to the 'theory practice divide' (Britton & Tippins, 2014) as their ability to practise the techniques and approaches developed in their ITE program is limited. Linking theory to practice is more difficult when practice time is both condensed and disconnected over time. Pre-service teachers' school placements do not usually highlight the problems of a lack of commitment to shared goals (Mikeska et al., 2009) or teaching 'out of field' (Nixon et al., 2016).

The complexity of teaching is not in the understanding of subject-related knowledge for the teacher, or pre-service teacher, but in knowing how to help the students in their classes learn and understand (Shulman, 1986). In addition to providing feedback, testing, reporting and classroom management, teachers have a responsibility to simplify complex processes into skills, knowledge and understanding that are more accessible to the learner. In educating pre-service teachers, ITE providers should model best practice in breaking down the complex processes of teaching, into simpler structures, thus supporting pre-service teachers through their transition and adjustment to proficient early-career teachers. This study provides an insight into the transition experiences of pre-service to practicing science teachers in Australia and highlights the features of their ITE program that supported their adjustment to becoming proficient, practicing science teachers.

3.2 Context of the Research

In addition to the core subjects that pre-service teachers study in their Master of Teaching ITE course, students are enrolled in two learning area subjects. This study examines the pedagogical approaches presented in the science-related learning area subjects of Biology, Chemistry, Physics and Science. Subject tutors provide pedagogical approaches and model best practice to develop effective teachers and enhance student learning in the science classroom (AITSL, 2015). This study evaluates the support and impact of their learning area subjects on early-career teachers' first semester in the science classroom.

The research questions guiding this study were:

1. How well did ITE science learning area subjects prepare pre-service teachers for their first year of teaching?
2. What further support was required by early-career teachers in their first year of science teaching?

3.3 Participants

The sample was 15 early-career science teachers, in their first year of teaching in 2017, who had been enrolled in one or two science learning area subjects in 2016. An email invitation was made to all eligible applicants and participation in the study was strictly voluntary. Ethical approval was granted for the study and participants were informed that the study and data analyses were conducted purely for research purposes. Participants provided their consent for the researcher to share their responses and were assured that responses would be de-identified. The survey was completed by the participants toward the end of their first semester of teaching.

The majority of participants were female, reflecting current trends in Australian schools (Australian Bureau of Statistics, 2016). Participants were between 20 and 29 years of age. Twelve of the participants were employed in government schools and three in independent schools in a capital city in 2017. All participant schools were in the metropolitan area except one, which was located in a regional town within 100 kilometres of the metropolitan area. In 2016, seven participants had been enrolled in the Biology learning area subject, three in Chemistry, two in Physics and 12 in Science. Nine of the 15 participants were enrolled in two science learning area subjects. Participant demographic information is presented in Table 3.1.

3.4 Methodology

Participants were asked a set of eight pre-determined questions by the researcher. Although they were given the option of doing this in person, by telephone or email, all but one preferred to answer the questions using email.

The eight questions asked of the participants were:

1. How well did your science learning area workshops and the Combined Science program* support your transition to teaching?
   (*The Combined Science program is a series of workshops that supports the teaching of Years 7–10 Science. All students enrolled in science learning area subjects in 2016 participated in this program.)
2. Which aspects of your teaching do you consider would have benefitted from further support in workshops and the Combined Science program?

Table 3.1 Participant demographic information

<table>
<tr><td>Gender</td><td colspan="2">Female</td><td colspan="2">11</td><td colspan="2">Male</td><td colspan="2">4</td></tr>
<tr><td>Age</td><td colspan="2">20–29</td><td colspan="2">11</td><td colspan="2">30+</td><td colspan="2">4</td></tr>
<tr><td>Type of school</td><td colspan="2">Government</td><td colspan="2">12</td><td colspan="2">Independent</td><td colspan="2">3</td></tr>
<tr><td>Geographical location of school</td><td colspan="2">Metropolitan</td><td colspan="2">14</td><td colspan="2">Regional</td><td colspan="2">1</td></tr>
<tr><td>Science learning area subjects</td><td>Biology</td><td>7</td><td>Chemistry</td><td>3</td><td>Physics</td><td>2</td><td>Science</td><td>12</td></tr>
</table>

Note. Nine participants were enrolled in two science learning area subjects

3. How well have you been able to link the theory and coursework you studied in 2016 with your classroom practice in 2017?
4. How well have the teaching skills modelled in your learning area workshops in 2016, supported your transition from theory to practice in 2017?
5. How well did the workshops prepare you for:
   (a) Getting to know your students and how they learn;
   (b) Knowing the content and how to teach it?
6. How well did the workshops prepare you for:
   (a) Planning for effective learning;
   (b) Creating and maintaining a supportive and safe learning environment;
   (c) Assessing, providing feedback and reporting on student learning?
7. What suggestions do you have for improving the contribution of the workshops and program for future teachers of science?
8. Do you consider that you will stay in the teaching profession for the next 5–10 years?

Questions 5 and 6 specifically addressed two of the Australian Professional Standards for teachers (AITSL, 2015). Both professional knowledge and professional practice are important as pre-service teachers bridge the theory-practice divide to develop as successful early-career teachers.

Participant responses were classified according to emergent themes, using an inductive approach (Thomas, 2006). For each question, themes were determined and tallied to identify the number of mutual responses. Response frequencies and specific participant responses reflecting general themes are identified in the next section.

3.5 Findings

The reflections of the 15 participants at the end of their first semester of teaching, as they considered the level of support that their ITE learning area subjects provided them in making the transition from pre-service to early-career teacher, can be classified under four broad headings.

3.5.1 Support for Transition to Teaching

All 15 participants considered that the workshops they attended as pre-service teachers supported their transition to teaching science subjects in secondary schools. The features of the workshops regarded as most helpful were the modelling of different pedagogical approaches (7 responses), the resources provided (4 responses) and the practical activities demonstrated by workshop leaders (4 responses), as illustrated in the following responses.

> Reflecting on my experience so far, the modelling of good teaching practices by the science teaching staff has been extremely useful. For example, seeing how an expert teacher starts a class, uses questions, maintains professional demeanour, structures a class, engages with students, uses classroom discussion, runs small group activities and wraps up a class was invaluable. I have found I had internalised many of the approaches I observed last year.
>
> I feel this (the workshops) were the strongest part of the program. Often when I experience an issue in the classroom I think of how a similar issue was handled in the science workshops.
>
> Apart from all the practical activities and the weekly demonstrations, which I use all the time, the unit planning assignment was really helpful. I have to plan all of my units at my school.
>
> It has been very beneficial to observe how many other teachers approach their practice and during these workshops I was able to gain ideas for what to do when I am at the front of the class. When teaching at school, there is rarely the time to observe other teachers and understand their approach. Some of the content taught in the Combined Science workshops was particularly helpful to have a teaching professional both teach it to me and give me ideas about how to teach it to students.

Combined Science workshops relating to identifying and overcoming student misconceptions (3 responses), unit planning (3 responses) and microteaching (teaching small groups of students with a partner prior to placement) (3 responses), were also identified as supporting the transition to science teaching.

> The workshops were very beneficial to targeting areas in which I was lacking expertise. I particularly benefitted from knowing possible student misconceptions and breaking down topics to link to prior knowledges that students might have.
>
> The science workshops encouraged me to conceptualise difficulties in understanding something as a misconception that can be corrected with effective teaching. It also taught me to search for these misunderstandings and be careful to present students with material that flushes misconceptions out if they are present.
>
> The number one thing that stuck with me and helped me with my transition was the microteaching. Working with another science learning area student for a small group of Year 8 students helped to bridge me from being an introverted lab technician into a performing teacher. Even now in Term 2, I still get the jitters standing in front of a class, but having that taste with a small group, preparing lessons, going back and getting feedback from the students, figuring out HOW to teach was a great way to start the course.

When considering how well their science workshops prepared them for getting to know their students and how they learn, four participants did not consider that this was directly addressed in either learning area or combined science workshops, although they conceded it had been discussed in core subjects in their course. Other participants indicated that workshops did provide ideas and activities to support this AITSL professional standard (4 responses).

> It was a big step for me to understand how little students know and how to teach without using language that is hard to follow or relate to. I found that the teaching professionals in this course were able to explain how to teach skills such as dissections and knowledge such as the history of the universe in a manner that had a nice flow and spoke in straightforward language that I could mimic and use in my classroom.

> We did lots of different activities that suit all types of learners and I found this to be really important. It is hard to imagine sometimes that other people learn differently to yourself.

Workshops focusing on student misconceptions in science and how these can be addressed were considered useful by two participants in understanding how students learn.

> One workshop I am really grateful for was the Misconceptions in Science workshop. It has come up time and time again this year where students have had the exact misconceptions we spoke about in this workshop and I knew exactly how to identify and address them.

Responses relating to the level of preparation science workshops provided for knowing the content and how to teach it, reflected the dilemma of workshop leaders in teaching Year 7–10 science content knowledge. Eleven participants appreciated that the focus of workshops should be pedagogy rather than content.

> Obviously, most of my content knowledge comes from my own education, but science workshops helped to refresh my memory and to see ways to teach them.
>
> This is an interesting question given the teaching of content was largely not covered in the course. However, fluency with the material was regularly modelled by the teaching staff. I work outside school hours to ensure I have the required knowledge accessible in my mind when in the classroom. I feel that pedagogical approaches to teaching science in general were favoured over content knowledge.
>
> It is reasonable to conclude that we are going to struggle outside our key learning areas to teach across such a broad subject like science. I think that many of the resources that were shown to us during the workshops were exceptionally helpful as sometimes knowing where to look is the most valuable knowledge.

Three participants considered that content was not explicitly addressed; however, two responses indicated that this was not too much of a concern.

> (Content was not addressed) particularly well but I don't begrudge them for that. The body of knowledge covered in junior science doesn't really surprise or bother me.
>
> I felt that school placements gave the main lesson in this area.

Planning for effective learning was also appreciated by participants who were unanimous in their appreciation of the support provided for developing effective learning (13 responses) with unit planning (4 responses), lesson planning (3 responses) and learning activities (2 responses) mentioned specifically as approaches to enhance student learning.

> One aspect of the workshops that has influenced me is the idea that in science we need to get the kids engaged. If you try and lecture Year 8 science students, you will bore them, and they won't learn anything. The science workshops pushed me to try and develop activities that are hands on.
>
> I feel really confident about developing and adjusting unit plans for my science subjects, which came from practice doing assignments, as well as the ability to reflect and discuss our unit plans with other students during the workshops.

Although seven of the ten responses relating to creating and maintaining a supportive and safe learning environment agreed that workshops had addressed these issues, participants acknowledged that more support in this area would have been beneficial.

> I think that overall the workshops showed how to create and establish a safe and supportive working environment but did not focus on techniques to maintain it, especially if we were presented with a turbulent class environment.

One participant reflected on the question in terms of the ethical welfare of her students.

> When it came to the topics of religion and ethics in science, I was worried how I would ensure that I did not offend anyone or make anyone uncomfortable in the class as it is sometimes hard to read students. I have been shown in this course ways to provide other activities for students who might not feel comfortable in situations such as dissections, etc. but still gain the same knowledge as the other students.

Nine of the eleven responses relating to assessment, feedback and reporting agreed that the workshops had provided pedagogical support for early-career teachers to draw on in their first year of teaching.

> The entry and exit cards and a continuing focus on formative assessment are things I use in my daily classes.
>
> Becoming familiar with rubrics during the workshops has been very helpful as well as knowing how to provide feedback to students at different levels.

3.5.2 Linking Theory and Practice

All 15 responses to this question were positive in their agreement that they were able to link theory and practice. Seven participants considered practical activities as a way of linking the theory discussed in their learning area workshops with teaching practice. Four participants identified the approaches modelled in workshops relating to specific topics such as earth science and biology useful in bridging the theory-practice divide.

> The Reconceptualising Rocks and Introduction to Biology workshops were really helpful and gave me effective pedagogical approaches and 'real-classroom' application of what we were doing. The resources from these workshops, and the others as well, have been a huge support this year in helping me plan engaging science lessons.
>
> I think the workshops helped me link theory with practice very well. One of the main reasons for this is the workshop-centric format of the course. The workshops allowed for the theory to be observed in a very practical setting. I think this greatly helped with the praxis.

Other responses identified microteaching as assisting the connection of theory to practice (2 responses). The experience of collaborating with a partner to teach a small group of secondary school students was appreciated for its contribution to improving confidence and highlighting the skills required for teaching larger groups of students. Although three participants commented that microteaching should be retained in future years, one participant indicated that it could include a greater emphasis on discussion and reflection.

> Microteaching was invaluable as a first teaching experience. Maybe also more of a scaffolded and explicit discussion after the microteaching around theoretical application in the classroom would be beneficial.

One concern highlighted in the linking of theory and practice was by participants who were uncomfortable teaching out of their specialist science subject area. Three participants conceded that the workshops had not provided enough pedagogical underpinning of their classroom practice outside their area of specialisation.

> I know that it is not really supposed to be part of the program but going through some of the absolute basics of some areas of science would have been really useful. I know that we did a couple of lessons on the different aspects of science, but I have never done any physics subjects, either in school or university, and so being able to learn some of the physics content would have eased my mind going into teaching.
>
> As a new teacher who had learning areas of physics and maths, I am quite confident in planning units for junior science classes that are studying physics, however when I am teaching biology or chemistry, I often feel that I am struggling to think of ways to make the lessons engaging and as effective as when I am teaching physics. Ultimately, I think we are simply restricted by the fact that we only have so much time during our degree and perhaps it is overly ambitious to expect to be completely prepared for the very difficult task of teaching science.
>
> I think it'd be useful to have more content in my non-physics teaching areas. This is my biggest gap as a new teacher.

3.5.3 Suggestions for Improving the Level of Support

In addition to the need to develop their 'out of field' teaching capabilities (4 responses), participant suggestions to further support their first year of teaching science included; extending the length of microteaching (2 responses), providing further information about safety when performing practical work (3 responses), providing ways to introduce STEM-based activities (1 response), including more examples of inquiry-based learning (1 response) and using ICT in secondary science classrooms.

Developing different approaches to engage students, particularly those without a natural interest or enthusiasm for science, was also identified as requiring more support (3 responses).

> One thing that has surprised me, and perhaps this is naïve, is that I have come across quite a few students who have hostile attitudes to learning science, something I did not find on placement. Perhaps some further instruction on getting on board those students who would prefer to be in an english or art class.

3.5.4 *Staying in Teaching*

Two thirds of the participants responded that they would be teaching in 5 years' time (10 responses).

Three participants did not respond to this question and two other participants had some reservations about whether they would still be in front of a class in 5 years' time.

> I think so. I might be involved in other types of educational contexts like the museum, holiday science workshops, if I get tired of teaching.
>
> I am not confident that I will be a teacher in 5–10 years' time, but I will be in the education sector at the very least.

3.6 Discussion

Overall, participants confirmed the relevance of the activities and resources presented in their science learning area workshops to their teaching practice as early-career teachers. In addition, workshops demonstrating the ways experiments, demonstrations and practical work could initiate student engagement and inquiry supported pre-service teachers in translating theory into practice (Britton & Tippins, 2014). Instructing pre-service teachers on the possible misconceptions that secondary students may hold in their understanding of science concepts and effective ways to address these were also regarded as supporting their transition to science teaching. Theoretical and practical activities modelled and discussed in workshops were considered useful preparation for teaching actual classes, while microteaching was considered important preparation for teaching science classes as early-career teachers (Koross, 2016; Wangchuk, 2019). In addition to practical activities, pedagogical support in developing unit plans, engaging and extending students were considered useful in planning for effective teaching and learning.

When reflecting on the conflict between the expectations of teaching and reality (Mason & Matas, 2015), some areas of their ITE program were identified as requiring further development. Providing diverse approaches to promote student engagement and inquiry-based learning activities were revealed as aspects of first-year teaching which required strengthening. Participants also identified concerns about teaching 'out of field' and the difficulties of planning for effective student learning when they believed their content knowledge was deficient or they did not have the pedagogical approaches for their 'out of field' teaching (Beswick et al., 2016: Cinkir & Kurum, 2015; Kenny & Hobbs, 2015).

The amount of time pre-service teachers spend in the science classroom can strengthen the links between theory and practice and allow time to explore different pedagogical approaches to enhance student learning. The findings of this study show that participants considered teaching real students, either in a microteaching setting or on placement, enabled them to apply and practice their teaching pedagogy in a safe and supportive environment (Koross, 2016; Wangchuk, 2019).

In their first year of teaching, participants acknowledged the need for support in navigating the school culture, administration, policies and processes. Early-career teachers considered that observing more experienced teachers' classes and formal and informal mentoring was essential in accessing both professional practice and the school culture (Buchanan et al., 2013). Opportunities to observe how experienced teachers approach classroom practice was considered a way of linking theory to practice, especially in conducting practical classes and provided pre-service teachers with different approaches for teaching skills, knowledge and behaviour management during practical activities.

> Watching other teachers has helped me reflect on the strengths and weaknesses in my own practices.
>
> Observations provide insight into how to approach structuring classes and how strategies for classroom management vary from teacher to teacher in terms of nature and effectiveness. I learned an enormous amount when watching others teach my own classes in another subject. I gained confidence in realising that I am not that far behind.

Although they conceded that finding time to observe the practice of more experienced teachers was not always easy, participants agreed on its importance in their own pedagogical learning journey.

3.7 Conclusion

ITE programs are the first step in ensuring early-career teachers remain in the teaching profession. Programs which support the development of skills and knowledge to ensure early-career teachers are confident and ready to teach are important in providing the pedagogy and skills required for commencing teaching (AITSL, 2015); however, schools also have a responsibility to prepare and support early-career teachers in their adjustment to both teaching practice and the local school culture (Buchanan et al., 2013). Creating a professional identity as a teacher requires more than being a proficient classroom teacher (Hobbs, 2013). It involves establishing a *professional identity* within a school culture and adapting local school practices (AITSL, 2015). Early-career teachers need to feel supported in their first years of teaching when attrition is most likely (Buchanan et al., 2013; Farrell, 2016).

The findings from this study provide evidence that the transition from pre-service to early-career teacher is complex and requires the combined support of the ITE provider and the school. ITE programs provide pedagogy which includes showing pre-service teachers how to simplify their own subject knowledge to make it accessible to their students. Schools provide more specific and directed support for early-career teachers, specifically focused on the school environment and culture. There is a need to ensure that the transition from pre-service to early-career teacher is seamless, appropriate and directly applicable so that adjustment to teaching is quickly achieved and attrition is minimised.

Reducing the separation between theory and practice by encouraging early-career teachers to apply the pedagogy learned in their ITE programs to their science classes (Hsu, 2016; Hutner & Markman, 2017) and observing how experienced teachers navigate this division is recommended as enhancing both professional practice and student learning. Schools must support early-career teachers to enable them to observe and learn from experienced teaching practitioners. Formal and informal mentoring within the school culture can assist not only with navigating school policy and administration but also with professional practice (Buchanan et al., 2013).

The participants in the study reflected on the strengths of their ITE course in science learning area subjects, suggesting that their preparation to become practicing science teachers was both appropriate and effective. Their suggestions provided insights into the aspects of their preparation for teaching which had assisted them in becoming proficient in the classroom and the type of support they believed would have further enhanced their adjustment.

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Chapter 4
Chicken Wings and a Deflated Football: Metaphors of the Complexity of Learning to Teach Science and Mathematics Out-of-Field

Linda Hobbs and Frances Quinn

4.1 Introduction

The phenomenon of teaching out-of-field, that is, teaching a subject or year level without the necessary qualifications or specialisation (McConney & Price, 2009; Ingersoll, 1998), continues to be of concern in Australia and internationally. In Australian secondary schools many students are being taught science and mathematics by out-of-field teachers (e.g., AMSI, 2013); in fact, Marginson et al. (2013) have signaled that Australia has one of the highest incidences of out-of-field teaching in comparison to other OECD countries. Unmet demand for science and mathematics teachers is a key reason for the relatively high incidence of out-of-field teaching (Weldon, 2016). Recent public commentary and discourse in the Australian educational sphere has focused on mathematics and science teaching, partly because of the perceived importance of STEM-related skills for national prosperity and associated moves towards interdisciplinary teaching (Timms et al., 2018), together with continuing declines in the number of students studying mathematics and science at upper secondary school level (Kennedy et al., 2014). Fewer university graduates in these STEM fields in recent years and poor recruitment into teaching degrees means that schools are increasingly reliant on out-of-field teachers (Marginson et al., 2013), a practice which may be contributing to continued declines in STEM participation through a self-perpetuating cycle. The limited supply of teachers specialised in science and mathematics means that the practice of assigning teachers out-of-field will continue. Therefore, understanding and supporting the

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learning of out-of-field teachers is essential for sustaining high quality learning environments.

The experience of teaching out-of-field is complex and unique to the individual and school context, as is the journey of learning to be an effective teacher under these circumstances. In this chapter we focus on teacher change and learning while teaching out-of-field, as a potential point of change in Australian STEM teaching, learning and student retention. While the research on current experiences of those affected by the out-of-field phenomenon (Sharplin, 2014; Du Plessis, 2015) go some way to highlighting the nature of the experience and the very real consequences that can arise, limited research actually examines the complex nature of teachers' learning experience over time. In 1995, Leiberman proposed that teacher learning should be conceived of "as an integral part of the life of the school" (p. 68), particularly in the context of school reform. While out-of-field teachers are not necessarily in a context of school or curriculum reform, the focus for teachers new to teaching an out-of-field subject is that they are in a context that is new for them and there is a necessity for learning in order for them to effectively carry out their roles. The task of learning to teach out-of-field is often an individual one, with the onus of change falling on teachers. Though they may operate within a supportive school culture, essentially the learning journey requires the individual teacher to adapt and learn to accommodate this role as part of their professional practice and identity.

Drawing on data from a longitudinal study of out-of-field teachers, this chapter reports on the learning journeys of teachers new to teaching a subject at secondary school level in Australia. In keeping with the theme of this book, we interrogate the complexities of the teachers' experience through surfacing and foregrounding important meanings salient to each teacher. We have adopted metaphor as a research tool to explore teachers' representations of and reflections on their journey of teaching, learning to teach, identity development and other factors that come to bear and are often challenging at this time. This exploration was undertaken as part of ongoing conversations with out-of-field teachers over 2–3 years; our engagement with teachers served both as a research endeavour and as a professional learning opportunity for teachers to reflect on and articulate elements of their emotions, learning and identities over time as they learned to teach out-of-field.

This chapter responds to the following research question from the larger project: "What shifts in understanding and identity occur as teachers learn to teach mathematics or science out-of-field?" Two sub-questions are relevant for the analysis provided by this chapter:

1. How do teachers describe the changes they undergo as they learn to teach a new subject?
2. What can we learn about the experience of learning to teach out-of-field from these metaphorical representations?

4.2 Understanding the Challenges of Out-of-Field Teaching

While all teachers, particularly new teachers, can face enormous challenges when placed in new situations, teaching out-of-field adds particular demands on teachers that they might not have otherwise experienced. These demands include challenges related to a lack of content knowledge, pedagogical knowledge and horizon knowledge (Darling-Hammond, 2000; Education & Training Committee, 2006; Ingersoll, 1998; Ponte & Chapman, 2008; Thomas, 2000; Vale, 2010), together with feelings of incompetence, disrupted identity, self-efficacy and well-being (e.g., Pillay et al., 2005; Seshea, 2017).

These challenges associated with out-of-field teaching potentially contribute to high levels of teacher stress (Sharplin, 2014), which can lead to teacher attrition, ineffective teaching, and ultimate costs to the education sector. Leadership decisions and attitudes have been shown to be critical determinants of the quality and effects of the experience of being out-of-field (Du Plessis, 2015). Under certain conditions, however, there is potential for out-of-field teachers to build new professional practice, expand their identities, and diversify their expertise and commitments (see Hobbs, 2013a; Selvakumaran, 2018).

4.3 The Use of Metaphor in Understanding Teacher Learning

This chapter is framed by a theoretical perspective focusing on teacher learning, and underpinned by the common phrase ‘teachers as learners’ (Feiman-Nemser, 2012). In referring to teacher learning, we draw on Hager and Hodkinson’s (2009) conceptualisation of learning as a social, embodied and cognitive process of “becoming” through boundary crossing:

> when a learner constructs or reconstructs knowledge or skills, they are also reconstructing themselves … Such personal reconstruction is sometimes explicit and agentic, but much of it is tacit from the perspective of the person concerned. (Hager & Hodkinson, 2009, p. 633)

Such learning is amplified when there is explicit attention to the “boundary” that is being crossed. The potential for learning at the boundary (Akkerman & Bakker, 2011) between in-field and out-of-field teaching, that is, having to learn to teach something new, arises when the discontinuities arising at this boundary are identified and reflected upon (see Hobbs, 2013b; Hobbs et al., 2019). The notion of a “boundary” is itself a spatial metaphor, useful to represent teachers moving from familiar to unfamiliar territory where they have little relevant specific background knowledge and may lack personal commitment, interest, confidence and competence. The “crossing” aspect of this metaphor recognises that such teachers can re-establish proficiencies so that with time they can become effective teachers of this out-of-field subject.

Assisting teachers to reflect on and articulate their experiences of teaching out-of-field can help them to identify the discontinuities arising for them at the boundary, that is, articulate problems faced and overcome, and changes in self and practice. However, because of the tacit nature of much teacher learning, helping teachers to reflect on and represent this change can be a methodological challenge for researchers.

Metaphor was selected as a tool for examining teachers' experiences of learning to teach out-of-field for several reasons. The first is particularly relevant to the theme of this volume; that metaphors "simplify and clarify 'meaning in the midst of complexity'" (Grant, 1992, p. 434 cited in Bullough & Stokes, 1994, p. 200). In simplifying the complex, metaphors become ubiquitous and powerful, providing a framework for enabling people to make meaning of their lives, and structuring and shaping people's realities, thoughts and actions (Lakoff & Johnson, 1980; Martínez et al., 2001). There is a danger that metaphors can oversimplify the complex nature of teaching; for example, Tobin (1990) reported on the ways that science teachers' metaphors of being a teacher constrained their classroom practice. When used for exploring abstract, novel and speculative ideas (Yob, 2003), metaphors can, however, lead to new forms of conceptual insight (Zhao et al., 2010). They can be used to identify situation-specific interventions (Carpenter, 2008) and professional lives and identities (Midgely & Trimmer, 2013). Metaphors are therefore a common heuristic used in teacher professional learning and when researching teacher education (e.g., Marchant, 1992; Marshall, 1990; Martínez et al., 2001; McGrath, 2006; Pinnegar et al., 2011; Reeder et al., 2010; Saban et al., 2007; Seung et al., 2011; Tannehill & MacPhail, 2014).

The particular utility of metaphors in relation to our research questions lies in their power of simplifying the complex by helping us to clarify our interpretation of the way that teachers think about their out-of-field teaching, and helping teachers themselves consider not only who they are as teachers, but other ways of thinking about their teaching and their teacher selves (Bullough & Stokes, 1994). Moreover, metaphors can potentially tap into and help to surface the more abstracted and tacit feelings and responses that may not be otherwise easily communicated by the teachers. According to Reeder et al. (2010), the power of the metaphor lies in its ability to communicate obtuse and abstract ideas, emotions, and facilitate reflection. Further, metaphors are tightly bound to teachers' developing identity (Bullough & Stokes, 1994) and are therefore very relevant to the out-of-field space, which can be highly emotional. Such emotionally charged spaces particularly occur where there are serious impacts on teachers' identity (Bosse & Torner, 2015; Hobbs, 2013a, b), feelings of 'at homeness' (Du Plessis, 2015), and the situation of competent teachers suddenly feeling incompetent (Blazar, 2015). Finally, metaphors can help us to explore teacher change: "a change in metaphors may indicate a change in how the world of teaching is conceived, a change in the evolving story of self" (Bullough & Stokes, 1994, p. 200).

4.4 Methodology

The broader three-year longitudinal study involved interviewing science and mathematics teachers who were teaching out-of-field from six case study schools in regional or rural areas across three Australian states. Taking a longitudinal approach to understanding teachers' experiences of learning to teach out-of-field shifts the research focus from the more usual single-point-in-time analysis of current experience, to how their experiences of learning to teach out-of-field change over time, with each new subject, and in each new context. Hence interviews were conducted with: teachers individually (twice yearly for up 3 years, depending on teacher movements and attrition); the teachers and their mentors or critical friend (once yearly); and members of the school leadership such as principals and department heads (at the beginning and end of the study). The study had an emergent design; each interview was only partly conceptualised at the beginning of the project, and changed each year based on the previous year's findings and subsequent changes in teachers' contexts.

To capture some of the complexity of the emotions or feelings that might not otherwise be clearly articulated when teachers were asked about them directly, metaphor was introduced in the Year 2 individual teacher interviews by asking teachers to suggest an object that reflected their feelings of learning to teach out-of-field. Teachers were asked the questions: "Could you identify an object that represents your feelings about learning to teach out-of-field? Why did you choose that object?" In the subsequent Year 3 interviews that were conducted with some teachers, teachers were reminded of the object they had chosen in the previous year, and asked if they would change it. These questions followed other questions relating to teachers' perceptions of how their out-of-field teaching practice had changed over the past year, what knowledge, skills and attitudes had helped them in their out-of-field teaching, and what they had learned in the previous year in relation to their out-of-field teaching; for instance, what could they do now they could not do before. By foregrounding their learning in this way by these preceding questions, we hoped to prime the teachers to consider the learning potential of teaching out-of-field when selecting an 'object'.

The intention of this process was to help elucidate important meanings of the teachers' out-of-field experiences. The creative act of selecting an object that is analogous with their experience can help teachers to communicate the meaning of the experience, in some sense by objectifying that meaning by using language that distances the experience from the individual. While we are aware that asking teachers to choose a single metaphor might risk oversimplifying the layered complexities of teaching out-of-field, this can help teachers to surface and articulate specific aspects of their unique journey of teaching and learning to teach out-of-field, their professional learning, and other factors that come to bear and are often challenged at this time, including confidence, competence, enjoyment and passions in relation to the subject and teaching generally.

Table 4.1 Participant teaching experience, qualifications and teaching allocations during the first 2 years of participation in the TASB project

Name	Qualification (specialisations)	In field allocations	Out-of-field allocations[a]
Garry (2)[b]	Grad Dip Ed (Agriculture), Upgraded quals to officially include Science beginning Yr 3 of project	Agriculture (7–12); Primary Industries (11–12)	Junior science [Yr 1–2]
Gia (2)	B.Maths/B.Teaching (Maths)	Maths (7–9); General 2 maths (12)	Information Software Technology (9–10) [Yr 1& 2], Junior Science [Yr 3]
Gwen (11)	Grad Dip (History); Further study completed and accreditation to teach Business (7–10); and in past 2 years: Science (7–10); Biology, Chemistry, Earth & Envt'l and Senior Science (11–12)	History (7–10); Modern History (11–12); Society and Culture (11–12)	Maths [Yr 1&2] *Geography (7–10); Commerce (9–10); Science (7–10); Senior Science (11–12); Chemistry (12); Biology (11); Agriculture (11–12); Business Studies; Legal Studies; French; PE; HPD*
Bobby (5)	Human Movement, Dip. Ed. (PDHPE)	PE, HPD	Maths (7–10) [Yrs 1 &2], Food Technology [Yr 3]
Sabra (1)	B.Ed. (P-10) (English, History)	English, Humanities (incl History, Geography, Economics) (7)	Art (7,8) [Yr 1 &2]
Samantha (4)	B.Arts (Literature, Cinema, Cultural Studies, History)/M. Teach. (English/ Maths)	English (11–12); Media (10–12); English (7)	Maths (7); Science (7); History (7) [Yrs 1 & 2]
Seth (5)	B. Arts with International Relations	Indonesian (7)	English (7); Maths (7); Science (7); Humanities (7) [Yr 1]
Eliza (3)	B. Engineering., GDE (Maths, VCE Physics)	Physics (11–12)	Computer Science (11), Chemistry (9/10), Textiles (8), [Yr 1], Textiles (7/8) [Yr 2]
Ethan (3)	B. Arts (History, Politics), GDE (History, Social Education)	Ancient history (10), Politics (9–10)	Geography (7–10), VCAL numeracy (9–10) [Yrs 1 & 2]

Abbreviations: *GDE* Graduate Diploma of Education, *VCE* Victorian Certificate of Education, *Maths* Mathematics, *VCAL* Victorian Certificate of Applied Learning, *PE* Physical education, *HPD* Health & Physical Development, *PDHPE* Physical Development, Health and Physical Education

[a] Italics indicate OOF areas taught by teachers prior to the project

[b] (Bracketed numbers) in this column indicate years teaching experience in year 1 of teacher involvement in the project

4.4.1 Participants

All teachers selected for the project were teachers of mathematics- and science-related subjects, some of whom were out-of-field in these subjects, or were teaching other subjects out-of-field. Table 4.1 lists the nine teachers who responded with an object to the relevant question in the year 2 interview, together with the subject specialisations they were qualified to teach, and their in-field and out-of-field teaching allocations, or 'loads,' during the project. Some teachers in the project could not think of an object; for example, one teacher responded by saying "With my scientific mind I'm hopeless at abstract thought so I'm really the wrong person to ask a question like this."

Evident in Table 4.1 is the changeability of the teachers' teaching loads, and the number and diversity of out-of-field allocations that the individual teachers were required to teach. Note that some participants (a particular example being Gwen) had also taught multiple out-of-field subjects prior to the project. Most teachers were within their first 5 years of teaching, while Gwen was experienced, albeit through sequential casual or short-term contract positions. All other teachers held on-going positions in their current school. Seven teachers taught science-related subjects out-of-field. Mathematics, numeracy or economics were taught out-of-field by five teachers. Two teachers had upgraded their qualifications as in-service teachers.

4.5 Analysis

A total of 12 metaphors were provided, although some teachers referred to a number of metaphors as they constructed a narrative about why their chose their metaphor. In analysing the metaphors to address the research questions we focused on what the teachers emphasised in their object and its description, their rationale for its selection, and what we could learn from this about teachers' 'feelings' about their learning, and their experience of learning to teach out-of-field. In our adoption of metaphor as an analytical tool in this space, however, we are also mindful of Carpenter's (2008 p. 281) advice that although metaphors can help us structure and understand data, and facilitate new insights, we need to be careful that our use of metaphors faithfully represents the data in a way that preserves its substantive meaning: "At their best, metaphors illuminate the meanings of experiences; at their worst, metaphors distort or obscure the essences of them." We are also aware that the representation of objects is partial in that it focuses on only some aspects of the learning experiences. A categorical analysis was used to look for commonalities and differences between the rationales provided. This involved extracting the interview excerpts that related to the metaphors and elucidating the 'meanings' that were being represented by each metaphor about the experience of learning to teach out-of-field, and then converging these different meanings into categories based on a common focus.

4.6 Results

The analysis identified that there were two metaphor categories that reflected two distinct ways of expressing the experience of learning to teach out-of-field: (1) "Being" an out-of-field teacher; and (2) "Doing" out-of-field teaching.

The first category includes six metaphors that focused on 'being' a teacher of a new subject or new content.

Two teachers described themselves as playdough (Garry) or putty (Samantha), with both references intending to portray the effect of one's self and practice being shaped by others:

Garry: Unless actually forced to mould it will not… squeeze it through your fingers and it will mould into a new shape…So the same as a science classroom it will adapt, it will change… if I wasn't forced to I'd kind of think that I'd still be sitting there just as regular playdough.

Samantha: It's very very malleable, but always returns to its similar form that it was before when you leave it alone. So if you force it to something and make it do it, it will, but it will also go back to what it was beforehand.

For Garry, the shaping effect of others, "being forced to", was seen as useful for effecting "change" through the need to "adapt", perhaps learning to be something better than "regular playdough". When asked a year later "what's happened to the playdough since we last spoke?" Garry alluded to a more permanent "shaping" that came with knowledge and confidence.

Garry: it's still definitely feeling like I'm playdough but I think, now that I've, I've got that basic shape… I've got that, that existing knowledge now and that, that confidence within the classroom.

The permanency of change mentioned by Garry is in contrast to Samantha's response, who recognised the elastic properties of putty which returns to its original shape after pressure is removed. Again, the idea of force being applied, the willingness of the teacher to respond to this force due to their "malleability", but that ultimately the teacher has the power to make their own decisions after the pressure is applied. The tension between individual agency and a powerlessness in determining roles, and therefore experiences and on-going professional growth of the teacher is evident here.

Gwen depicted the messiness of being out-of-field as two fictional characters, Taz the Tasmanian Devil (Looney Tunes) and Little Miss Messy (after the Mr. Messy character of Hargreaves, 1972):

Gwen: Tasmanian devil or that Miss Messy ball of string. That's like crazy. Little Miss Messy because it's just a ball of uncontrollable shit – that you've kind of just got control of. Enough to be, like she has form but only because she needs to …Tasmanian Devil thingy that the cartoon – like zzzzz and he just hoons around – he just makes a cloud of shit wherever he goes – it's really busy and I don't know – got all these things going in your head and just that.

Represented in this metaphor is the busyness, and fast-paced nature of being out-of-field, and a lack of organisation as a result of the many things the teacher needs to do and think about. The effect of disruption to what is "going on in your head" is evident as being in chaos and out of control. In describing some "form" that she took that was marginally adequate for the role "only because she needs to", this metaphor points to a minimum level of "form" that a teacher needs but that can be hard to achieve.

Another metaphor focused on the feeling of pressure caused by a lack of knowledge and organisation was captured by Bobby's object of the cone:

Bobby: When you are at the top of your game, you've got more space. If you're feeling disorganised you're at the bottom of the cone and you're feeling squashed and you've got no room. The curriculum can make you feel that way sometimes like algebra, I'm even scratching my head, even though we don't get to it until term three. I'm already planning how to make it a bit more fun and I've still got nothing. Feeling in the bottom of the cone. With the financial maths, I've got more space, room to move so the more thought I put into it, I'm starting to feel like I've got more room there. I go back to my first year of teaching maths to now, it is like that. A bit more knowledge, a bit more space, so a cone or a cylinder…And any lesson I can be in the cone, I don't have that space, sometimes I do feel like I'm down the bottom, how can I get to the top.

A year after sharing this cone metaphor of his out-of-field practice in mathematics, Bobby used the metaphor of open space, referring to a greater sense of expansiveness associated with his practice in a different out-of-field subject, in which he had strong prior knowledge and extensive work history, and his teaching more generally:

I: So are you still in that cone now do you think?
Bobby: No.
I: What kind of shape are you in now?
Bobby: An open space.
I: And tell me about the open space – is it nice being there?
Bobby: Yeah.
I: How come?
Bobby: Just room to move.

Bobby offered the insight that being in the open space himself allowed him to take his students along with him from a place of constriction and pressure to one with more space and comfort:

Bobby: I think some of the students – even I guess you could look at them being in the cone as well, and that I think that I have been able to – I guess – get them to the top of the cone or even into that open space with me, and I think it might just be a feeling of comfort or a feeling of being on top of your game

Ethan used a deflated football to represented use as a teacher not matching the intended purpose, deflation of the ego and being pressured down by the demands of teaching out-of-field, and the need to re-inflate confidence over time:

Ethan: over time so you walk in and out-of-field and you feel like a deflated football so you might have been self-important; you might have been the best teacher out there – you know useful and you've been kicked around the park… suddenly you walk into a class and your ego takes a bit of a second place I suppose and things get pressured down and then you are sort of compressed down and then I think over time you start refilling yourself again with confidence… it's not as useful as you necessarily want it for. It's not there for your original purpose either.

Ethan suggested that inflating the football, or inflating one's ego and confidence, was possible by seeing that they can have a possible impact on their students: seeing student success, "getting taps on the back from the kids saying I've actually enjoyed that and I've learnt that", "a student that's come in with a frown and they've left with a smile then you know you've actually made their day".

These six objects represent different effects of out-of-field teaching on the teachers' 'being': the effects of being shaped, feelings of being out of control, the pressure of having to deal with the lack of knowledge needed for teaching, and the deflation to one's ego and confidence and the need to build confidence over time.

The second category of metaphors focused on the "doing" or the practice of teaching new content, in particular, the experience of having to learn the practice. Five metaphors were identified.

The progression of changing practice overtime is represented by Gia as the action of a whisk on eggs, where the end result is having some form and fluffiness, that it takes shape over time:

Gia: Something that's a bit soft at first but gets, maybe like a whisk. Yeah, starts gently but then it's like nice and fluffy by the end of it, and it's good by the end of the term…I don't know, sometimes because it (my teaching) goes through the whisk occasionally. Because there's still bits I still need to learn, [it] depends on the subject each time though, so depends on which topic I'm actually teaching. So if I'm teaching spreadsheets I don't struggle really at all because it makes sense, there's still a lot of tricks though, you can never learn Excel completely I don't think. But I'm much more on top of my game there, whereas now with the animation it's starting off very slowly, yeah.

There is a feeling of looseness, perhaps runniness and uncontrollable flow when she needs to actively learn what she is teaching and how to teach it, especially when entering into teaching a new subject or topic (e.g., teaching animation) for the first time. There is also a sense of tentativeness in her approach borne from this lack of knowledge. Then with experience of teaching, the action of the whisk, 'going through the whisk', which is perhaps the day to day teacher learning, planning, enactment and reflection, the process of teaching, what needs to be taught and how to teach it becomes firmed, takes form and shape, and has order. Tentativeness gives way to a sense of confidence and being sure about what is required.

In the following year, Gia had moved to teaching science out-of-field, and adopted the metaphor of a decalcified chicken wing (drawing on a recent memorable science practical experiment), to describe her feelings about "winging it" while learning to teach in a different out-of-field area:

Gia: like a chicken wing because I'm winging it…So, it's raw and it's doused in vinegar. [...] – and it's floppy because the bone – calcium's gone.
I: So, you're like a decalcified chicken wing?
Gia: Decalcified chicken wing.
I: In what way?
Gia: Because the experiment seemed to be working but they're a bit rushed it's not cooked properly.
I: So, you're saying this is you? You need more cooking, more time?
Gia: Little bit more cooking, yeah.

Although using a different object to express herself, in this response Gia raises similar concerns as her previous "Whisking eggs" metaphor: a sense of floppiness and needing to be properly cooked. Both metaphors emphasise the need for time to develop the form and substance that comes with being properly "cooked" in (or by) those teaching experiences.

A rolling hexagon was used by Sabra to represent her teaching of out-of-field subjects as being more difficult to get moving and progresses less easily than when teaching in-field:

Sabra: Maybe a hexagon because instead of a circle that rolls easily, it still rolls but just not as quickly… I've got to think about more how to make it move as naturally as my English does

The contrast between the ease with which a hexagon and circle rolls shows the process of teaching out-of-field as having slower and stunted movement and being less natural because of the extra time and effort needed to 'think'. Movement here refers to the process of teaching.

Seth's object, rollercoaster, referred to his teaching generally rather than specifically to out-of-field teaching, since most of his teaching was out-of-field. Seth describes the excitement of teaching as moving upwards but then expecting and anticipating changes and challenges, specifically looking out for the 'drop':

Seth: I'm fairly positive about teaching in my out-of-field area, teaching it itself is a rollercoaster. So there's always those up and down days and I feel like most of the time I'm on the way up of the rollercoaster when I'm teaching, I feel like it's exciting, what's going to happen next? And it's, it's all still a bit of a learning experience, for that first time when you're going, slowly climbing up the rollercoaster and you don't know where the drops going to come.

The rollercoaster metaphor typically refers to the highs and lows of teaching, especially for teachers in their first years in the profession. But Seth adds to this imagine the feeling of excitement and anticipation that can be associated with new situations, where each step into the unknown involves risk taking, trust that it will be ok, and faith in the process of learning. Given the high out-of-field teaching load of this teacher we can project that this representation of teaching something new is contributed to by a role largely comprised of learning to teach new subjects.

Eliza's image of a dimmer switch (that is, a switch that controls the amount of light emitted by a lightbulb) represents her experience of gradually understanding and gaining clarity around what is required to teach her new subject:

Eliza: It starts off, and it's a bit dark. Like you walk in and it's like, where the hell is everything. It's not clear. You don't know what – you can sort of make out where things are… Over time it gets brighter and clearer, and you can see exactly what you should be aiming for, or more exactly, because someone still might move stuff around, but you know, and it just gets clearer. So, from the start, you have an idea, it's just that it gets more identifiable as the light gets turned up and you get more information.

Eliza refers to gaining clarity around the knowledge of what and how to teach the subject. At first the need to grope around in the dark is confusing, while wondering "where the hell is everything", having to seek out "what you should be aiming for" and understand the lay of the land. Over time and with experience the teacher is enlightened as these things become more and more clear.

Common to these five objects is the representation of 'change over time' as teachers gain experience with teaching a new subject or topic. The action of the whisk, cooking time, and increasing visibility appear to represent the increasing level of experience and exposure to the knowledge and skill of teaching the new subject over time. The results are greater clarity and firmness of teachers' understanding, similar to the effect of the dimmer switch allowing for greater clarity. The rollercoaster highlighted the anticipation experienced when an understanding of how and what to teach unfolds in the moment and over time. These three objects highlight the temporal nature of learning to teach a new subject. In comparison, the hexagon highlights the reduced efficiency of teaching out-of-field, and the need for greater effort in learning what and how to teach.

4.7 What Can We Learn About the Experience of Learning to Teach Out-of-Field?

While many of these experiences can be expected for beginning teachers generally, they do give interesting insights into the specific experience of learning to teach out-of-field. Four themes relating to the nature of this experience are evident in these metaphorical representations: pressure, agency, disruption, and challenge. Also evident are some indications as to the expected learning outcomes for the out-of-field teacher.

4.7.1 Pressure

Teachers can experience pressure when they have limited expertise in teaching the subject and they need to learn quickly in order to appear competent. This was particularly evident in those metaphors that relate to being constricted and feeling small, for example, being in the confined space at the small part of the cone or the deflating of the football. This experience of feeling small initially is both cognitive and emotional. The workload pressure caused by the cognitive engagement, time and energy needed to learn new content, new ways of teaching, and identifying and supporting students is associated with feelings of incompetence and emotional fragility, relative to teachers' more familiar in-field subject area. Indeed, workload pressure is a constant concern for the teaching profession (National Education Union, 2018) worldwide, resulting from the increasing complexity of teachers' work, increased workload and administrative tasks. At the same time greater levels of accountability are contributing to teacher dissatisfaction and attrition (see Mason & Matas, 2015). Such pressures are exacerbated by teachers having to learn new content and teaching approaches, as well as reconsider their identity as competent well-informed teachers (Hobbs, 2013a, b). In Australia, Sharplin (2014) and Handal Watson et al. (2013) identified that additional pressures from out-of-field teaching can, indeed, lead to teachers leaving the profession.

In relation to learning over time, both of these metaphors speak to a feeling of relieving pressure associated with spatial expansion – moving to the less constricted part of the cone, gaining open space, or filling the football to make it expand. Supporting out-of-field teachers while they feel small as they expand as practitioners clearly highlights the need for attention to teachers' related cognitive and emotional needs, which may not be expressed directly to teaching colleagues. Helping teachers to surface tacitly held or unwelcome aspects of their reconstruction in the out-of-field space would appear to be a potentially fruitful aspect of the ongoing teacher professional learning that can happen via attentive and supportive day-to-day relationships and interactions within school staffrooms.

4.7.2 Agency

Teaching out-of-field can constrain the extent to which teachers can both exercise agency and feel agentic. External shaping places expectations on teachers to be malleable and flexible, moulding them into something unfamiliar and strange. Agency is a dualistic construct that acknowledges that people can influence their own lives and environment, while also being shaped by social and individual factors (Lasky, 2005). The playdough and putty metaphors highlight this dualistic nature, with teachers being both informed and assisted in learning the new role by others, while at the same time feeling the pressure of conforming with expectations. Teachers identities are related to agency: "teacher's realisation of his or her identity, in performance within teaching contexts, is a sense of agency, of empowerment to move ideas forward, to reach goals or even to transform the context" (Beauchamp & Thomas, 2009, p. 183). For the out-of-field teacher, agency in being able to control their allocation to teach a subject and make pedagogical decisions based on a sound foundation of knowledge and experience can be compromised, thus having implications for their identity construction. Also evident was a dilemma for the teacher to shaping themselves in this change environment, that is, whether to change and improve, or whether to revert to a previous form after pressure is removed. This dilemma can be particularly relevant when teaching out-of-field looks to be only a short-term proposition, and there is resistance to committing time and energy to learning.

4.7.3 Disruption

Disruption is caused by the newness of teaching a new subject, a sense of the unfamiliar, and crossing a boundary into a new field, for example, encountering difference between the known and less/unknown when entering unfamiliar territory (Suchman, 1994). This was evident in the dimmer switch metaphor, where there was lack of clarity in what was needed to be known. The effect of disruption was also depicted as being confused, uncontrolled, in free-fall almost, where there is a struggle to maintain some order or form, evident in the cartoon characters of Taz the Tasmanian Devil and Little Miss Messy. Because of the discontinuity caused by this disruption, and in order to become familiar and gain some order, the teachers referred to navigating a way through the unknown, with potential outcomes being a re-establishment of order and control, new knowledge and skills, and a new perspective on themselves as knowers and orchestrators of their teaching role. The temporality of learning to be an out-of-field teacher is critical here, recognising that being an out-of-field teacher is a process of becoming, and not a static experience or a single crossing of a boundary; it involves knowledge development over time, trialling of new practices, and taking risks at each movement forward and sideways. Certainly, the dimmer switch metaphor presents this productive experience and 'process' of coming to know, leading to edification of the teacher and potential role expansion. But this is contrasted with the potentially destructive, violent and exhaustingly crazy image of the cartoon characters. It is noteworthy that the teacher using the cartoon metaphors had taught in multiple out-of-field contexts over many years, and that although she articulated confidence and pride in her ability to do so, through these metaphors she expressed considerable cost to her 'being' uncontrolled and lacking organisation. Disruption caused by crossing the boundary/s into new field/s therefore can be seen to prompt new learning and role expansion, but also the struggle for surviving the confusion and messiness, which can reach a threshold after which recovery is questionable.

4.7.4 Challenge

Learning to teach out-of-field is essentially a challenging process of establishing or re-establishing competence and confidence in knowledge and teaching practices. The nature of this process, as it is experienced, was represented by the rollercoaster, rolling hexagon and dimmer switch metaphors. These metaphors depict this experience of learning as being difficult and requiring effort. It is inherently temporal and experiential in nature, meaning that teachers need time to: experiment; experience the changes; learn what to expect and when; and identify what resources are needed and how to find them. Learning can feel like a struggle, like rolling a hexagon, as knowing what and how to teach does not come naturally. Anticipating the difficulties and successes and dealing with mistakes can be distracting, and learning is difficult due to a lack of clarity, at least to begin with. What once may have been tacit and natural now becomes unnatural, and more time and energy is required to plan and problem solve. This extra effort needed to concentrate on the knowledge and practices that were previously tacit can be aligned with what Blazer (2015) calls the re-novicing of out-of-field teachers, where teachers can experience similar struggles in their teaching as beginning teachers; at least to begin with. Over time and with experience, as suggested by the dimmer switch metaphor, greater clarity can be reached, however the roller coaster is a reminder that all teaching has its ups and downs – including at times hitting the drop zone. For the newly out-of-field teacher, not being able to anticipate these drops is part of this re-novicing.

4.8 Expected Outcomes of Teacher Learning

We can examine these metaphors to identify what it means to successfully learn to teach an out-of-field subject. Technically, a teacher would no longer be considered out-of-field if they have completed the necessary qualifications. However, practically and personally, a number of factors can make a teacher ‘feel’ out-of-field (or in-field), as identified by Hobbs (2013a, b). These factors relate to context, the personal backgrounds and resources of a teacher, and the support they can access or provide for themselves. Therefore, no longer ‘feeling’ out-of-field involves more than simply gaining a new qualification. What would be the expected learning outcomes of a teacher who is ‘learning’ to teach the new subject? Apart from the obvious changes in knowledge and expertise in practice, the experience has implications for teachers’ practice, emotional commitments and identities. Two inferences can be made about the outcomes of having successfully “learned” to teach out-of-field.

The first inference is that the practice of an effective teacher of an out-of-field subject has characteristics of speed and firmness. Speed refers to the action of the teacher as no longer being stunted and knowledge becoming more tacit and normalised with an efficiency borne from experience. Firmness refers to the effectiveness of the teacher, where they are not ‘runny’, that is, struggling to gain a solid grip on what is required, but instead teaching practice is more deliberate and organised.

The second inference is that becoming an effective teacher of an out-of-field subject may over time be associated with shape, clarity, tidiness, lightness, spaciousness, and maximum usefulness. Shape refers to the teacher’s identity as it is shaped by themselves and by others. The shape would be recognisable for the teacher, the teacher would be agentic in determining this shape, and others would be affirming of it. Clarity refers to a teacher’s knowledge of practice and of content which has clarified and sharpened, and is no longer obscure and dim. Tidiness refers to the control that the teacher has where the messiness and uncontrollability of the many pressures on the teacher subside and give way to organised or ordered actions, knowledge, and interactions with those around them. Lightness refers to the effects of changing teacher knowledge, and no longer feeling the pressures of being out-of-field, nor the insecurity in lacking the expertise. Spaciousness refers to the expansion of teacher confidence, emotional reserves, knowledge and expertise; in some respects consistent with Engestrom and Sannino’s (2010) notion of learning by expansion that comes with crossing boundaries and developing horizontal expertise. Maximum usefulness refers to aligning one’s role with the teacher’s calling – their ‘intended purpose’ – as a teacher with a passion in a particular discipline, which can feel sidelined when teaching an out-of-field subject. Interaction between practice and identity over time can create new passions and identity expansion occurs when the teacher sees that they can be useful in the new space. They know something that can be of value for the learner, potentially bringing the students with them to a place of more spaciousness.

4.9 Conclusion

These accounts are compelling as they indicate the potential cost of teaching out-of-field on the individual in terms of confidence, self-efficacy, and sense of self in relation to their role and others. But they can also help to signify key areas of growth. Metaphors, as captured by this research, present an alternative way for teachers to represent their experiences.

Methodologically, it was evident that metaphors, used in this way in research, are both simple and complex. They are not stable or all-encompassing; instead they are partial and labile, foregrounding different emotions. They are sometimes reactionary, being situated in current or recent events that can trigger certain emotions and responses (e.g., cartoon characters depicting current state of mind, immediate shaping of the playdough and putty). Others, however, can depict the long-term experience (e.g., deflated football re-inflating, dimmer switch turning on, anticipations and drops of a rollercoaster, whisk creating change in firmness). Also, they can change over time, as was illustrated by Gia and Bobby, although both of the metaphors used by each teacher did seem to target the same quality of the experience (firmness and space, respectively). They are partial in nature, acting as productive constraints so as to hone in on something about the experience, thus foregrounding certain aspects and ignoring others. It was through articulating the relationship between the metaphor and the meaning – the simple and the complex- as a logical argument that the depth of the experience became apparent for the teacher. This was perhaps more so than might have been appreciated and articulated by the teacher if simply asked to explain the effects associated with teaching out-of-field.

It is difficult to talk about out-of-field teaching, or indeed teaching in general, without the use of metaphor. Asking teachers to choose and articulate a metaphor helped to represent the complexity of the experience for each teacher, as well as the variety of experiences across teachers. The potential for disruption to be destructive (Miss Messy and Tasmanian Devil) was contrasted with disruption leading to teacher edification through moving teachers to a new state or form (playdough). The experience of learning to teach out-of-field field was a dynamic and temporal one, and for some seen as part of their professional learning as they generate and maintain quality teaching despite the challenges of teaching out-of-field.

The effect of context was also evident. As such, this research has the potential to inform school leaders and policy makers of the challenges and support needs by illuminating out-of-field as not necessarily a ‘problem’ per se, but as a complex phenomenon where there is potential for learning, and where the need for support is paramount due to the challenges that can arise. An important caveat to this research is that the impetus for change should not lie only with the teacher, but should be distributed to school leaders, policy makers, and the whole school culture and community. Within a supportive context, teacher learning outcomes depend on the nature and extent of the effects of teaching out-of-field as they are perceived and experienced by teachers, the actions and acknowledgement by others, and the capacity, room and willingness of the teacher to engage in personal reconstruction and growth.

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Part II

Perceptions, Teaching and Learning of Socio-scientific Issues in Diverse School Contexts

Chapter 5

Climate Change Education: Simple or Complex? The Impact of Culture on Students' Willingness to Reduce Global Warming

Keith Skamp, Eddie Boyes, and Martin Stanisstreet

5.1 Introduction

The major cause of climate change is increasing concentrations of atmospheric greenhouse gases (predominantly carbon dioxide, methane, nitrous oxide) – mainly a result of human actions – and this is an existential threat to Earth systems (International Panel on Climate Change (IPCC), 2014). From a science teaching perspective it might appear as if a simple solution to this issue is ensuring that students learn about the causes and effects of global warming and that humans are mainly responsible for what is occurring. Students, as tomorrow's citizens, will then take appropriate pro-environmental action. Unfortunately, although there is long-standing evidence that a 'basic' knowledge about global warming does influence students' concerns about climate change[1] (e.g., see Lee et al., 2015), we know that for many people awareness and knowledge about the causes and effects of global warming does not translate into action (Kollmuss & Agyeman, 2002). The apparent pedagogical simplicity of a linear connection (knowledge leads to action) needs to be enhanced by more sophisticated educational pedagogies.

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[1] Anthropogenic pollutants added to the atmosphere result in an exacerbation of the natural greenhouse effect, leading to an increase in the average temperature of the lower level of the Earth's atmosphere and of the oceans ('global warming'). A major consequence of this is long-term changes in weather patterns over a region or across the planet ('climate change'). Although the term climate change is now the more widely used, we have elected in this paper to use the term 'global warming' because it describes the primary consequence within this process.

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Alternative climate change pedagogies are needed, not only because of the knowledge – action gap, but also because climate change is a wicked sustainability problem in that "it is a huge, complex and systemic challenge, difficult to clearly define or foresee the consequences of solutions… (with) different stakeholders provid(ing) conflicting information…" and, from an educational perspective, it "is difficult to combat with prevailing ways of thinking and behaving" (Lehtonen et al., 2018, p.860, parentheses added). One way that climate change educational strategies that seek mindset and behavioural change can be better informed is by a deeper knowledge of the many variables, and their interactions, that impact on people's willingness to take pro-environmental action (e.g., see Hines et al., 1986/87; Pruneau et al., 2006).[2] In this paper we focus on two under-researched factors: students' beliefs about the effectiveness of specific actions in reducing global warming and the impact of a country's culture.

Both variables warrant further study as more research is needed about international public opinion related to climate change policy and the impact of a wide range of (a country's) variables (e.g., Knight, 2016; Marquart-Pyatt, 2015). At present there is "little understanding of how people see the *effectiveness of policies* related to the international dimension of climate change" (Drews & van de Berg, 2015, p.15, emphasis added) – this would apply to several of the actions reported here. Some studies have started to appear (e.g. Knight, 2016) but cross- national studies of students are rare. Similarly, reporting the impact of a country's culture on climate change decisions addresses this call for more international research, especially across student populations. Such studies, apart from the authors (e.g., Skamp et al., 2019a, b), were not located. Furthermore, Wals et al. (2014) have posited a link between world views, belief systems and identity, and taking pro-environmental action. These are all related to a country's 'cultural press' (Schwartz, 2014), adding further justification for exploring culture as a variable.

Beliefs about the effectiveness of specific actions was investigated using a specially designed questionnaire. It explored students' (n > 12,000; grades 6–10 across 11 countries) beliefs about eight actions in reducing global warming as well as their willingness to take these actions. The actions related to transport, energy, and voting choices. The impact of a country's culture was investigated by determining the relationships between quantitative measures of a country's culture and students' 'natural willingness to act' [NWA] – one of several novel indices derived from the questionnaire data (see 'Method' section). These cultural measures referred to specific dimensions and orientations, such as individualism vs collectivism, that characterize a

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[2] We acknowledge that some authors (e.g., Courtenay-Hall & Rogers, 2002) argue that quantitative approaches to environmental education research has its limitations. However, we believe it continues to offer insights about mindset and behavioural change, as is illustrated by the findings in this paper.

country's culture (see e.g., Schwartz, 2011).[3] A key finding suggests culture significantly impacts on students' willingness to act to reduce global warming.

5.2 Climate Change Education: Simple or Complex?

In many countries, education for sustainability (or environmental education)[4] is an across-the-curriculum priority area (e.g., see ACARA 2018; Skamp, 2009). Education for sustainability encompasses climate change education. All teachers have a role to play. In fact, Schreiner et al. (2005, p.12, parentheses added) argue that teachers are "essential" in providing "climate (change) education for empowerment". Science teachers are to contribute to this cross-curriculum priority and climate change education teaching goal. The science teacher's role, therefore, extends beyond the, albeit important, facet of improving conceptual knowledge – which *is* needed as students may hold many alternative conceptions about climate change (Boyes & Stanisstreet, 1993; Dawson, 2015 *inter alia*). However, successful 'education for empowerment' means students are willing to take action to reduce global warming; conceptual knowledge alone, for many students, will not lead to action. Teachers, therefore, need to engage students in more complex pedagogy, such as that around other socio-scientific issues, since global warming is clearly a socio-scientific issue. Investigating such issues fulfils many science education roles; these include not only improved conceptual understanding of the science content but also transferring it, for example, to decisions that students make in their daily lives. A socio-scientific issue approach addresses more of the variables involved in students' decision-making and willingness to act related to global warming as it requires a consideration of social, economic, environmental, cultural and political factors related to global warming. Such teaching is not straightforward. When trying to decide what actions to take, students need to consider the competing elements of the 'triple bottom line' of social (people), economic (profit) and environmental (planet) factors (Elkington, 1998). Teachers need to be aware of the danger of letting profit "become the undisputed component of the triple bottom line" (Jickling & Wals, 2008, p.3) and, while not overlooking it and the other factors, need to appreciate that the "ethics of the planet" must always have priority (Colucci-Gray et al., 2005, p.248).

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[3] Schwartz (2014), for example, outlines his conception of culture and his theory underpinning seven cultural value orientations that are "useful for describing and comparing societies" (p.547). How these orientations were measured is overviewed, together with the analyses from 77 national groups leading to the conclusion that countries can be treated as 'cultural units'.

[4] Education for sustainability is usually considered a broader concept than environmental education (McKeown & Hopkins, 2007); for many countries environmental education has been an across the curriculum priority for decades while in more recent times 'sustainability' has become the cross-curriculum priority.

Science teaching, therefore, requires additional process outcomes to be addressed, such as the development of effective argumentation and critical evaluation, when discussing socio-scientific issues (here climate change) (Christenson et al., 2014; Lombardi et al., 2016). Apart from the added pedagogical complexity, there is another hurdle to be overcome. Many teachers (including science teachers) do not engage with environmental education for a range of reasons (e.g., Prabawa-Sear & Dow, 2018; Gough, 2008). If teachers are more aware of the variables that influence students' willingness (or lack thereof) to take action to reduce global warming, apart from conceptual understanding, then they may be more willing to engage students with this socioscientific issue.

5.3 Conceptual Background

5.3.1 Types of Pro-Environmental Actions

The 'actions' in this study are typical of four of Herman's (2015) five 'types' of actions students could take to reduce global warming. These actions vary in the personal investment involved. They are: (1) passive actions requiring minimal direct personal investment (here, support for more environmental education); (2) direct actions that conserve energy (here, e.g., take public transport); (3) support for government pro-environmental initiatives (here, e.g., vote for governments that will impose an environmental tax); (4) lifestyle choices (e.g., eating less meat); and (5) spend more for consumables (e.g., fuel, here, alternative sources of energy). The specific actions reported here are whether students would act on their beliefs about the effectiveness of using electricity generated from renewable and nuclear sources (type 5), take public rather than private transport, or use smaller cars (type 2), support additional environmental education (type 1, hereafter referred to as 'education'), and vote for politicians that would impose environmental taxes ('taxation'), add further environmental laws ('legislation') and support international treaties ('treaties') (type 3). These decisions relate to "two complimentary and mutually reinforcing roles" individuals (including students) have in reducing greenhouse gas emissions, namely supporting political decisions aimed at reducing global warming and taking direct action through individual life-style changes (Rosentrater et al., 2013, p.936).

5.3.2 Sources of Greenhouse Gas Emissions and Pro-Environmental Actions

Two of the three types of actions explored in this study can be aligned with the global sources of greenhouse gas emissions. The main source is heat and electricity production from fossil fuel use (25%), followed by agriculture and land use (24%), industry (21%) and transportation (14%) (US Environmental Protection Agency [EPA], 2017). Reducing fossil fuel use is therefore one effective way to reduce global warming. Of the actions investigated in this paper people can take direct actions in relation to transportation and possibly, to some extent, the source of their electricity generation. Indirectly most can influence government decisions about all four areas, including land use and industry through their voting power, for example voting for governments that would introduce a carbon tax. The latter is "one of the most cost-effective means" of reducing greenhouse gas emissions (Pizzer in Rosentrater et al., 2013, p.956). Although 'education' is not directly associated with the sources of greenhouse gas emissions, it is a significant social approach to reducing global warming, with the IPCC (2014) seeing it as an 'enabling factor'. As Marquart-Pyatt (2015, p.1036) comments, education not only raises awareness and enhances knowledge about climate change, it "shapes environmental concern… instilling individual norms and values and (encourages) openness to new ideas". Students may be one step removed from virtually all of these decisions; however, they will be able to take such decisions in the near future and may, even now, be able to influence their school, family and even governments (as with the recent global student protests about climate change: see e.g., Glenza et al., 2019). The latter is relevant as some secondary students, for example, believed that climate change is also the responsibility of governments, and not just individuals (Harker-Schuch & Bugge-Henriksen, 2013). Furthermore, students' decision making may be affected by their knowledge of their country's impact on global warming: of the countries in our survey, apart from China (30%), the USA (15%) and India (7%) are the countries mainly responsible for global greenhouse gas emissions, although the European Union accounts for 9% (US EPA 2017).

5.3.3 Variables that Impact Pro-Environmental Actions

As previously alluded to, various models have been advanced to explain environmental behaviour. Hines et al.'s (1986/87) seminal meta-analysis of 128 research studies indicated that as well as knowledge, attitudes and behavioural intentions, other influential variables were involved (e.g., locus of control) including situational factors such as economic constraints. More recent studies have indicated further factors impinging on decisions to take pro-environmental actions: Pruneau et al. (2006) identified 27 such variables. In the present study, the initial focus is on the relationship between beliefs and willingness to act.

Beliefs express one's commitment to a viewpoint; they need not be evidence- or reason-based (Gauld, 1987). Although many variables affect a willingness to take action for the environment, one major research review concluded "…people act in congruence with their beliefs: this is the ultimate belief-behaviour connection" (Heimlich et al., 2013, p.270). It also determined that a very strong predictor of actual environmental action was a 'willingness to act' (p.269). Thus the 'willingness to act' measured in our study is a realistic indication of what students will actually do. This also applies to voting intentions as Schultz et al.'s (2010) international study (across 38 countries) concluded most 14 year olds intend to vote.

5.3.4 The Belief-Action Connection

There is a well-established gap between adults' and students' environmental 'awareness' and 'knowledge', and their 'willingness to act' on what they know (Kollmuss & Agyeman, 2002). Various barriers to acting upon *concerns* about climate change have been identified. These include: many types of knowledge, such as causes of global warming and what are effective actions; credibility of sources about global warming; locating responsibility elsewhere; "future blindness" (climate change is a distant threat); inability to change lifestyle; other issues have greater priority; other people will not follow; lack of action by governments, business and industry; and cognitive conflation of other issues with climate change (e.g., Lorenzoni et al., 2007). As indicated earlier, a variable that has been little explored, apart from Skamp et al. (e.g., 2019), is the impact of a country's cultural press on students' willingness to take action. Here, we report on whether cultural press influences students' natural willingness to act on their beliefs about the effectiveness of eight actions to reduce global warming.

5.3.5 Culture

As our study drew from 11 countries with different socio-cultural traditions, we were able to quantify whether cultural norms impacted on a measure of the interactions between students' belief and action, namely their *Natural Willingness to Act (NWA)*. Measures of a country's socio-cultural values (Hofstede, 2001; Inglehart & Welzel, 2005) or orientations (Schwartz, 2014) made this possible. A brief summary of the cultural values and orientations that correlated with students' NWA measures on the eight actions are in Table 5.1.

5.4 Research Questions

1. What are the beliefs that students hold about the extent to which four direct and four indirect actions might reduce global warming (students' *Believed Usefulness of Action*)?
2. How do the degrees to which students intend to undertake these eight actions differ (their *Degree of Willingness to Act*)?
3. What connections, if any, are there between students' *Believed Usefulness of Action* and their *Degree of Willingness to Act* for these eight actions?
4. To what extent are national cultural variables associated with any differences found between students' *Believed Usefulness of Action* and *Degree of Willingness to Act*?

Table 5.1 Socio-cultural dimensions or orientations

Socio-cultural indices, dimensions or orientation	Some features of these dimensions
Survival vs self-expression	Countries aligned with self-expression values tend to be post-industrial and relatively wealthy with political and economic stability – survival is taken for granted. The opposite is the case in countries with low survival values.
Small vs large power distance	Measures the way power is distributed across members of a society. Low power-distance countries (e.g., UK and Australia) are more consultative and democratic; conversely in high power distance countries (e.g., Brunei and Oman) there is an expectation that power will be more differentially distributed.
Individualism vs collectivism	More individualistic cultures (e.g., USA, Australia and UK) orient towards self-sufficiency whereas collectivist cultures (e.g., Singapore and Korea) tend to appreciate more, for example, the extended family.
Autonomy (intellectual and affective) -Embeddedness	*Embedded* societies derive meaning from identification with and participation in the *group*. People in *Autonomic* cultures are individualistic and expect to seek their own preferences. In the latter *Intellectual Autonomy* refers to individuals who generate their own cognitive ideas while *Affective Autonomy* refers to individuals who engage in personally-affirming behaviours.

Hofstede (2001), Inglehart and Welzel (2005), Schwartz (2014)

5.5 Method

5.5.1 Questionnaire Design and Administration

A closed-form questionnaire was employed to investigate students' willingness to act on certain pro-environmental measures. Their beliefs in the efficacy of these same measures in reducing global warming was also determined. The instrument contained two sections. The first had 8 items related to how willing students would be to support, undertake or vote for certain measures; there were five possible responses. The questions were worded in such a way as to draw attention to a 'deterrent' to agreeing to act in that way, such as 'even though it might stop me doing some of the things I really enjoy'. This introduced a degree of realism in to the questions – that reducing global warming has some personal costs – and avoided all students responding positively to every item. These responses gave a measure of students' *Degree of Willingness to Act.* The second section had items determining students' beliefs about the efficacy of the eight actions in reducing global warming, again with five responses. Analysis of the responses to the second set of items gave a measure of students' *Believed Usefulness of Action* . Although the items in the two sections were paired, they were in different orders so that this was not immediately obvious. These items took the form of 'If …., global warming would be reduced by…' (Table 5.2). These responses to the two sets of items were designed to be semantically matched, so there was some "measurement correspondence"; this

Table 5.2 Wording of the questionnaire items, here displayed so that the 'pairing' of the items can be seen

Theme	*Degree of Willingness to Act*	*Believed Usefulness of Action*
Legislation (Vote for)	I would vote for a politician who said they would bring in laws to help the environment, even though it might stop me doing some of the things I really enjoy	If politicians made the right kind of new laws, Global Warming would be reduced
Taxation (Vote for)	I would vote for a politician who said they would increase taxes to pay for things that would help the environment, even though it meant me having less money to spend	If politicians made people pay more tax and spent the money on the right kind of things, Global Warming would be reduced
International Agreements (Vote for)	I would vote for a politician who said they would sign agreements with other countries to help the environment, even though I might have to change the way I live	If there could be more agreements between different countries about not putting certain gases into the air, Global Warming would be reduced
Education (support)	I would like to learn more about helping the environment, even though it would mean extra work for me	If people were taught more about it, Global Warming would be reduced
Transport (use)	Even if it took me longer and was more inconvenient, I would try to use buses and trains instead of a car	If people didn't use their cars so much, Global warming would be reduced
Transport (type)	Even if it was not as fast or luxurious, I would try to get a car that uses less petrol or diesel	If people had smaller cars that used less petrol or diesel, Gloabl Warming would be reduced
Power generation (renewable)	Providing more of our energy was produced from the wind and waves and sun, I would be willing to pay more for electricity	If more of our energy was produced from the wind, waves and sun, Global Warming would be reduced
Power generation (nuclear)	Providing more of our energy was produced from nuclear power stations, I would be willing to pay more for electricity	If more of our energy was produced from nuclear power stations, Global Warming would be reduced

The items of the questionnaire are displayed so that the 'pairing' of the items can be seen. In the actual questionnaire the pairing was covert because these items were embedded with others that were all in random order, and items were in different orders in the two main sections; the pairing was covert

improves the predictive behaviour of questionnaires (Kaiser et al., 1999). Thus, other factors being equal, one might expect that the greater the perceived efficacy of a particular action, the more likely that action would be undertaken. For instance, if an individual thought that an action reduced global warming 'by nothing at all really', it would be reasonable if that person responded that they would 'probably not' undertake it. The way in which the responses to both sets of items were scored is shown in Table 5.3.

Table 5.3 Wording of the permissible responses to the two sets of items

Believed Usefulness of Action If I thought an action would help global warming by…	Score	*Degree of Willingness to Act* Then I would…	Score
by quite a lot	1.00	definitely (do it)	1.00
by a fair amount	0.75	almost certainly (do it)	0.75
by a small but useful amount	0.50	probably (do it)	0.50
by a very small amount – hardly noticeable	0.25	perhaps (do it)	0.25
by nothing at all really	0.00	probably not (do it)	0.00

The questionnaire was originally devised for use in the UK with English-speaking students (n = 952). Subsequently it was administered in ten other countries. For use in the other countries where the teaching language was not English, the questionnaire was translated into the teaching language. It was then back-translated, independently by another person, into English. Next, the back-translated version was compared to the original English version by native English speakers. Where inconsistencies were found they were corrected by iterative discussions between the English researchers and those in the target country.

Questionnaires were completed individually in normal classroom conditions under the supervision of the students' usual classroom teachers and/or one of the researchers. Although the questionnaires were completed under examination conditions, no time limit was imposed and teachers assured the students that the results would be anonymous.

5.5.2 Analyses of Data and Construction of Novel Indices

The responses were encoded as described above and statistical analyses undertaken using SPSS. Following this, various novel indices were constructed to quantify the relationships between students' willingness to undertake actions and their belief in the efficacy of those actions. The measures of the *Degree of Willingness to Act* for a particular measure were plotted against the value of the *Believed Usefulness of Action* for that action and the regression line fitted. This produced a graph of the type shown in Fig. 5.1. Although there are drawbacks to using ordinal scales (Reid, 2006), semantic matching of the responses (Table 5.3) ensured that linear regression was less sensitive to such limitations. We termed the gradient of the trend line the *Potential Effectiveness of Education*. Two other indices were derived from the intercepts of this trend line. Of interest in this paper is the intercept when the *Believed Usefulness of Action* is zero; it shows the likely action of students who believed that such an action would be ineffective in reducing global warming; we designated this the *Natural Willingness to Act* (*NWA*): the *NWA* and other indices are shown in Fig. 5.1.

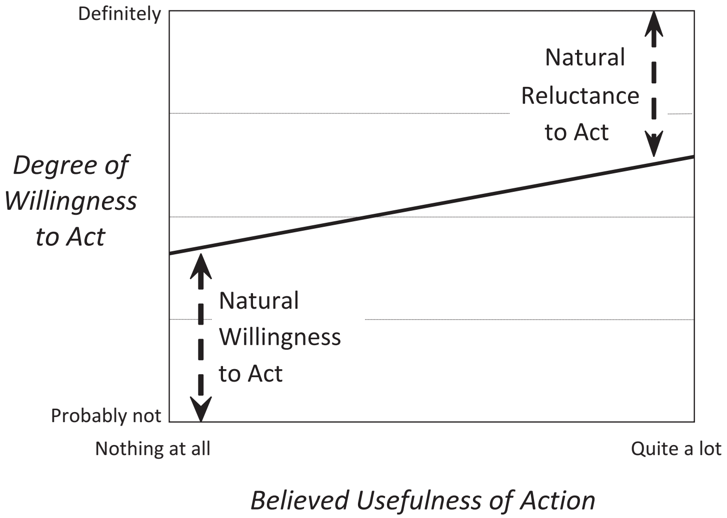

Fig. 5.1 Annotated graph to illustrate the Natural Willingness to Act, the Natural Reluctance to Act and the gradient of the slope – the Potential Effectiveness of Education

5.5.3 Validity Issues

The items on the questionnaire were representative of direct and indirect actions that have been identified as reducing global warming (e.g. IPCC, 2014; Maslin, 2014). Three science education researchers with backgrounds in physical, chemical, environmental and social sciences agreed on the selected actions and item wording. The questionnaire therefore captures the key ideas in the conceptual space related to the purposes of this study. Its items link directly with the study's research objectives and questions. Items also used language that upper primary and secondary students would understand; the questionnaire was field tested with 134 year 8 students and discussed with teachers before final wording was agreed. Reliability was addressed by ensuring that the items were clear and unambiguous, the administration of the questionnaire was always by teachers in the normal educational setting and there was not a time limit. Many aspects of face, content and construct validity and reliability were therefore met (Cresswell, 2015; Neuman, 2013).

5.6 Results

The questionnaire was completed by 12,627 students in USA-equivalent Grades 6 through 10 (19% in Grade 6, 20% in Grade 7, 20% in Grade 8, 20% in Grade 9 and 21% in Grade 10). Of the students, 51% were male and 49% were female. Characteristics of the sample are in the Appendix.

Table 5.4 Belief in the effectiveness for each of the eight measures (B) and willingness to act (A)

	Taxation		Legislation		Intern Agreements		Use buses		Smaller cars		Use renewables		Use nuclear		Support more EE	
	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A
Australia	40	19	49	30	70	24	66	18	56	37	68	32	38	10	56	36
Brunei	43	34	57	57	68	49	68	31	50	56	68	36	43	26	65	75
Greece	39	26	50	41	58	38	64	36	56	36	63	39	38	25	51	57
India	58	60	65	75	74	71	79	58	66	69	70	49	60	49	79	78
Korea	42	22	48	36	62	26	79	37	73	31	69	36	60	19	55	31
Oman	57	46	73	62	73	65	72	32	65	50	63	50	54	33	73	80
Singapore	47	35	61	50	74	51	80	53	69	53	78	**21**	59	21	70	58
Spain	47	31	59	45	79	38	78	44	58	50	78	48	38	14	57	50
Turkey	51	47	42	48	63	49	60	34	58	57	62	38	52	30	82	83
UK	37	16	43	21	59	22	68	19	50	21	65	23	47	10	49	23
USA	36	19	46	30	64	24	61	20	68	38	66	37	44	13	56	36
Overall	45	32	54	45	68	41	71	36	60	44	69	40	48	23	63	55

The unprocessed results are shown in Table 5.4, which reports the percentages of students from different countries who believed that various actions would be effective in reducing global warming and the percentages of those willing to take each action. For clarity, the *Believed Usefulness of Action* figures are the combined percentages of those who believed that the action would reduce global warming 'by quite a lot' and 'by a fair amount'. Similarly, the *Degree of Willingness to Act* figures are the combined percentages of students who would 'definitely' and 'almost certainly' undertake the action.

5.6.1 Country Differences in the Believed Usefulness of Action

Comparing the overall figures for all countries, it appears that students had reasonable confidence in the efficacy of an Herman Type 1 action, passive actions needing little personal investment such as more Environmental Education (overall 63%), with students from Turkey, India, and Oman showing most belief. The majority of students also thought that Hermann Type 2 actions, exemplified here by use of smaller cars or public transport, could reduce global warming, although belief in the latter was stronger (60%, 71%). Students from India, Korea and Singapore appeared to have the most confidence in these measures, although students from Spain also had confidence in public transport and students in the USA had belief in the effectiveness of smaller vehicles. About half of the students believed that governmental initiatives such as environmental taxation (45%) or legislation (54%) would be effective, but there was more belief in international treaties (68%) – these would be categorised as Type 3 proposals. Here, students in India and Oman showed a relatively high level of confidence in all three government actions, young people from

Singapore had confidence in legislation and international treaties, and students from Spain also believed in such treaties. The use of non-carbon-based energy sources such renewable energy (69%) or nuclear power (48%) might be considered Type 5 activities. Students from India, Spain and Singapore appeared relatively confident in the use of renewable energy sources to reduce global warming; students from India, Korea and Singapore were comparatively confident in the efficacy of nuclear power in this context, although at a lower level than for renewable energy.

5.6.2 Country Differences in the Degree of Willingness to Act

Overall, about half of the students (55%) were willing to undergo more environmental education, with students from Turkey, India and Oman being most willing. When it came to changing behavior about personal transportation, overall, about a third of students (36%) were willing to travel by bus, but more (44%) were willing to use smaller cars. Students in India and Singapore were the most willing to use buses, with students in India, Turkey and Brunei being most prepared to make use of smaller cars. Under half of the students overall were prepared to support increased environmental legislation (45%) or international agreements (41%), but fewer still (32%) were willing to countenance increased taxation. Students in India and Oman were the most supportive of environmental legislation, international agreements and taxation, although the last of these was at a lower level. Finally, under half of the students overall (40%) were prepared to support the use of renewable energy sources, and even fewer (23%) felt able to consider the use of nuclear energy. Here again it appeared that students in Oman and India were the most willing to support the use of renewable energy sources, although this was true of students in Spain too. Students in India and, to a lesser extent Turkey, were prepared to support the use of nuclear power.

5.6.3 Associations Between **Natural Willingness to Act** *and Cultural Indices*

It was decided that the most useful measurement to explore the relationships between environmental attitudes and cultural indices was the *Natural Willingness to Act* (*NWA*). This, as described above, is a cohort (or country) measure predicting the willingness to act when it is believed that no benefit to global warming will result. The NWA values for the 8 actions across the 11 countries are in Table 5.5 and the results of the correlations are shown in Table 5.6. Although there were no statistically significant correlations of the NWA with some cultural values and orientations (e.g., masculinity-femininity, traditional-secular rational and

Table 5.5 Means for Natural Willingness to Act for Taxation (Tax), Legislation (Law), International Agreements (IA), Environmental Education (EE), public transport (Use bus), smaller cars and renewable and nuclear energy

	Natural Willingness to Act							
Voting for/ supporting	Tax	Law	IA	Use Bus	Small car	Use renewables	Use nuclear	EE
Australia	0.25	0.29	0.26	0.24	0.44	0.26	0.22	0.33
Brunei	0.36	0.54	0.47	0.42	0.59	0.39	0.37	0.69
Greece	0.34	0.46	0.42	0.38	0.43	0.43	0.33	0.60
India	0.54	0.65	0.64	0.51	0.60	0.39	0.41	0.55
Korea	0.27	0.39	0.32	0.34	0.35	0.34	0.26	0.34
Oman	0.39	0.52	0.58	0.30	0.55	0.53	0.35	0.73
Singapore	0.31	0.40	0.33	0.38	0.51	0.34	0.29	0.43
Spain	0.31	0.40	0.32	0.30	0.45	0.36	0.21	0.41
Turkey	0.46	0.51	0.46	0.32	0.59	0.46	0.40	0.65
UK	0.16	0.24	0.23	0.19	0.29	0.24	0.20	0.27
USA	0.24	0.33	0.30	0.17	0.35	0.32	0.22	0.30
Overall	0.33	0.43	0.39	0.32	0.47	0.37	0.30	0.48

Table 5.6 Correlations between cultural variables and actions (NWA) related to the eight measures to reduce global warming

Cultural Orientation Value	Tax	Laws	IA	Use Bus	Smaller Car	Renew	Nuclear	EE
Embeddedness	ns	0.61*	0.69*	ns	0.71*	0.60*	0.63*	0.66*
Affective autonomy	−0.60 (p = 0.05)	−0.68*	−0.69*	ns	−0.75*	−0.74*	−0.64	−0.72*
Power-distance	0.66*	0.82***	0.73*	0.77**	0.80**	0.65*	0.77*	0.81**
Survival-self-expression	ns	−0.60 (p = 0.05)	ns	−0.69*	ns	ns	ns	ns
Individualism-collectivism	ns	−0.61*	ns	−0.73*	ns	ns	ns	−0.59 (p = 0.05$_4$)

*<0.05, **<0.01, ***<0.001, *ns* not significant

uncertainty- avoidance dimensions: see Hofstede, 2001; Inglehart & Welzel, 2005), other cultural indices showed correlations with the NWA of some actions.

Those countries with a high *Embeddedness* culture (e.g., Oman, India and Turkey) in which people identify with and participate in the group tend to be those with higher NWA values, that is, those who are intrinsically willing to undertake a range of environmental actions. These include voting for environmental protection measures, using smaller cars, using alternative, non-carbon-based energy sources and undertaking more environmental education. In contrast, the countries in which the social mores are that of high *Affective Autonomy* (e.g., UK, USA and Australia), where individuals tend to behave in personally-affirming manners, show an intrinsic reluctance to undertake those same environmentally-sympathetic actions.

There were also statistically significant positive correlations between the NWA values of the different countries and the *Power-Distance* cultural dimension. So, students in countries in which the social norm is that power is distributed differentially (e.g., Oman, India and Turkey) are more likely to have an innate willingness to undertake environmentally-sensitive behaviours, independent of their beliefs in the efficacy of such actions. Conversely, students in those countries with low *Power-Distance* social mores (e.g., UK, Australia and USA) – that is, arranged in a more democratic and consultative manner – are less likely to undertake environmentally sympathetic behaviours. The actions described above applied to *all* of the types of actions studied.

For two of the actions, willingness to support environmental legislation and preparedness to use public rather than private personal transport, there were statistically significant correlations with two cultural dimensions, *Survival* versus *Self-Expression* and *Individualism* versus *Collectivism*. Those countries that are relatively wealthy, politically stable and economically secure, and where physical survival is the norm (e.g., USA, Australia and UK) are less willing to pursue environmentally sympathetic behavior in terms of personal transport and accepting eco-friendly legislation. The opposite appears to be true in countries with comparatively less economic and political security (e.g., Turkey and India).

The same two pro-environmental behaviours appear to be associated with the *Individualism* versus *Collectivism* cultural dimension. Individualist countries (e.g., USA, Australia and UK), which are inclined to be orientated towards self-sufficiency, tend to be those in which there is less of an innate willingness to modify methods of personal transport or to accept environmental legislation. In a complimentary manner, collectivist countries (e.g., Brunei, India), in which the extended family is more valued, tend to be those in which these two environmental actions are accepted.

5.7 Discussion

In the following, students' beliefs in the effectiveness of various measures to reduce global warming will be discussed, followed by their willingness to act. Specific reference is made to countries mentioned in the 'Results' section. The impact of culture on their Natural Willingness to Act (NWA) will conclude this section.

5.7.1 Beliefs in the Effectiveness of Various Actions

More of these students rated use of public transport, followed by electricity generation from renewables and supporting international agreements as the most effective ways to reduce global warming. As, globally, electricity and heat production is the major source of greenhouse gas emissions, with transportation also a significant contributor (US EPA: see Conceptual Background), then, in relation to these options, a majority of these students' beliefs were well informed. The continuous efforts of the United Nations (2019) to obtain multilateral accord across nations, such as the Paris Agreement, is indicative of how necessary such international agreements are. Of the other options less than half of these students believed nuclear generated electricity and increased taxes would reduce GHG emissions. These are less informed beliefs because having a price on carbon is "one of the most effective means of curbing carbon-dioxide emissions" (Pizzer in Rosentrater et al., 2013, p. 417958) and nuclear generated electricity results in minimal GHG emissions, although not necessarily across its life cycle (Diesendorf, 2014). Apart from considering the financial impact on themselves, students may not appreciate that a tax on carbon would also impact industry and agricultural and other land use emissions which are very significant contributors to global emissions (US EPA, 2017).

Although belief in the effectiveness of these measures is warranted and student ranking does partially reflect the major sources of GHG emissions there is, overall, still a significant minority of students (and a majority in two instances) that do not believe such measures are effective and in some countries this was 60% or more (for taxation [Greece, Australia and Spain] and nuclear generated electricity [UK, USA, Greece and Australia]). Many reasons could account for the beliefs in the lack of effectiveness of some measures. These include: limited or alternative conceptions (e.g., confused ideas about the nature of nuclear energy and carbon emissions; that taxation would increase climate change); not accepting that global warming is caused by human activity; how the media and governments frame climate change; teachers' lack of certainty about some environmental issues; and 'wishful thinking' which is when measures perceived be effective are those that imposed the least financial burden (Skamp et al., 2019a, b).

In those countries where more students believed in the effectiveness of one or more of the actions (see 'Results') various self-reported attributes may contribute to their positive pro-environmental beliefs. More students, for example, self-reported they were environmentally friendly in Oman (86%), Turkey (79%) and India (76%); and, in addition to these countries, that global warming was real in Singapore (90%), Korea (85%) and Spain (80%). These data may be compared to countries where the lowest responses were found for beliefs in effectiveness: for environmental friendliness (UK 45%) and that global warming was real (UK 61% and USA 65%) (Boyes et al., 2014). There may, of course, be various contextual factors such as relatively more Korean students believing in the effectiveness of nuclear generated electricity because they have many such power plants (with no reported shutdowns) (International Energy Agency, 2013; World Nuclear Association, 2011) and more Spanish students believing in renewable energy because it produces more of its energy from renewable sources than any other country in the sample (MINETUR, 2014).

5.7.2 Willingness to Act on or Support the Measures

There was stronger support for the eight measures from students who self-reported they were better informed about global warming and/or were worried about it and/or thought it was real, and/or considered themselves environmentally friendly (i.e., India, Turkey, Brunei, Singapore, Oman) (Boyes et al., 2014; Skamp et al., 2019a, b). Although there is a loose connection between some of these variables and people taking action (e.g., see Aksit et al., 2018; Drews & van den Bergh, 2015), in this study there is an alignment between students' responses to these self-reported variables (high or low agreement with) and countries at either end of the willingness to act continua. Furthermore, for the above countries (India etc.), as well as South Korea, but not Singapore, there was no decline across the secondary school years in students' willingness to take some of the actions (e.g., vote for the three measures and support more environmental education) (Skamp et al., 2019b). This suggests that students in these developing countries could be experiencing more effective environmental education, although other variables could be responsible; for example, students in developed countries tend to be less interested in helping others and think that experts should look after environmental problems (Sjoberg & Schreiner, 2010).

Overall there was general support for Herman's (2015, p.24 and references therein) 'low-cost-high-cost model of pro-environmental behaviour', except that Herman's level 2 model of person investment (conserving energy) was usually less supported than level 3 (voting for government policies). Most support, overall, was for learning more about the environment (environmental education) (Herman, level 1), followed by being willing to vote for government pro-environmental policies (apart from taxation) (level 3), then conserve energy (use smaller cars, but less so for public transport) (level 2) and pay more for electricity from non-carbon emitting sources (level 4 or 5). This pattern persisted across countries whether at the high (India, Oman, Turkey) or low (UK, USA, Australia) end of willingness to take action to support an initiative, albeit at higher and lower percentage levels (Table 5.7). A possible interpretation for this variation is that these students interpret Herman's level 2 (conserving energy) category to be at a higher level of personal investment than voting for pro-environmental government policies (and this seems to be especially related to using public transport).

There are, of course, many variables that may be influencing students' willingness to take action to reduce global warming such as social-psychological factors, climate change perceptions and contextual factors (Drews & van den Bergh, 2015). Some of these have been considered above; also the impact of a range of specific contextual variables (e.g., trust in governments, availability of renewable and nuclear generated electricity) on each of the eight actions has been reported elsewhere (Boyes et al., 2014; Skamp et al., 2019a, b). In the following we specifically focus on the connection between students' beliefs in the effectiveness of the eight actions and their willingness to take those actions.

Table 5.7 Willingness to support actions requiring more personal investment

Country	Level 1	Level 2 Reduce energy		Level 3 Voting for government policies			Level 4 or 5 Pay more for pro-environmental electricity	
	Environmental Education	Smaller cars	Public transport	Laws	IA	Taxation	Renewable energy	Nuclear
Low end willingness countries								
UK	23	21	19	21	22	16	23	10
USA	36	38	20	30	24	19	37	13
Australia	36	37	18	30	24	19	32	10
High end willingness countries								
India	78	69	58	75	71	60	49	49
Oman	80	50	32	62	65	46	50	33
Turkey	83	57	34	48	49	47	38	30

Herman (2015)

5.7.3 *The Belief-Action Gap: Impact of Cultural Variables*

An inspection of Table 5.4 clearly indicates the disparity between the proportion of students who believe in the effectiveness of an action and their willingness to take the action. Overall the differences between belief and action were least for environmental education (8%) and voting for new laws (9%) and greatest for using public transport (35%) and electricity generated from renewables (29%). As indicated earlier (see 'Conceptual background' and 'Methods' sections) the impact of culture on these belief-action differences was investigated using the novel derived index, *Natural Willingness to Act (NWA).* The findings as shown in Table 5.6 report strong correlations (Pearson 'r' ranges from 0.60 to 0.81) between three cultural orientations and most of the actions to reduce global warming and correlations between two other cultural orientations and a smaller number of pro-environmental actions.

Countries with highly embedded (Oman 4.5, Singapore, 4, India 3.97, Turkey 3.77; cf. Spain 3.31, UK 3.34. Greece 3.41, Australia 3.59[5]) and power-distance (Oman 80, Singapore 74, India 77, Turkey 66; cf. UK 35, Australia 36, USA 40, Spain 57) cultures are positively correlated with seven and eight of the actions respectively. These two cultural indices have been positively correlated with each other in an environmental attitude study (Ng & Burke, 2010). As high affective autonomous cultures (e.g., UK 4.26, Greece, 3.92, USA 3.87, Australia 3.86; cf. Oman 2.87, Turkey 3.37, Singapore 3.3, India 3.46) have opposite characteristics to embedded cultures, it was not surprising that this orientation was negatively correlated with seven of the actions (and approached significance on the eighth). This presented a challenge as highly embedded and high-power distance countries have

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[5] The values for the cultural indices and orientations are from Hofstede (2001), Inglehart and Welzel (2005) and Schwartz (email communication 2017). Only examples from either end of the scales or dimensions are listed.

been associated with fewer environmental controls and their citizens can have a reduced capacity for sustainability actions for the environment (Husted, 2005; Schwartz, 2014). However, as embedded cultures identify with group cohesiveness and working towards group goals (Schwartz, 2011), then if students identify with school and familial settings that share pro-environmental values they may identify with them. As support for actions to reduce global warming did not fall across the secondary years in several of these countries then this may be the case. Furthermore, there is a similarity between students' (S) and adults' (A) support for international agreements in these embedded countries (e.g. India A: 70%, S: 71%; Turkey A: 56%, S: 49%), whereas the opposite is true in affective autonomous countries (e.g. USA A: 69%, S: 24%; UK A: 78%; S: 22%); this adds support for this interpretation. Similarly, people in authority positions (politicians, teachers) in high-power distance countries can have "a significant impact on the opinions' of their citizens" (Husted, 2005, p. 364), so if they espouse sustainability policies and actions, then students (in these countries) may align with their views. As there is a higher trust in governments in these countries compared to low power distance countries (e.g. India 78%; Singapore 78%; Turkey 57%; cf. USA 35%; UK 39%; Australia 49%) (OECD, 2017) then based on this assumption it would add support for the higher NWA trend. Consistent with these interpretations is that more students in collectivist countries (India 48, Turkey 37, Greece, 35; cf. USA 91, Australia 90, UK 89) supported two of the measures. As 'environment' is a more collectivist (than an individualist) construct (Sarıgollou, 2009), collectivist societies would be expected to support pro-environmental positions and actions. Such a view is consistent with adults in countries such as India and Turkey believing that taking action to reduce global warming will encourage other countries to follow (Kim & Wolinsky-Nahmias, 2014). This may be contrasted with high individualist and affective-autonomous cultures. The USA's culture, for example, has been characterized as "assertive, pragmatic, entrepreneurial, and even exploitative (towards) the social and natural environment" (Schwartz, 2014, p. 561). Finally, in countries where survival is taken for granted and people can concentrate of self-expression (USA 1.76, Australia 1.75, UK 1.68; cf. Korea −1.37. Turkey, −0.33, Singapore, −0.28, India −0.21), students appear less willing to take public transport or support more environmental laws. In more affluent countries students may prefer the convenience of their own transport and not support laws that may impede their day-to-day actions.

These correlations do suggest that 'cultural press' could be an influential variable in accounting for major differences in students' willingness to act on their beliefs. The contrast is stark between some countries and although Herman's (2015) 'low-cost highcost model of pro-environmental behaviour', as well as other student attributes and various contextual variables, may partially account for these cross-country differences, cultural press cannot be ignored.

5.8 Limitations and Further Research

As indicated, most issues in survey design and administration were addressed (see ‘Validity’). Sampling was not randomised, except for NSW, although it was representative where possible (see Appendix); hence complete generalizability cannot be assured. There are other limitations to this study. The cultural indices were derived from adult samples and are here applied to youth; in interpreting the student responses to the questionnaire it needs to be borne in mind that students may hold a range of alternative conceptions about the causes of global warming (e.g., Boyes & Stanisstreet, 1993; Dawson, 2015) and hence what actions could be effective. Also social desirability (Bang et al., 2000) and “belief” bias could influence their decisions: the latter is the “tendency to evaluate the validity of an argument according to whether it agrees with the (individual’s) conclusions or not, rather than on whether or not it follows logically from the premises” (Wu & Tsai, 2011, p.388). While it is appreciated that the cultural correlations are not necessarily cause and effect, the findings do suggest future research possibilities, such as whether cultural press is an antecedent or intervening variable. Even with these limitations we believe this study provides useful comparative insights into students’ beliefs, across five school year levels and 11 countries, about the effectiveness of measures to reduce global warming and their willingness to act on their beliefs.

5.9 Conclusion: Ways Forward

Superficially it would seem that a simple way forward in encouraging students to make rational decisions about how to reduce global warming and to take appropriate actions would be to increase their awareness of, and knowledge about, the causes of climate change, especially that it is primarily due to human activity. This has been found to impact ‘concern’ (Aksit et al., 2018; Sinatra et al., 2012), and (from the current and other authors’ studies) does appear to be linked to some extent to their beliefs about the effectiveness of various actions to reduce global warming, and then taking those actions. It has been mentioned that many other variables are also related to the students’ beliefs and willingness to act reported in this paper, and teachers need to be aware of these. However, what has not been previously highlighted is that students’ willingness to act on their beliefs about reducing global warming does appear to be influenced by their nation’s cultural press. How teachers address this issue is far more complex than a focus on conceptual understanding: how do teachers, especially in ‘affective autonomous cultures’, encourage students to move from thinking of themselves first, to what is best for society and the environment. Students need to be more willing to take actions at Herman’s (2015) higher levels.

Engaging students in a socioscientific pedagogical approach to the issue of climate change – see 'Introduction' – is a more challenging approach for teachers to take, but has had some success (as in Dawson, 2015; Herman, 2015); even so teachers still need to be cognisant that "socioscientific reasoning and decision making may often be subject to personal and sociocultural factors rather than logic, empiricism, and a familiarity with the nature of science" (Herman, 2015, p.3 and references within). When cultural press is added to such socioscientific contexts, then the complexity of science education, when considering real world issues, becomes apparent (cf. Wals et al., 2014). An appreciation of this 'cultural press variable' underlines why it is important for teachers and their students to understand "how the 'world is constructed' and especially the 'contemporary world' from other ethnic, religious, cultural, and social perspectives" (interpretation adapted from Gonzalez-Gaudiano & Meira-Cartea, 2010, p.29). Clearly these matters require pedagogical reflection by teachers before, and as, they engage students in thinking about the climate change crisis.

This study has outlined some of the challenges facing teachers of science when aiming to empower their students for climate change action. This wicked climate change (and climate change education) problem is "too urgent and important to suffer 'death by formal curriculum'" (Kagawa & Selby, 2010, p.242) yet teachers must work within such a framework. Implementing pedagogies associated with a socio-scientific issue approach has been suggested. If it is possible for science teachers to also include strategies that reconnect students to nature (and hence the Earth) (Lehtonen et al., 2018) then this sense of 'connectedness' may lead to an emotional response to climate change to support an intellectual response. This suggests a "need for the complementary and recursive use of artistic, embodied, experiential, symbolic, spiritual and relational learning" (Kagawa & Selby, 2010, p.242). As implied above, education to resolve (not solve) wicked problems requires considered reflection by science teachers and more complex pedagogies than the modification and formation of acceptable conceptual understandings (Jordan et al., 2014).[6]

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[6] Jordan et al. expand on some pedagogies to address wicked problems that could be applied to climate change education. They are: promoting careful observation and continual curiosity; have more conversations with diverse stakeholders; and engaging in collective and distributed sense-making.

Appendix

Sample Descriptions: Location and Other Characteristics

Country	Description of sample characteristics
Oman	12 schools in Muscat (capital city), Al Dakhlya and Batinah South regions. All the major centres in Oman (not just Muscat) were included, hence "purposeful". Within each centre, students were randomly selected. Policy dictated that all grades were single sex.
South Korea	13 accessible schools—4 elementary (grade 6), 4 middle (grades 7–9) and 5 high (grade 10)—from the Seoul metropolitan area; characterised as "medium" SES.
Greece	3 different areas of the Thessaloniki metropolitan area (the second largest Greek city): east, centre and west side, corresponding to 3 SES levels: high (east and centre), medium (centre/west) and low (west). The sample is representative (in terms of religious, linguistic, cultural or ethnic characteristics) of the Greek urban student population, hence "purposeful".
USA	California (urban), Ohio and Florida (suburban) and Minnesota (rural), hence "geographic" and "type of locality" range.
Singapore	5 different schools (elementary, junior high and senior high) in different communities. SES of students differs markedly from family to family and school to school. Many ethnic groups are represented—"official" languages are English, Chinese, Tamil and Malay but most speak English at school.
India	4 large English medium schools in metropolitan Delhi. These fee-paying schools drew largely from predominantly Hindu, middle and upper middle class families (medium to high SES) although some free places were reserved for "disadvantaged" students.
Spain	6 government schools in medium SES areas of Madrid (city area and Alcorcon and Tres cantos).
England	4 suburban social catchment area state (i.e. non-fee-paying) community comprehensive (i.e. non-selective intake) schools in the north west of England—with no formal religious association.
Brunei	Government schools, except for some private secondary schools.
Turkey	3 randomly selected primary schools (grades 6 through 8) and 2 secondary schools (grades 9 and 10) in Kırşehir, a city in central Turkey (of medium SES across Turkish cities).
Australia	Government schools in NSW were randomly selected; this resulted in 5 primary and 3 secondary schools located in cities and large and small regional centres—all were in medium SES areas.

Location, social economic status (SES)—high, medium, low—and other relevant school features are listed. These descriptions and indicators were provided by authors from the respective countries. Further details about most samples are in related refereed publications focusing on findings from the overall global warming questionnaire for specific countries. These are too numerous to cite but may be located by surveying publications by the authors from the different countries represented in this paper

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Chapter 6
Using Socioscientific Issues to Promote the Critical Thinking Skills of Year 10 Science Students in Diverse School Contexts

Vaille Dawson and Grady Venville

6.1 Introduction

School science is an ideal subject to develop critical thinking skills such as argumentation. Individuals not only require an understanding of scientific concepts, but they require critical thinking skills to be able to analyse and synthesise scientific evidence. While this outcome of school science may seem simple, the field is complex with little agreement about what does and doesn't work. Despite a mandate internationally to integrate critical thinking with science content (e.g., Australian Curriculum Assessment and Reporting Authority [ACARA], 2019), there are concerns and uncertainty amongst science teachers about how to develop these skills in their classrooms (Nielsen, 2012). The research presented here describes and evaluates the development of the cognitive critical thinking skill of argumentation (Facione, 1990) in science. The conceptual framework that informs this study comprises critical thinking, argumentation and socioscientific issues.

6.1.1 Critical Thinking

Critical thinking is the main theoretical construct that underpins this research. Critical thinking is the ability to think rationally and reflectively when deciding what to believe or do. An important aspect of critical thinking is the ability to construct and evaluate arguments (Ennis, 1985). Facione (1990) developed an extended

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definition of critical thinking through a Delphi study that related rational and reflective thought to judgment and decision-making. He explained that critical thinking comprises both cognitive skills and dispositions. Specific cognitive skills and subskills have been identified including analysis, evaluation, interpretation, explanation, and argumentation (Abrami et al., 2015). Critical thinking dispositions identified include open-mindedness, flexibility, curiosity, and suspending judgement.

Abrami et al. (2015) reported a comprehensive meta-analysis of over 400 quasi-experiments and experiments where critical thinking skills were taught. The most effective approaches were those that used a combination of pedagogical strategies: *authentic, situated real-world problems* such as role plays; *dialogue comprising teacher-led discussion* which could be whole class or small group, face to face or online; and *coaching*, which was defined as explicit modelling, questioning, and probing by the teacher and peers. These three pedagogical strategies of authentic contexts, teacher-led dialogue, and individual coaching have been effectively implemented with adolescents to improve their critical thinking skills in science classrooms (Zohar & Ben-David, 2008; Zohar, 2004).

Zohar and Ben-David (2008) concluded that explicit instruction in critical thinking skills in middle school science classrooms seemed to benefit low achieving students more than high achieving students as high achieving students often were already able to demonstrate the skills unaided. This was an important finding that guided the study reported in this paper that focused on students in diverse school contexts.

The development of *critical and creative thinking* is a general capability of the Australian curriculum, the country in which this study was conducted, and is required to be integrated into all subjects (ACARA, 2019). Critical thinking skills can be developed in school science lessons, however, some science teachers are reluctant or unable to explicitly teach them. Reasons include a perceived lack of suitable resources, insufficient time due to a crowded curriculum, and science teachers' inexperience with teaching strategies that promote debate and discussion (Nielsen, 2012). There is also a perception held by some teachers that critical thinking skills are too difficult for some students, especially low achieving students (Warburton & Torff, 2005; Zohar et al., 2001). Yet, it has been shown that explicit teaching of critical thinking skills in school science can not only improve students' critical thinking but their science content knowledge as well (Zohar & Dori, 2003; Zohar & Nemet, 2002).

This study contributes to research on the teaching of critical thinking by using research outcomes on the use of argumentation and socioscientific issues as an explicit platform to develop secondary school students' critical thinking skills. The research was undertaken in diverse school contexts and included early career teachers, experienced teachers, and students of variable academic abilities. The study is representative of the theme of the book because the teaching of critical thinking skills like argumentation would appear to be an obvious and simple thing to do for experienced teachers; however, for the reasons outlined above, the classroom reality is very complex. Teaching argumentation is challenging and the ways to best enhance learning are contested, in particular with the added pressures of limited time and resources.

6.1.2 Argumentation

Argumentation can be defined as a process where an assertion or claim is developed along with supporting reasons and justifications. An argument (written, oral, or thought) is the product and comprises a claim with data or evidence and may also include a warrant, backing, qualifier, and/or rebuttal (Toulmin, 2003). Because argumentation and debate about competing claims form the basis for the development of new knowledge in science, there have been calls for argumentation skills to be taught in science classrooms (Sadler, 2004) and more recently in national curriculum documents (e.g., ACARA, 2019).

It has been shown that improving students' science knowledge alone does not improve their argumentation skills. Rather, it seems that knowing how and when to use scientific or other knowledge is important (Shea et al., 2015). Providing students with opportunities to practice evaluating and justifying both written and oral arguments in an engaging context can help them develop their critical thinking skills. Encouragingly, in a 3-year study, Crowell and Kuhn (2014) found that the development of argumentation skills was not only sustained but led to substantial improvement in those students with low skills initially.

There has been debate about how best to teach argumentation skills (Erduran, 2008; Sampson & Clark, 2008). A range of student-centred authentic approaches have been used in science classes with controversial issues emerging as useful contexts to engage students in scientific debate about the types of issues they may encounter as adults. Some authors (e.g., Osborne et al., 2004) advocate the use of Toulmin's argumentation model as a scaffold for students. Toulmin's model provides clarity and guidance for novices (teachers and students) regarding the structural elements of an argument.

Assessing the quality of arguments developed by students also has proven problematic. While Toulmin's structure provides guidelines to help students learn to develop an argument by including the elements of data, backings etc., critique has emerged around the use of Toulmin's argumentation model to assess argumentation quality (Erduran, 2008). Using Toulmin's model, the structural components of a high-level argument (e.g., backings, qualifiers, rebuttals) could be present, yet the content could contain incorrect data or illogical reasoning. As a result, other methods of measuring argument quality have been advocated including examining the complexity of the argument (e.g., presence of grounds and justifications), the types of categories, and type of reasoning (Venville & Dawson, 2010; Sadler & Zeidler, 2005). Measuring the types of categories in an argument can demonstrate a consideration of multiple perspectives (Dawson & Carson, 2018; Sadler & Donnelly, 2006). Sadler and Zeidler (2005) examined the types of informal reasoning (intuitive, emotive, and rational) used by undergraduate science and non-science majors when constructing arguments about socioscientific issues in genetics. They found that science majors not only had a better understanding of genetics but they used rational arguments more frequently that non-science majors.

This study addressed this confounding complexity related to research on argumentation through its use of two concurrent methods to evaluate the quality of written arguments. In this study, Toulmin's argument structure and the number of types of categories are used to measure argument quality about a climate change socioscientific issue and Toulmin's argument structure and type of informal reasoning (rational, emotive, intuitive) are used to measure argument quality in a genetics context.

6.1.3 Socioscientific Issues

Socioscientific issues (SSI) are topics that are contentious, have an underlying scientific basis, and are of interest or concern to human society (Sadler & Dawson, 2012). They may raise ethical, legal, environmental, economic, religious, political, or social concerns. Often the underpinning science is multidisciplinary and contested, with no clear-cut solutions to the issues. Examples of SSI that have been used in school science settings to improve student learning include gene technology, climate change, and mobile phone use. Because of their contentious, multidisciplinary and social nature, SSI are complex and demanding for students to comprehend. A challenge for science teachers, therefore, is to find the right balance between simplifying the SSI enough to engage students and to allow them to learn how to argue and make decisions while doing justice to the real-world multi-layered complexity of these issues.

In making decisions about SSI, the skills required align with those of critical thinking. Individuals need to: weigh up risks and benefits; analyse and critique evidence; suspend judgment; cope with competing demands; consider the rights of multiple stakeholders; and choose from a range of options. As recommended by Abrami et al. (2015) SSI can provide the types of authentic real-world problems that are not only stimulating and engaging but provide a platform for applying critical thinking skills.

In this study, two of the four cases focus on the SSI of gene technology (Cases A and B) and the remaining two on climate change (Cases C and D). These SSI were selected as the underlying science aligns with the Year 10 Australian science curriculum topics of genetics and Earth science respectively. Gene technology is a rapidly changing and complex field of science. The farming of genetically modified crops, increasing availability of genetic testing for single gene and multifactorial disorders, forensics, paternity, and ancestry DNA testing all raise ethical, medical, and legal issues. Climate change was chosen as it is a controversial, multidisciplinary, global issue that affects all young people. The underlying science is complex and publicly contested and there are political, environmental, economic, and ethical aspects. This study contributes to research on SSI by demonstrating their implementation and impact in diverse classrooms.

The aim of this research was twofold. First, the aim was to explore the effect of explicitly introducing the critical thinking skill of argumentation in the context of SSI in diverse school and classroom contexts. Second, the aim was to describe and analyse how different teachers use argumentation about SSI in diverse school contexts.

The research questions addressed in this research were:

1. Does explicit teaching of argumentation about SSI improve Year 10 students' argumentation skills?
2. How do teachers develop critical thinking skills using argumentation about SSI in diverse schools?

6.2 Research Method

A multiple case study design with participants from four Western Australian schools was developed to address the research questions (Merriam, 2009). In each of the cases (A, B, C, and D), a science teacher participated in a professional development workshop on gene technology or climate change science, argumentation skills, and SSI, and then subsequently taught argumentation to their Year 10 students. Quantitative data comprising a pre- and post-instruction questionnaire and qualitative data including lesson audio-transcripts, classroom observation field notes, teacher and student interview transcripts, teacher and student work samples were collected during each case study. The multiple data sources allowed triangulation and cross case analysis to ensure the rigour of the research design.

University and school sector ethics approvals were obtained prior to commencing the study. The schools, teachers, and students are not identified and pseudonyms are used throughout. The cases were selected for maximum diversity based on teacher experience, school sector, NAPLAN (National assessment program – literacy and numeracy) results, and the schools' ICSEA (Index of Community Socio-Educational Advantage). NAPLAN is a test conducted annually throughout Australia in Years 3, 5, 7, and 9 to measure students' literacy and numeracy skills. Comparisons can be made between the school and Australia-wide results. ICSEA is a measure of socioeducational advantage that allows comparisons of socioeconomic status to be made between schools across Australia. ICSEA is set at an average score of 1000 with a standard deviation of 100 (*My School*, 2018). School level ICSEA and NAPLAN results are published annually on the *My School* website.

6.2.1 Sample and Context

6.2.1.1 Case A

Case A is a low ICSEA, coeducational government school with low NAPLAN results and an early career science teacher. Miss A has a bachelor degree in biology and is in her second year of teaching. The school has an ICSEA value in the bottom quartile and could be described as socioeducationally disadvantaged. In the

NAPLAN, students in Year 9 performed substantially below the Australian average in both literacy and numeracy (*My School*, 2018).

Miss A taught argumentation in the context of genetic testing and genetically modified foods to her Year 10 class with 23 students over two 55 min periods as part of a 10 week genetics topic covering DNA, genes and chromosomes, autosomal and sex-linked, dominant and recessive inheritance, common single gene genetic disorders and genetic engineering. A total of 13 students completed both the pre- and post-instruction questionnaire of genetics understanding and argumentation about a genetics SSI. The lessons were observed and comprehensive field notes were recorded. A comparison class (n = 21) who were taught the same genetics topic by an experienced science teacher without the argumentation lessons also completed the pre- and post-instruction questionnaire.

6.2.1.2 Case B

Case B is a medium ICSEA independent Christian school with above average NAPLAN results and an experienced science teacher. Mrs. B has a bachelor degree in biological science and has been teaching for 10 years. The school has an ICSEA just above 1000. In the NAPLAN, students in Year 9 performed above the Australian average in literacy and numeracy (*My School*, 2018).

Mrs. B taught argumentation in the context of forensic testing to her Year 10 class with 19 students over two 55 min periods as part of a 10 week genetics topic covering DNA, genes and chromosomes, autosomal and sex-linked, dominant and recessive inheritance, common genetic disorders and forensic testing. A total of 13 students completed both the pre- and post-instruction questionnaire of genetics understanding and argumentation about a genetics SSI. The lessons were observed and Mrs. B was interviewed. A comparison class (n = 17) who were taught the same genetics topic by Mrs. B without the argumentation lessons also completed the pre- and post-instruction questionnaire.

6.2.1.3 Case C

Case C is a high ICSEA coeducational government school with high NAPLAN results and an experienced science teacher, Mr. C has a bachelor degree in environmental science and has been teaching for 12 years. The school has a high ICSEA in the top quartile and could be described as socioeducationally advantaged. In the NAPLAN, students in Year 9 performed significantly above the Australian average in literacy and numeracy (*My School*, 2018).

The school had a focus on thinking skills in science. Mr. C taught argumentation about a climate change SSI to 25 Year 10 students who had recently studied an Earth sciences topic. The argumentation lessons were taught in the final two science lessons of the school year after completing an 8 week Earth Science topic. A total of 23 students completed both a pre- and post-instruction questionnaire. Six students were interviewed in groups of two. A comparison class was not available for this case.

6.2.1.4 Case D

Case D is a medium ICSEA independent boys' school with average NAPLAN results and an early career science teacher. Mrs. D has a bachelor degree in agriculture and is in her third year of teaching . The school has an ICSEA value that is close to the Australian average of 1000. In the NAPLAN, students in Year 9 performed close to the Australian average in literacy and above the average in numeracy.

Mrs. D taught argumentation about a climate change SSI to her class of 31 students over one 55 min lesson as part of a 4 week Earth Science topic covering global cycles, climate change and the enhanced greenhouse effect. A total of 26 students completed both the pre- and post-instruction survey. Six students were interviewed in groups of two. A comparison class was not available in this case.

6.2.2 Professional Development

Before the argumentation lessons, the four teachers participated in a half-day professional development workshop about strategies for teaching argumentation using SSI (Carson & Dawson, 2016). Mr. C had also participated in a 2 year *Thinking Science Australia* program using cognitive acceleration materials (Oliver & Venville, 2017).

Prior to the workshop, teachers were provided with pre-reading on SSI and argumentation. In the workshop, the teachers were exposed to ways of using SSI in science classrooms and their role in developing critical thinking skills and scientific literacy. Teachers were also introduced to the parts of Toulmin's argument structure using examples. They were provided with curriculum resources and learning activities which could be used to develop students' argumentation skills. The resources included contemporary information on genetics or climate change science and two writing frames related to gene technology SSI, or climate change SSI. The writing frames had been trialled previously with Year 10 science students (Dawson & Carson, 2018; Venville & Dawson, 2010).

6.2.3 Argumentation Lessons

A suggested format for the argumentation lessons was provided to the teachers: introduce the nature of SSI and controversy using familiar contexts; introduce the idea of how to convince or persuade others; explicitly introduce Toulmin's argument model using familiar examples; and practice and reinforce argument structure using writing frames with questions. However, the teachers were encouraged to modify the format and resources to suit their teaching preferences and their students. The approach taken in each case is outlined in the results.

Each of the writing frames comprised a scenario that raised a dilemma. The writing frames required users to role play a stakeholder and to make and justify a decision. They also included questions to scaffold the development of a quality argument and could be used by students individually, in small groups, or as a whole class. Following Sadler's (2004) recommendation to use local contexts to teach argumentation, two genetics SSI were provided, one on genetically modifed foods and another on prenatal testing for cystic fibrosis. The consumption of genetically modified foods is contentious in Australia and cystic fibrosis is one of the most common autosomal recessive disorders in Australia with all neonates tested at birth. One of the climate change SSI was about a government proposal to build a wind farm in Western Australia on farming land that was currently used for grazing sheep and cattle. The second climate change SSI was about a local government proposal to build a waste to energy treatment plant. The writing frames had been trialled previously in pilot study schools.

6.2.4 Data Sources and Analysis

6.2.4.1 Questionnaire

Students completed a written questionnaire at the start and end of the science topic (except for Case C where students had completed their Earth Science topic). The questionnaire comprised two parts. The first part assessed understanding of genetics (Cases A and B) or climate change science (Cases C and D) using multiple choice, true/false and open-ended questions. Total scores, with a maximum of 52 for genetics and 30 for climate change, were entered into SPSS. Differences in students' pre- and post-instruction scores were compared using a one-way repeated measures ANOVA. The second part comprised an SSI about designer babies (Cases A and B) or Hydrogen fuel buses (Cases C and D), where students were asked to make a decision (claim) and construct an argument to justify their decision. The students had not previously seen the SSI and scaffolding questions (which were in the writing frames) were omitted. The questionnaires and coding schemes had been previously trialled with a similar cohort of students.

The quality of the students' arguments was analysed using two methods. For all cases, the structural quality was assessed using Toulmin's argumentation framework (Toulmin, 2003). Two researchers blind coded the pre- and post-instruction statements and assigned a level and score from 0 to 4: Level 0 (score = 0) was no response; Level 1 (score = 1) included a claim only; Level 2 (score = 2) included a claim, data, and/or warrant; Level 3 (score = 3) included a claim, data, warrant, backing, or qualifier; and Level 4 (score = 4) included a claim, data, warrant, backing, qualifier, and/or rebuttal. For the designer baby SSI (Cases A and B) each statement was coded as rational (score = 3), emotive (score = 2), intuitive (score = 1) or 0 for no response. For the Hydrogen fuel bus SSI (Cases C and D) the number of types of categories (e.g., environmental, economic, ethical, human factors) were coded and recorded. All arguments were coded independently by two experienced researchers and inter-rater reliability was >91%. Data were entered into SPSS. Pre- and post-instruction levels for each group (experimental and comparison) were compared using a Wilcoxon Signed Rank Test. Differences between the experimental and comparison groups were analysed using a Mann-Whitney U Test.

6.2.4.2 Qualitative Data

Argumentation lessons were audio-recorded and fully transcribed and comprehensive field notes were recorded. The transcripts were analysed using a grounded theory approach to determine the effectiveness and extent to which the teachers supported the development of critical thinking by using authentic contexts, engaging in teacher-led discussion and questioned and probed individual students.

All teachers were interviewed after the argumentation lessons about their perceptions of what students had learned. For Cases C and D, six students of variable academic ability (selected by the teachers based on previous science achievement) were interviewed in pairs about their perceptions of the argumentation lessons. The teacher and student interviews were fully transcribed and analysed using an inductive approach for emergent themes.

6.3 Results

For each case, the questionnaire results are presented to answer research question 1 followed by classroom observations and interview findings (research question 2).

6.3.1 Case A

There were 31 Year 10 students enrolled in the experimental class of whom 23 attended each of the two lessons. Only 13 students completed both the pre- and post-instruction questionnaire. The low response rate was a combination of poor attendance, lack of return of consent forms, and unwillingness to participate even though the students seemed to enjoy the lessons. Permission was not given to conduct student interviews. There were 28 students enrolled in the comparison class, 21 of whom completed both the pre- and post-instruction questionnaire. Table 6.1 summarises the change in Case A students' understanding of genetics and their argumentation quality, before and after the genetics topic.

6.3.1.1 Genetics Understanding

The repeated measures ANOVA indicated that the students' mean scores on the genetics understanding part of the questionnaire for both experimental and comparison groups improved significantly over time, $p < .005$ for the experimental group with a large effect size (Cohen's $d = 1.14$) and $p < .05$ for the comparison group with a medium effect size ($d = 0.63$). This result was expected given that the students were studying genetics during the period between the pre-instruction and post-instruction questionnaires. The repeated measures ANOVA also indicated that the gain in the experimental group mean score on the genetics understanding part of the questionnaire was not significantly different from the gain in the comparison group mean score.

6.3.1.2 Argumentation and Informal Reasoning

A non-parametric Wilcoxon Signed Rank Test was used to compare the pre- and post-instruction argumentation levels. The Wilcoxon Signed Rank Test showed a statistically significant difference in the experimental group post-instruction levels of argumentation compared with their pre-instruction levels of argumentation ($p < .005$), with a large effect size (Cohen's $d = 3.15$). The comparison group argumentation levels also significantly improved ($p < .005$), with a large effect size ($d = 1.28$). A Mann-Whitney U test was performed to compare the difference in argumentation levels pre- and post-instruction between the experimental and comparison group. The Mann-Whitney U test showed that while the pre-instruction levels of argumentation in the experimental and comparison groups were not significantly different prior to instruction, the experimental group post-instruction level of argumentation was significantly higher than the comparison group post-instruction level of argumentation ($p < .05$).

The Wilcoxon Signed Rank Test showed a statistically significant difference in the experimental group post-instruction informal reasoning score compared with their pre-instruction informal reasoning score ($p < .0002$), with a large effect size ($d = 4.28$). The comparison group informal reasoning score also significantly improved ($p < .01$) with a large effect size ($d = 0.90$). The Mann-Whitney U test showed that while the pre-instruction informal reasoning score in the experimental and comparison groups were not significantly different, the experimental group post-instruction informal reasoning score was significantly different from the comparison group ($p < .05$).

6.3.1.3 Classroom Observations

Miss A had carefully planned the sequence of activities for the two lessons which occurred on consecutive days. In the first lesson, she introduced the concept of SSI as 'a social or scientific issue, regarding the public'. She used teacher-led discussion to determine students' prior knowledge about how to persuade others and then provided examples of arguments asking students which were the 'best' and why. She introduced cystic fibrosis (the context of the writing frame SSI) as an autosomal recessive disorder and, using the writing frame, students worked through an SSI on prenatal testing for cystic fibrosis. She explicitly introduced the parts of an argument (claim, data, qualifier, backing, rebuttal) using the merits of the local football team as an example. She emphasised the need to provide evidence when convincing others. She played Devil's advocate and reinforced listening to views of peers.

At the start of the second lesson, students were asked to write the names and definitions of the parts of an argument using a think-pair-share. She had written the first letter of each part on the whiteboard. She returned to the cystic fibrosis SSI and led a whole class discussion. She encouraged role-taking ('put yourself in his shoes') and perspective taking ('from an ethical perspective, what if you knew…'). She emphasised that argument was about the quality of scientific evidence. She illustrated this with examples from the local community blog on fluoride in water and fishing from nature reserves and explained that sometimes, 'individuals make false statements and use false data'.

She introduced a second SSI on genetically modified foods. She observed that students written answers were brief and asked them to 'add more depth to your answers' (encouraging backings). She skilfully responded to individual student comments (e.g., 'you can't make assumptions' and she praised individual students' efforts (e.g., 'that is good decision-making, using and asking for evidence') and probed for more detail (e.g., 'Ok, we have had general rebuttals, how about being more specific?'). She concluded the lesson by explicitly stating the importance of argumentation skills. She stated, 'argumentation is an internal dialogue. Will I get in a car with a drunk driver? Will I stay at school? Ask questions. Consider the advantages and disadvantages, and reasons and arguments for and against'.

In summary, Miss A was able to effectively employ pedagogical strategies of familiar contexts, teacher-led discussion and explicit instruction in aspects of critical thinking.

6.3.2 Case B

There were 19 Year 10 students enrolled in the experimental class, 13 of whom completed both the pre- and post-instruction questionnaire. There were 20 students in the comparison class, 17 of whom completed the questionnaire. Table 6.1 summarises the change in Case B students' understanding of genetics and their argumentation quality before and after the genetics topic. Permission was not given for students to be interviewed.

Table 6.1 Cases A and B: Mean pre- and post-intervention genetics understanding, argumentation levels and informal reasoning scores

		Case A		Case B	
Group	Measure	Pre-instruction Mean ± sd	Post- instruction Mean ± sd	Pre-instruction Mean ± sd	Post- instruction Mean ± sd
Experimental (n = 13)	Understanding	14.7 ± 4.0	22.2 ± 8.3**	9.90 ± 6.6	24.2 ± 7.4***
	Argumentation level	0.46 ± 0.66	2.54 ± 0.66**	1.69 ± 0.48	1.77 ± 0.60
	Informal reasoning	0.15 ± 0.56	2.69 ± 0.63****	1.31 ± 1.11	2.00 ± 1.15
Comparison (n = 21)	Understanding	14.8 ± 6.6	18.9 ± 6.2**	14.1 ± 7.7	26.2 ± 10.5***
	Argumentation level	1.00 ± 0.95	2.29 ± 1.06**	2.24 ± 0.83	2.29 ± 0.85
	Informal reasoning	0.95 ± 1.40	2.29 ± 1.06*	2.35 ± 0.79	2.12 ± 0.99

* $p < .01$ ** $p < .005$ *** $p < .001$ **** $p < .0002$

6.3.2.1 Genetics Understanding

The repeated measures ANOVA indicated that the students' mean scores on the genetics understanding part of the questionnaire for both experimental and comparison groups improved significantly over time, $p < .001$ for the experimental group with a large effect size ($d = 2.05$) and $p < .001$ for the comparison group with a large effect size ($d = 1.32$) This result was expected given that the students were studying genetics during the period between the pre-instruction and post-instruction questionnaires. The repeated measures ANOVA also indicated that the gain in the experimental groups mean scores on the genetics understanding part of the survey was not significantly different from the gain in the comparison group mean score.

6.3.2.2 Argumentation and Informal Reasoning

The Wilcoxon Signed Rank Test showed that pre- and post-instruction argumentation levels and informal reasoning scores did not change significantly for either the experimental group or the comparison group.

6.3.2.3 Classroom Observations

The classroom observations go some way to explaining the quantitative results. Mrs. B was provided with the cystic fibrosis SSI used in Case A but was unable to use it with her students. In an initial interview, Mrs. B explained that she had introduced students to SSI and parts of an argument the previous lesson. She planned to conduct an activity on DNA family relationship testing which was based on a true case in the US where a young man appeared who claimed to be related to a family whose child had gone missing years earlier (Sampson & Schleigh, 2013).

At the start of the observed lesson, she used a prepared Powerpoint to provide examples of SSI (e.g., cloning to reduce birth defects and genetic testing for Huntington's disease). She provided a definition of argumentation and reintroduced the concept of a claim, evidence, and justification. Mrs. B spoke and didn't question students. She then introduced the DNA family testing activity by reviewing electrophoresis and STRs (short tandem repeats). Students were provided with copies of the STR family relationship analysis test and asked to work in groups of three to provide a claim, evidence and justification about whether the banding pattern for the young man matched the family and was the 'lost child'.

The students appeared to enjoy the activity and found it interesting and challenging. However, student discussion was predominantly about interpreting the electrophoresis results rather than argumentation. The students clearly wanted the 'lost child' to be part of the family and ignored evidence which showed the young man wasn't related. They gave more weight to data supporting their claim and ignored anomalies.

In summary, while Mrs B taught scientific content (e.g., DNA structure, alleles, STRs electrophoresis) through the use of an SSI in an authentic context, there were few questions asked by the teacher to reinforce argumentation skills.

6.3.3 Case C

6.3.3.1 Climate Change Understanding and Argumentation

There were 31 Year 10 students in the class of whom 23 completed both the pre- and post-instruction questionnaire on climate change science and argumentation. The experimental group's climate change understanding did not improve significantly, which was not surprising given students completed the pre-questionnaire after they had finished studying Earth Science. As shown in Table 6.2, there was a significant improvement in students' argument levels, ($p < 0.005$) with a large effect size ($d = 1.03$). The number of types of categories ranged from 0 to 4. In regards to the mean number of types of categories, there was a non-significant increase. The increase in categories was in the number of environmental and ethical reasons with no change in the number of economic and human factors.

6.3.3.2 Classroom Observations and Interviews

Mr. C taught argumentation to his top streamed Grade 10 class over two consecutive lessons. These lessons were conducted after students had studied Earth Science. He introduced the lesson by explaining that the purpose of the lesson was to 'learn how to practice constructing a sound argument in relation to environmental issues, in particular climate change. Now I know that climate change is controversial but why might it be controversial?' Mr. C questioned and probed students as they responded. He invited students to write responses on the whiteboard and grouped them into

Table 6.2 Cases C and D: Mean pre- and post-instruction climate change understanding and argumentation scores

Group	Measure	Pre-instruction Mean ± sd	Post- instruction Mean ± sd	Difference	Significance
Case C (n = 23)	Understanding	14.9 ± 3.7	15.4 ± 4.2	0.50 ± 3.5	NS
	Argumentation	2.00 ± 0.30	2.43 ± 0.51	0.43 ± 0.59	$p < 0.005$
	Number of categories	1.57 ± 0.66	1.91 ± 0.73	0.34 ± 0.88	NS
Case D (n = 26)	Understanding	13.0 ± 1.9	15.1 ± 2.9	2.1 ± 2.94	$p < 0.005$
	Argumentation	2.08 ± 0.39	1.96 ± 0.66	−0.12 ± 0.52	NS
	Number of categories	1.77 ± 0.82	1.65 ± 1.02	−0.12 ± 0.99	NS

NS Not significant

categories (e.g., physical, financial, human). In using authentic contexts, he asked two students to role-play a prepared argumentation dialogue between an environmental scientist and an oil executive about drilling for oil in a marine park. The class was asked to respond to the argument and analyse the strategies used by each person (e.g., collecting evidence, refuting evidence, providing backings). Mr. C was affirming and respectful of students' views. He explicitly reminded students about previous lessons using thinking skills.

In the second lesson, Mr. C used a PowerPoint he developed himself, which introduced the structure of arguments and used science related arguments to illustrate the components. Through whole class discussion, he reviewed the science of wind turbines and briefly reviewed climate change before students began a wind farm SSI in groups of three. Mr. C introduced the concept of trade-offs when making decisions and also questioning the sources of evidence. He played Devil's advocate in questioning, provided science information as needed and encouraged students to use their scientific knowledge.

In summary Mr. C used authentic contexts, expertly managed whole class and small group discussion, provided scientific knowledge as needed, and asked probing questions of individual students.

Mr. C enjoyed teaching the argumentation lessons and believed that some students 'walked away with a bit of an understanding about how to argue, at least in a more formal sense…about the structure…and these things like backings and qualifiers.' He believed argumentation is an important process for students to practice, as 'They're going to have to make these sorts of decisions and the reality is they might not go and do research…but they'll at least perhaps think about the pros and cons and what other information they need before they make a decision.' Students agreed that the lessons made them aware that there is more than one side to an issue: 'He showed us both sides, encouraged us to think of advantages and disadvantages on our own and… we had to think about it ourselves'. Students also became aware of how to structure a persuasive argument, with 'evidence and realistic data' and 'You got to use facts and evidence and then you have got to try and persuade them to agree to your side of the disagreement.'

6.3.4 Case D

6.3.4.1 Climate Change Understanding and Argumentation

There were 28 Year 10 students in the experimental class of whom 26 completed the questionnaire before and after instruction. The students' climate change understanding did improve significantly ($p < 0.005$) with a medium effect size ($d = 0.88$). In terms of argumentation levels, there was a non-significant decrease. The number of categories ranged from 0 to 3 and decreased post-instruction. There was a small increase in the number of environmental reasons, and a decrease in economic, ethical and human factors.

6.3.4.2 Classroom Observations and Interviews

Mrs. D introduced argumentation in one 55 min lesson to her top streamed Year 10 science class, as part of a 4 week Earth Science topic. In this lesson, she stated, ‘we’re going through a process called decision-making argumentation’. She introduced the concept of an SSI through discussion of a coal-fired power station and electricity supply and prices. Mrs. D stated that climate change was an SSI and discussed the structure and features of a quality argument using a provided role play of a fisherman and a marine scientist arguing about whether fishing should be allowed in marine reserves. Mrs. D used whole class discussion for the entire lesson, except for when students were writing on their wind farm writing frame. Due to impending exams and her concern about disadvantaging her students, only one lesson was allowed for SSI and argumentation.

The teacher agreed that she felt ‘really restricted on time’ but thought the students enjoyed the lesson because their ‘behaviour was a lot more interested and engaged than perhaps some of the previous lessons,’ and the students’ responses to ‘the questions and the prompting were quite high-level thinking’. She enjoyed teaching the argumentation and felt the wind farm scenario was particularly appropriate, given many of her students are from a farming background. She stated, ‘It was a lot more free discussion that they were able to engage in, whereas normally it’s quite a formal lesson that we go through where we take notes, then they do exercises to consolidate those notes’. This statement was supported by one student who stated, ‘You can compare it more to life and it was more applicable to what we do normally rather than just read out of a book.’

Despite no measurable improvement in students’ argumentation skills, all six interviewed students stated that they learnt how to develop arguments. For example, one student said he learnt that, ‘In order to make a good argument you actually need proof, evidence, reasoning…. Rather than just saying what you think, you need to back that up with proof’ and another stated, ‘we learnt about argument and how to provide a clear and concise argument using scientific facts’.

In summary Mrs. D worked through authentic contexts and led whole class discussion but there was insufficient time for student questioning.

6.4 Discussion

The selection of these four diverse cases aimed to examine pedagogical strategies used by teachers to teach argumentation and to determine the impact of teaching argumentation using genetics or climate change SSI. In all four cases, students were taught argumentation using authentic SSI, classroom discussion, and writing frames. Each case revealed different findings in relation to science understanding and complexity of argument structure and quality, when including argumentation in the science classroom.

In Case A, while understanding improved significantly in both the experimental and comparison groups, the argument quality improved significantly more in the experimental group. It is concluded that explicit teaching of argumentation and SSI together can improve students' written argumentation skills about an unfamiliar SSI in the same context. There was also a greater improvement in genetics understanding which was not significant, in part due to the small sample size.

In Case B, the teacher was provided with SSI and argumentation curriculum materials that had been used previously (Venville & Dawson, 2010). However, she was unable to use the materials. In the lesson, argumentation was introduced but not reinforced highlighting the complexity of teaching argumentation. She did use SSI but as a means of developing an understanding of DNA testing concepts. Tidemand and Nielson (2017) in their in-depth study of five Danish secondary school biology teachers also found that SSI were more likely to be used as a means of teaching science content rather than an opportunity to engage with an issue.

In Case C, high achieving students with an experienced teacher, demonstrated a significant increase in argument structural quality and a non-significant increase in the number of types of categories. The increase in argument quality cannot be attributed to an increase in content knowledge, as the students had completed the Earth Science topic before doing the pre-questionnaire. The teacher and these students had previously been exposed to critical thinking skills through *Thinking Science* (Oliver & Venville, 2017). They may thus have been 'primed' for improvement in demonstrating argumentation complexity, as proposed by Sadler and Fowler's (2006) Threshold Model of Content Knowledge Transfer.

In Case D, there was an improved understanding of climate change but no change in either argument structural quality or the number of types of categories. This lack of change could be explained by the reduced amount of time spent on argumentation (one lesson). Thus, a single lesson on argumentation may be insufficient to improve students' argumentation quality, despite improved understanding.

Argumentation is an example of a critical thinking skill and while this skill is complex and difficult to teach, our findings show there are simple steps that teachers are able to put in place to support student learning. Overall, we conclude that argumentation about SSI can be incorporated into traditional science topics in diverse schools without sacrificing improved science understanding (Cases A, B, and D). The improved argumentation skills cannot be ascribed to content understanding alone (Cases A, B, C, and D). It seems that the quality of argument is not about knowledge per se, but about knowing how and when to use that knowledge (Shea et al., 2015). We also conclude that a modest, explicit intervention of at least two 50-min lessons can demonstrate a measurable improvement in students' argumentation skills (Cases A and C). In contrast, a single lesson intervention (Case D) or implicit teaching of argumentation (Case B) does not result in a measurable improvement in argumentation.

There are several limitations in this research study that affect the strength of the findings. First, as with all case study research, the findings are not able to be generalised to other school settings, teachers, or students. We have endeavoured to provide sufficient context for the reader to evaluate the transferability of the findings.

There may be issues around the sensitivity of the instrument as all interviewed students in case D claimed that their argumentation skills improved and could provide detailed descriptions of how to construct an argument, and yet there was no measurable improvement. We recommend the use of an instrument that provides a more detailed investigation of reasoning as used by Romine et al. (2017). This, however, needs to be weighed up against ease of use.

In Cases A and B, students were not randomly assigned to experimental and comparison groups as classes had already been assigned prior to the study commencing. Cases C and D had no comparison groups with which to compare the experimental class. In our experience, it is not always possible to have a comparison class in busy schools where academic grades are important, and these types of interventions are seen as an 'extra' or 'add-on' for teachers to participate in.

6.5 Conclusion

As global citizens, students require the knowledge and skills to understand and think critically about complex SSI which they are likely to encounter. Argumentation skills can enable students to better debate these SSI. While complex and challenging pedagogically, teachers can take simple steps to support student learning of the critical thinking skill of argumentation. Our research showed that by providing teachers with professional development and appropriate teaching resources, argumentation using SSI can be used by both early career and experienced science teachers as a teaching strategy to improve diverse students' argumentation skills. It is recommended that preservice and in-service teacher professional development be provided to enable teachers to explicitly introduce their students to argumentation with an emphasis on authentic contexts, skilful questioning, and teacher-led discussion.

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Part III
Exploring the Development of Scientific Literacy

Chapter 7
Can the Complexities of Developing Students' Literacy Skills Around Physical Science Concepts Benefit from a Singular Approach to Teaching Academic Vocabulary?

Christopher Nielsen

7.1 Introduction

The complex construct of integrating literacy with science teaching and a need for evidence-based research on this subject has become a growing focus of researchers of science education (Hand et al., 2010; Jagger & Yore, 2012). It is acknowledged that vocabulary acquisition is an essential element of literacy development, particularly in regard to reading and writing (Cohen, 2012; Fang, 2006; Young, 2005). In discussing such complexities, Wellington and Ireson (2012, p.3) ask: "What should science teachers do about their specialist language and the language of secondary education?" Their suggestion is to "… treat language with care, to be aware of its difficulties, and to bear in mind that although pupils can and do use scientific terms in speech and writing this does not mean that they understand them" (p.3–4).

As the various domains of scientific inquiry have evolved, scientists have constructed descriptive and explanatory terminology through the use of vocabulary which conveys specific conceptual meaning. Sometimes the conceptual meaning of these words are unique to one domain. Complexity arises because sometimes scientific vocabulary can have multiple meanings which are context dependent, depending on the domain, or have a completely different meaning in an everyday context. In the physical sciences, students learn about interactions that occur within dynamic systems. Blown and Bryce (2017) contend that the development of a conceptual understanding of the dynamic relationships between the Earth, Sun and Moon involves a learning transition from everyday thinking (embedded) to abstract, symbolic thinking (disembedded). Blown and Bryce (2017) suggest that: "Perhaps most difficult are the ideas which involve dynamic concepts, ones where the movements of celestial objects have to be envisioned together in order to grasp what comes

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about and why" (p. 623). The transition between embedded and disembedded thinking can result in students shifting back and forth between every day and scientific language to communicate their understanding (Blown & Bryce, 2017). While the communication of this understanding can, and arguably should, be multi-modal (Anthony et al., 2010; Blown & Bryce, 2017; Tytler, 2018; Waldrip et al., 2010), both verbal and written expressions of disembedded thinking are directly associated with students' vocabulary acquisition (Wellington & Osborne, 2001).

Students can be challenged by these complex vocabulary requirements, sentence structure, use of passive voice and other language demands of scientific discourse (Cohen, 2012; Fang, 2006; Krajcik & Sutherland, 2010; Peacock & Weedon, 2002; Shanahan, 2012; Snow, 2010; Taboada, 2012; van den Broek, 2010). If these challenges are not addressed within the science classroom, student engagement may be lost and students may not wish to pursue the study of science (Krajcik & Sutherland, 2010; Pearson et al., 2010). Studies conducted by Cassels and Johnstone (1985), Farrell and Ventura (1998), Johnstone and Selepeng (2001), Marshall et al. (1991), and Pickersgill and Lock (1991) have found that the acquisition of science vocabulary in both primary and secondary classrooms has been hindered by pre-established student misconceptions, issues for teachers in teaching the correct use of words which have multiple meanings, and the need to specifically teach the meanings of words within a subject's context. These studies indicate a need to establish suitable teaching and learning experiences which would result in a reduction of students' incorrect usage of vocabulary in the science classroom. The issue is raised: can the complexities of developing students' literacy skills benefit from a singular approach to teaching academic vocabulary?

It has been found that science teachers should not assume that students arrive in the classroom with adequate skills in the language arts for the learning of science (Cohen, 2012; Rodriguez, 2010; Rupley & Slough, 2010; Taboada, 2012; Webb, 2009). Therefore, these skills need to be taught explicitly in a context that makes sense for all students (Bradbury, 2014; Cohen, 2012; Fang, 2006; Krajcik & Sutherland, 2010; Pearson et al., 2010; Rodriguez, 2010; Rupley & Slough, 2010; Shanahan, 2012; Young, 2005). In addition, it has been demonstrated that English Language Learners (ELLs), also referred to as English as Second Language (ESL) or L2 students, would benefit greatly in their acquisition of scientific knowledge through explicit, scaffolded instruction in the use of language arts skills whilst in the science classroom (Husty & Jackson, 2008; Moje et al., 2001; Rodriguez, 2010; Rupley & Slough, 2010; Webb, 2009; Webb, 2010; Yore & Treagust, 2006).

Jagger and Yore (2012) indicate that, despite a focus on the theoretical aspects of language in science teaching, there is a lack of evidence-based research which might benefit science teachers in choosing pedagogical practices for the purpose of improving literacy education. There is also considerable agreement that there is an identified need for professional development in integrating literacy for teachers of science, in order that these teachers may understand and best utilise the connections between literacy and science education (Bradbury, 2014; Fortino et al., 2002; Jagger & Yore, 2012; Johnson, Fargo & Kahle, 2010; Pearson et al., 2010; Shanahan, 2012; Yore & Treagust, 2006).

A small number of studies have been conducted in primary schools (August et al., 2009; Jackson & Ash, 2012; Kim & Linan-Thompson, 2013; Putman & Kingsley, 2009; Smith et al., 2013; Upadhyay & DeFranco, 2008) and in secondary schools (Miller, 2009; Shook et al., 2011) to investigate the effectiveness of various pedagogical strategies intended to integrate vocabulary instruction in the science classroom.

These studies have found that the following considerations may have an impact on the desired outcomes of a vocabulary integration program:

- the influence of students' prior knowledge (Miller, 2009; Upadhyay & DeFranco, 2008)
- activities which engage and motivate students to learn (Miller, 2009; Putman & Kingsley, 2009)
- students' cultural differences (Jackson & Ash, 2012; Miller, 2009)
- the language background of students – both ELL and non-ELL (August et al. 2009; Jackson & Ash, 2012; Kim & Linan-Thompson, 2013; Miller, 2009; Shook et al. 2011)
- contextualising vocabulary, rather than stand-alone usage (Jackson & Ash, 2012, Miller, 2009; Smith et al. 2013; Upadhyay & DeFranco, 2008)
- combining inquiry-based learning and explicit instruction (Jackson & Ash, 2012)
- use of direct instruction and self-regulation (Kim & Linan-Thompson, 2013) and student collaboration and self-regulation (Shook et al., 2011)
- word types – both technical and non-technical (Miller, 2009)
- providing multiple exposure to academic vocabulary (Putman & Kingsley, 2009; Shook et al. 2011)
- developing student comprehension through a variety of activities (Jackson & Ash, 2012; Miller, 2009; Upadhyay & DeFranco, 2008) including visual representations (Miller, 2009)
- appropriate teacher professional development and use of pedagogy (August et al. 2009; Jackson & Ash, 2012, Miller, 2009; Shook et al. 2011; Smith et al. 2013)

The last point listed above raises the question: How might in-service specialist science teachers, who may not have received specific literacy training, go about navigating the challenges associated with integrating vocabulary instruction into classroom lessons? Marzano et al. (2015) have attempted to address the need for both suitable teacher professional development and effective pedagogy by providing a six-step approach to vocabulary instruction developed from the findings of evidence-based research (Marzano, 2005; Marzano, 2006). Marzano et al. (2015) drew on effective pedagogical practices related to explicit instruction, student engagement, contextual practice, multimedia methods, multiple exposures to vocabulary terms and the diverse needs of students when developing their approach to vocabulary teaching. The resultant six-step approach has been designed for use by both primary and secondary school teachers.

The Marzano Six-Step Approach To Vocabulary Instruction

- Step 1 – Teacher explanation, description or example
- Step 2 – Student explanation, description or example (own words)
- Step 3 – Students make a picture, symbol, graphic representation
- Step 4 – Periodic student activities – vocabulary notebook – add to knowledge, revise and refine
- Step 5 – Periodic student discussion of vocabulary terms
- Step 6 – Periodic student games to play with terms

Analysis of the Marzano six-step approach as a teaching strategy has been conducted by Haystead (2009a, b, c). A series of independent action research studies were conducted by teachers in a community of elementary, middle and high schools located in a midwestern region of the USA. Haystead (2009d, p. 1) has provided a summary of the results of teacher action research and data collection, which were all required to use a "… pre-test-post-test non-equivalent groups design". Of the 38 action research studies reported on by Haystead (2009a, b, c, d), 24 were conducted at the elementary school level (K – Year Five), six were conducted at the middle school level (Years Six to Eight), and eight at the high school level (Years Nine to Twelve). These studies varied in the nature of the academic discipline being taught as well as the year level of the participants. Haystead (2009d) concluded that, overall, the Marzano approach resulted in a measurable improvement in students' knowledge of academic content through direct vocabulary instruction. This conclusion was drawn despite a noticeable variation in the effect sizes which occurred across these studies, ranging from −0.24 to 2.01 (weighted means), due to the majority of the individual studies indicating a positive, albeit inconsistent, gain (Haystead, 2009d).

The variation in effect sizes reported on by Haystead (2009d) raises questions such as: why did this variation occur; and how could it be mitigated? Haystead (2009b) attempted to address this issue by investigating the effects of only partially implementing the six-step approach at the middle school level and concluded that it is essential that all six steps are required for improving outcomes. Yet, in another study involving high school teachers, despite all participants using the six-step approach with their classes, the effect size for individual classes measured as a percentage gain varied from 1% to 48% (Haystead, 2009c). Such a wide variation indicates that other factors may be at play which impact on the effectiveness of the Marzano six-step approach.

7.2 Aim

The aim of this study was 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 et al. (2015). It was proposed 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. The following research questions underpinned data collection and analysis.

7.3 Research Questions

Question 1: *What are a teacher's and students' perceptions of the usefulness of certain strategies that integrate vocabulary instruction in a secondary science classroom?*

Question 2: *How do students' perceptions of the usefulness of integrating specific vocabulary instruction in science education compare to their teachers' perceptions of outcomes resulting from this instruction?*

Question 3: *How might explicit vocabulary instruction in a secondary science classroom best suit student needs, with the aim of developing students' ability and confidence to apply academic words when explaining scientific concepts?*

7.4 Study Design and Method

A concurrent mixed methods case study design (Plano Clark & Ivankova, 2016; Yin, 2014) was developed for the purpose of data collection and analysis. Participants were recruited from two pre-existing Year Seven science classes which were taught by the teacher-researcher in a single sex (male) secondary school. These two classes have been designated as Class A (22 students) and Class B (21 students). The students in each class were from a similar mix of socio-economic backgrounds and exhibited a range of literacy levels which reflected the general student population of the school. Both classes were taught the same sequence of lessons for the topic of astronomy concurrently, over a period of 4 weeks in total. This topic would normally be concluded by the end of a school term, however various disruptions to timetabled lessons resulted in both classes completing the topic in the following term, after a three-week break from lessons.

Quantitative data were collected in the form of school-assessed student literacy levels using the Australian Council for Educational Research (ACER) Tests of Reading Comprehension (TORCH) and pre and post instruction vocabulary tests for all students in Class A and Class B. The pre- and post-tests were in the form of a vocabulary self-awareness chart developed by Grant and Fisher (2010). Twelve scientific terms were chosen from vocabulary that would be used by the teacher and students in the course of learning about the relationships between the earth, the moon and the sun. The words selected for this study were a mixture of domain specific, single meaning and multiple meaning words relevant to the topic of astronomy, as follows: 'orbit', 'axis', 'rotate', 'revolve', 'waxing', 'waning', 'crescent', 'ellipse', 'solstice', 'gravity', 'tide', and 'eclipse'. Students were asked to indicate, for each vocabulary term, whether they: knew a definition; knew a scientific explanation; or didn't know either yet. Students could then write, draw or use a combination of writing and drawing to provide both definitions and explanations in spaces provided for each of the 12 vocabulary terms selected for this study. This form of testing allows for a more sophisticated level of understanding to be demonstrated by students, compared to the use of multiple-choice questions, and reduces the possibility of student answers being guesses.

The pre-test was conducted in the first lesson for the topic, within a forty minute time limit. Subsequently, both classes received specific vocabulary instruction using the six-step approach developed by Marzano et al. (2015). The classes were informed that the teacher-researcher was trialling a method for teaching vocabulary. The six steps of the Marzano process were presented to all students in a PowerPoint presentation. Students were informed that each of these six steps would be introduced throughout the topic. Subsequently the teacher-researcher informed classes of each time one of the six steps was being implemented during a lesson. The twelve vocabulary terms were introduced in the lesson sequence in the order depicted above, beginning with 'orbit' in the first lesson following the pre-test and concluding with the word 'eclipse' towards the end of the lesson sequence.

The teacher-researcher developed three activities specifically for the six-step instructional approach. These activities were: the use of a printed vocabulary notebook; a discussion activity (referred to as 'What If?') requiring students to apply their understanding of terms within new contexts; and a game based on Jeopardy, where students scored points by providing an appropriate question for each vocabulary word. These activities were developed following guidelines provided by Marzano et al. (2015). During the topic students also completed a school developed assessment task requiring students to research and answer questions on the Earth's moon and one other moon in the solar system. The assessment task was not written with the six-step approach in mind, however it was possible to associate this task with aspects of the six steps. On completion of the topic, post testing was conducted to determine the extent of any changes in student understanding and their correct use of vocabulary terms. The post-test was in the same format as the pre-test.

Qualitative data were collected through the use of focus group interviews with student participants, and reflective journal entries written by the teacher-researcher. Seventeen students initially agreed to be interviewed for this study. Of these participants, 11 students were available on the days when interviews were held in the week following the post-tests: eight students from Class A and three from Class B. Audio recorded interviews of approximately 15 min duration were conducted with students in three separate focus groups (three to four students per group) to determine how students perceived the six-step approach. The interviews were semi-structured and conducted in a conversational style. Questions were asked to determine students' recall of activities and the students' thoughts on the usefulness of the instructional process (asking for positives and negatives). Opinions were also sought from students on any improvements that might be made to the lessons they experienced.

The teacher-researcher maintained a reflective journal for the duration of the topic, recording thoughts on aspects of his pedagogy and student responses which might have some bearing on the outcomes of the Marzano six-step process. A journal entry was recorded as soon as practicable following each science lesson for Class A and Class B.

7.5 Data Analysis

Data collected from the pre- and post-tests was coded and categorised to determine the level of progress in students' understanding of the twelve selected vocabulary terms. Single item numerical scores (Creswell, 2012) were allocated for each definition and scientific explanation provided by students. Difference scores (Creswell, 2012) for students in each class were determined for each of the vocabulary terms.

Responses for student definitions were placed into three categories:

- ***Correct*** – students have expressed an understanding of a concept without providing any contradictions or misconceptions.
- ***Partially correct*** – indicating that a student has a partial understanding of a vocabulary term, but also holds a misconception.
- ***Incorrect or unknown*** – indicating that a student did not understand a term or did not provide a response.

The student responses to the scientific explanation section of the pre-tests and post-tests were also placed into three categories:

- ***A complete explanation was provided***
- ***A partial explanation was provided*** – showing limited understanding
- ***Incorrect or not answered***

Responses recorded for student interviews were coded and placed in a matrix to determine any recurrent themes (Bazeley, 2013) which arose from the students' perceptions of the vocabulary teaching strategies undertaken. The analytical matrix was divided into the following categories related to the Marzano six-step instructional process: teacher explanations; student descriptions and explanations; student diagrams; discussion; student review; and the game activity. Each of these categories were further divided into sub-categories for all the associated activities which occurred during the topic sequence. Interview transcripts were used to determine where each individual participant referred to one or more of the sub-categories, with the following coding applied: the participant recalled the activity without researcher prompting; the participant found the activity to be helpful for learning vocabulary; the participant did not find the activity to be helpful for learning vocabulary; the participant found the activity to be difficult to complete; the participant observed that other students were not engaged in the activity. For each of these types of response, interview participants were encouraged to elaborate on their perceptions of the approach to vocabulary instruction. The teacher-researcher's reflective journal entries were compared with participant's interview responses to establish and compare points of confluence and difference in the teacher-researcher and students' perceptions of activities conducted throughout the topic.

7.5.1 *Results*

7.5.1.1 Students' Definitions – Pre- and Post-Test

In comparing the results for the definitions provided by students in Class A and Class B (Table 7.1), the top five words learnt by the greatest percentage of students in each class were the same (axis, gravity, orbit, rotate, tide); although the relative rankings for these words were not the same in each class. The remaining seven words were also ranked differently for the percentage correct in each class, however the words 'solstice', 'ellipse' and 'crescent' appeared in the lowest four rankings for each class. Improvement in providing correct definitions for Class A ranged from 2% to 48% of students for the individual vocabulary terms (Figs. 7.1 and 7.2), while improvement for Class B ranged from no improvement to 43% of students for the individual terms (Figs. 7.3 and 7.4).

Students in Class A exhibited an overall improvement in providing correct definitions for all 12 vocabulary terms, with the most improvement occurring for the

Table 7.1 Post-test ranking of definitions provided by Class A and Class B

Level of understanding (% of students providing a correct definition, post-test)	Class A: vocabulary	Class B: vocabulary
Complete – 100%	Gravity	
Very high – 90 to 99%	Rotate, orbit	Orbit
High – 80 to 89%	Axis, tide	
Moderately high – 70 to 79%	Waning	Gravity
Moderate – 60 to 69%	Waxing	Rotate, axis
Slight – 50 to 59%	Eclipse, ellipse, crescent	Tide
Poor – <50%	Revolve, solstice	Revolve, waning, waxing, crescent, solstice, eclipse, ellipse

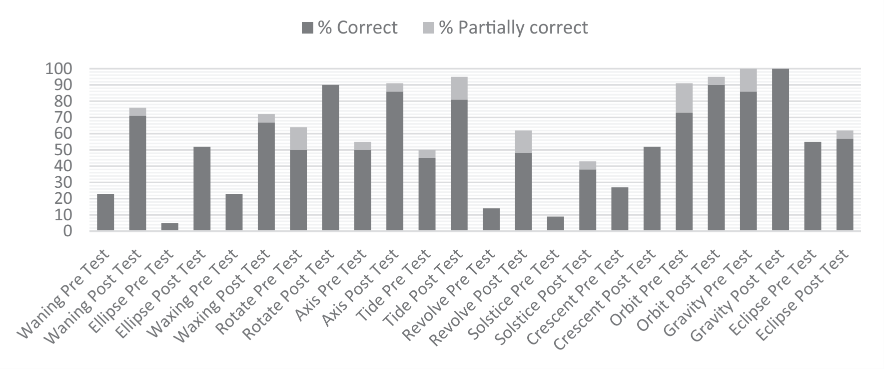

Fig. 7.1 Class A – Pre-test and post-test results for student definitions

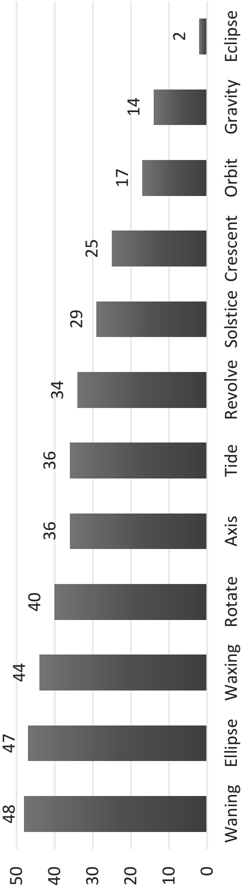

Fig. 7.2 Class A – Post-test gain in providing a correct definition, as a percentage of the class

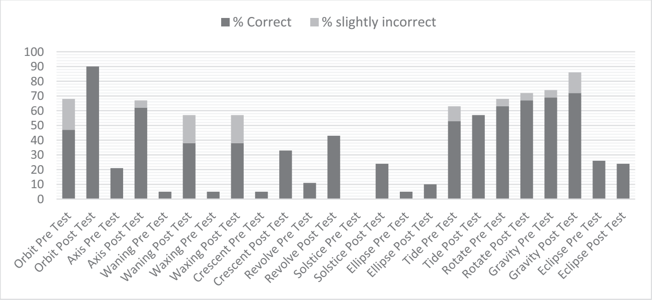

Fig. 7.3 Class B – Pre-test and post-test results for student definitions

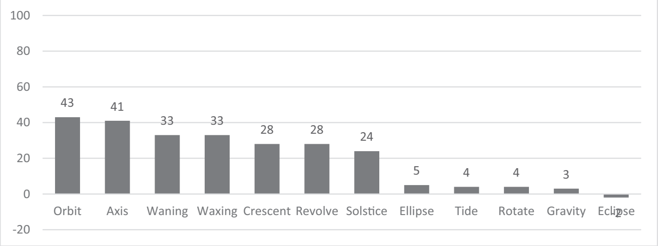

Fig. 7.4 Class B – Post-test gain or loss in providing a correct definition, as a percentage of the class

word ‘waning’ and the least improvement for the word ‘eclipse’ (Fig. 7.2). All students in Class A were able to provide a satisfactory definition for the word ‘gravity’ in the post-test, while ‘solstice’ was the post-test term with the fewest number of correct definitions (Fig. 7.1).

Students in Class B exhibited an improvement in providing correct definitions for 11 of the 12 terms, with the exception of ‘eclipse’, with the most improvement occurring for the word ‘orbit’ (Fig. 7.4). Ninety percent of students in Class B were able to provide a correct definition of ‘orbit’ for the post-test, while ‘ellipse’ was the post-test term with the fewest number of correct definitions (Fig. 7.3).

7.5.1.2 Students’ Scientific Explanations – Pre- and Post-Test

Both classes demonstrated an overall improvement in providing scientific explanations for the selected vocabulary terms (Figs. 7.5 and 7.6), when both the full and partial explanation results are considered. As was the case with student definitions, there were differences in the level of improvement for scientific explanations across the two classes and for individual terms. For some words, very few students were able to provide a full explanation in the post-test, although there tended to be a

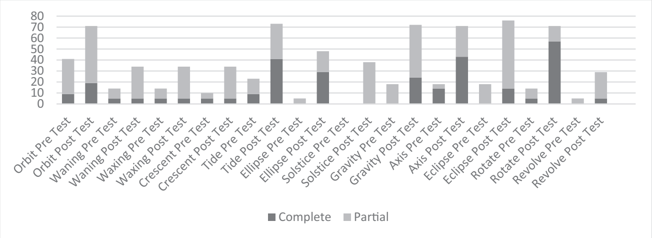

Fig. 7.5 Class A – The percentage of students providing a complete or partial scientific explanation

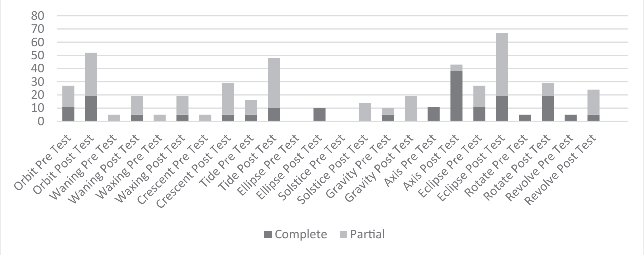

Fig. 7.6 Class B – The percentage of students providing a complete or partial scientific explanation

substantive increase in partial explanations. For example: For Class A (Fig. 7.5) there was no post-test increase in the percentage of students' full explanations provided for the words 'waxing', 'waning' and 'crescent'; however the number of partial explanations for each of these words increased by approximately 20% of the class. Similarly, for Class B (Fig. 7.6), the percentage of students' full explanations for the word 'revolve' did not differ for the pre- and post-tests, however the number of partial explanations also increased by approximately 20% of the class.

For Class A (Fig. 7.5), the highest number of full explanations in the post-test were provided for the word 'rotate', while the least number of full explanations were provided for the word 'solstice'. If both full and partial explanations are considered, six words had a combined total for which 70% (or more) of students provided an explanation. These words were: 'orbit', 'tide', 'gravity', 'axis', 'eclipse' and 'rotate'. For the remaining vocabulary terms, less than 50% of Class A were able to provide an explanation of some kind.

For Class B (Fig. 7.6), the highest number of full explanations in the post-test were provided for the word 'axis', while the least number of full explanations were provided for the words 'solstice' and 'gravity'. 'Gravity' was the only word for which the number of full explanations provided in the post-test was less than the number provided in the pre-test, although the total number of combined full and partial explanations did increase. Overall, the percentage of students who provided an explanation of some type (i.e. combined results for full and partial explanations) was generally lower for Class B than for Class A. Only two words were provided with explanations by more than 50% of Class B. These words were ‘orbit’ and ‘eclipse’.

7.6 Discussion

The first research question posed for this study was intended to identify both student and teacher perceptions of an approach towards vocabulary instruction. The remaining two research questions were intended to provide a means of examining how these perceptions might provide a deeper understanding of the factors involved in achieving student learning outcomes, and how consideration of these factors might inform future teaching practice. In answering these research questions, three interconnected themes emerged, ranging from a general view point of the overall success of the vocabulary instruction (Theme 1), to a more complex consideration of the levels of individual success resulting from the strategies implemented (Themes 2 and 3). The following discussion is structured around these three emergent themes.

7.6.1 Discussion Theme 1

The process of integrating vocabulary teaching into secondary science lessons could be perceived to be successful. There was an overall improvement in student understanding for most of the vocabulary terms.

From the teacher-researcher’s point of view: The post-test results indicated that participant students generally improved their knowledge and use of scientific vocabulary for the topic in this study, albeit with varying levels of improvement. From the students’ point of view: Overall there was a perceived benefit obtained from the use of specific vocabulary instruction in the classroom. Over the course of the student interviews, it became clear that the introduction of specific words at the beginning of the topic made students more conscious of the importance of learning vocabulary. They were able to positively compare their experience with that of other science topics which did not emphasise a set of key words at commencement. All of the students interviewed identified at least one strategy that they considered to be helpful. Most of the teaching strategies chosen provided some further clarity for the students interviewed and the combined effect of the strategies generally aided the development of their understanding of the chosen vocabulary terms.

From a simplistic viewpoint, it could then be stated that the teacher-researcher’s implementation of activities based on the Marzano six-step approach was successful for teaching and learning scientific vocabulary. On the other hand, a fine grained examination of the variability in student engagement in activities and the variability in student understanding of specific vocabulary terms, reveals some of the complex factors that impacted on the results of this study. These factors are discussed further within Themes 2 and 3.

7.6.2 Discussion Theme 2

There were varying levels of student engagement shown for the strategies selected for incorporating the six-step approach for teaching vocabulary.

The choice of activity appeared to have had a considerable influence on student engagement during this case study. Varying levels of student engagement were commented on by students throughout the student interviews and also observed by the teacher-researcher during lessons. The activity most often perceived as helpful by student participants was the game of Jeopardy. This game was consistently considered to be a fun activity (usually the first aspect mentioned by students); and the game provided a means for students to both individually and collectively explore their understanding (as observed by both students and the teacher-researcher).

The activity perceived by students as being least helpful was the 'What If?' group discussion activity. This task required students working within small groups to make predictions on what might happen if existing relationships between the earth, the sun and the moon were to change. For example, what might happen if the earth had two moons? Many students were unable to comprehend what was required to successfully complete this task. This may have been due to the manner that the task was presented to them, or a lack of prior experience with the process of problem solving to explore concepts and form conclusions when presented with a new context, or an insufficient understanding of the concepts themselves, or any combination of these factors.

Marzano et al. (2011) have identified four questions which will have an influence on student engagement that students ask themselves about a learning activity. These questions are: How do I feel? Am I interested? Is this important? Can I do this? Reflecting on the lack of success of the 'What If' activity, it was concluded by the teacher-researcher, through both personal observation and student feedback, that many students probably answered 'no' to the last question. The provision of introductory scaffolding of the activity did not appear to assist enough students to become confident about completing the task. This is reflected in the following student response:

> I think the 'What If' questions were a bit hard. … Like, you wouldn't know what would happen if the Earth had two moons or you wouldn't happen, you wouldn't know what would happen if the moon was double in size and, until it actually happens.

The response indicates that the student was unable to associate a problem-solving approach with this activity, despite the prior modelling of problem solving demonstrated by the teacher-researcher to introduce this activity. Only one of the students interviewed expressed interest in the activity and found it engaging. It was noted by many of the interviewed students that, for both classes, the lack of engagement for some students led to ‘mucking around’ which then had a detrimental influence on the intended outcomes of the activity.

Apart from the problems experienced in the delivery of the ‘What If?’ activity, it was observed by the teacher-researcher that the level of challenge for other activities also varied amongst students, and this was reflected in students’ degree of continuation of practices introduced in the classroom, for homework set outside of the classroom. It was also evident that student confidence in participating during discussions varied amongst students. Some students would not speak during a discussion unless prompted by the teacher-researcher. In addition, classroom culture and general behaviour played a role in the level of student engagement. The teacher-researcher journal entries noted that Class B exhibited more behavioural management issues, resulting in disruptions to lesson continuity, than did Class A.

7.6.3 Discussion Theme 3

On conclusion of the vocabulary instruction, students’ apparent understanding of the selected vocabulary terms and their effective communication of both definitions and scientific explanations for these terms varied considerably.

There were two trends that require elaboration within this theme. Firstly, there was a core group of words which were learnt far more successfully, both for definitions and scientific explanations, when compared with the results for the remaining vocabulary terms. Secondly, significant variations occurred in results when comparing individual students and the results for the two classes. Each of these trends will be examined in turn.

7.6.3.1 Variation Between the Vocabulary Terms

It is likely that one or more aspects of the teaching strategies chosen may have contributed to these vocabulary terms forming this core group, as previous research has shown. For example, important aspects of teaching strategies which could lead to the successful integration of vocabulary instruction in the science classroom include: the choice of activity; providing meaningful contexts in which terms are presented and practised; the timing of the introduction of individual terms within a topic; and the amount of time available to practice the use of individual terms (Evagorou & Osborne, 2010; Fisher & Frey, 2008; Gomez et al., 2010; Marzano et al. 2015; Wellington & Ireson, 2012; Wellington & Osborne, 2001). The choice of activity has been discussed (see Discussion Theme 2) and found to have had an apparent influence on student engagement during this case study.

In regard to the timing of introducing the vocabulary terms, there is evidence from this research that this may have influenced student outcomes. The 12 vocabulary terms were introduced to both classes in the following order over the 4 week lesson sequence: 'orbit', 'axis', 'rotate', 'revolve', 'waxing', 'waning', 'crescent', 'ellipse', 'solstice', 'gravity', 'tide', and 'eclipse'. The first seven of these terms were provided to students in the first lesson for the topic. The remaining five terms were introduced approximately 2 weeks (Class B) and 3 weeks (Class A) later.

It is worth noting that four of the core group terms from the post-test ('axis', 'gravity', 'orbit', and 'rotate') were amongst those introduced to students in the first week of the topic. Subsequently, three of these words ('axis', 'orbit' and 'rotate') were extensively used both leading up to and within the major assessment task for the topic. Students had to understand the terms 'axis', 'orbit' and 'rotate' to be able to complete the topic assessment task successfully. These terms featured in questions which were required to be answered by students. This would suggest that the early introduction of a vocabulary term, along with the opportunity to repeatedly practice the use of that term, was influential in facilitating student learning.

7.6.3.2 Variation Between Students and Classes

While there was little variation in the vocabulary terms which were most successfully understood by students in either class, the extent to which they were learnt was quite different for each class. For example, in Class A, 71% of students provided a complete or partial scientific explanation for the word 'rotate', whereas only 29% of Class B students provided a complete or partial scientific explanation for the same term. Generally, students in Class A demonstrated a significantly greater understanding of the vocabulary terms in both the definitions and scientific explanations provided than did the students in Class B. Variation in the post-test results was also evident when comparing individual results within both classes. These results ranged from students who provided only one or two suitable responses in their post-test, to students who provided suitable responses to all 12 vocabulary terms. Research suggests that there are at least three aspects important to learning vocabulary which may have had an influence on the variable results which occurred in this case study. These aspects of learning vocabulary are: the linguistic categorisation or word type which can be allocated to academic words (Fang, 2006; Fisher & Frey, 2008; Marzano, 2010; Wellington & Osborne, 2001); the context in which a word might be used, including multiple meanings (Fang, 2006; Fisher & Frey, 2008; Marzano, 2010; Wellington & Osborne, 2001); and the level of an individual student's literacy skills and prior knowledge (Christenbury et al., 2009; Conley et al., 2008; Marzano, 2010).

In their examination of the literacy requirements of science education, Wellington and Osborne (2001) produced a taxonomy of science words classified into four levels: naming words; process words; concept words; and mathematical 'words' and symbols. These levels were presented by Wellington and Osborne (2001) within a hierarchy indicating the degree of abstraction for each category, with naming words at the lowest level through to mathematical 'words' and symbols at the highest level.

It might be expected that the core group of terms identified in this case study would consist of naming words and possibly process words, given that these categories are indicated by Wellington and Osborne (2001) as having a lower level of abstraction. Instead, the core group of terms are spread across the different levels, suggesting that the nature of abstraction was not necessarily a critical factor in developing students' understanding of the selected terms. It is possible that two other factors shown to have an effect on vocabulary learning: the context in which words are practiced and the literacy levels of students, may have had a greater influence on the degree to which the vocabulary terms chosen for this case study were learnt and understood by students.

Fang's (2006) detailed analysis of language learning in science education suggests that both student familiarity and the practice of linguistic skills within specific scientific contexts are key components of learning science vocabulary. In regard to student familiarity, the five words which scored highest for completely correct definitions in the pre-test for Class A were: 'gravity', 'orbit', 'eclipse', 'rotate', and 'tide' (in descending order), and for Class B: 'gravity', 'rotate', 'tide', 'orbit' and 'eclipse' (in descending order). Four of the top five words for both classes' pre-test results appear in the post test five core terms ('gravity', 'orbit,' 'rotate' and 'tide'). This would suggest that student familiarity has had a significant influence on the post-test results in this case study.

Furthermore, it is worth considering the extent to which students were able to practice reading, writing and speaking each of the specific vocabulary terms using scientific contexts during the case study. As previously noted, the words 'axis', 'orbit' and 'rotate' were used extensively by the teacher-researcher and students throughout the topic to describe the motion and relationships of the earth, the moon and the sun. Students were provided with many opportunities to practice sentence construction for these terms. The words 'gravity' and 'eclipse' were introduced to both classes later in the topic, with 'eclipse' being introduced last of all, and practiced in only three of the 16 lessons. It is likely that the lack of contextual practice made available for these words has influenced the post-test results.

7.6.3.3 Student Literacy Levels

The above two sections of Discussion Theme 3 indicate that, for this case study, there were multiple influences on student learning outcomes which were associated with the pedagogy chosen for lessons, student practice and students' prior knowledge. In addition to these factors, students' learning and achievement in the classroom has been shown by research to be influenced by a student's language background, including ELL students (Christenbury et al., 2009; Conley et al., 2008; Hinkel, 2011; Pitcher et al., 2010); literacy skills (Christenbury et al., 2009; Conley et al., 2008; Marzano, 2010, Pitcher et al., 2010); and specific learning abilities and/or disabilities, such as autism, giftedness, twice exceptional students and other categories (Baum & Olenchak, 2002; Siegle & McCoach, 2005; Weinfeld et al., 2005).

For this case study, data were collected in relation to one of the above factors only – student literacy levels, using a reading comprehension assessment tool published by the Australian Council for Educational Research (ACER). The ACER Tests of Reading Comprehension (TORCH) provide an estimate of a student's reading ability which is indicated by a stanine ranking for a student's specific age and year level as follows: Stanine 1 – well below average, Stanines 2 and 3 – below average, Stanines 4, 5 and 6 – average, Stanines 7 and 8 – above average and Stanine 9 – well above average (de Lemos, 2001). This final section of Discussion Theme 3 considers how participant students' literacy levels for reading comprehension may have had an influence on their post-test results.

Participant students for this case study had undergone TORCH assessment earlier in the year. Stanine rankings for the 17 participant students were as follows: Stanine 3 (2 students), Stanine 4 (3 students), Stanine 5 (3 students), Stanine 6 (3 students), Stanine 7 (1 student), Stanine 8 (1 student), Stanine 9 (1 student), and not tested (3 students). Of the participant students, the responses which demonstrated the most comprehensive understanding of the vocabulary terms for both definitions and scientific explanations in the post-test were achieved by the Stanine 9 student. By comparison, the two Stanine 3 students achieved the least amount of improvement in their responses for both categories in the post-test. A possible explanation for these contrasting results might lie in the need for students to develop their phonological processing (awareness of the sound structure of words) to facilitate reading comprehension (Curtis, 2004). Research has shown that students' "… growth in phonological processing slows down considerably … by the time they reach adolescence" (Curtis, 2004 p. 120). In addition, Curtis (2004) has found that students with reading difficulties will plateau their phonological processing earlier than students without reading difficulties. This lack of sufficient phonological processing can lead to incorrect pronunciations and a lack of contextual understanding when reading texts aloud (Curtis, 2004), and often, "… difficulty with multisyllabic words because they fail to analyse them fully, opting instead to make a guess based on their analysis of the first part of [a] word" (p. 122).

There were limited opportunities for improving phonological processes within the structure of the activities chosen by the teacher-researcher for the Marzano six step approach. One activity, the use of a vocabulary notebook, did include the practice of generating synonyms and antonyms for each vocabulary term by students. The completion of each section of the vocabulary notebook was introduced by the teacher-researcher by providing scaffolded instructions for four vocabulary terms. This provided the opportunity for students to contribute to classroom discussion by both offering and comparing possible synonyms and antonyms for the selected vocabulary terms. It was noted by the teacher-researcher that, while some students were very enthusiastic about supplying possible synonyms and antonyms during class discussion whilst being guided through the use of the vocabulary notebook, students with identified reading comprehension difficulties were far less likely than those without reading difficulties to provide suggestions. In addition, most of the students with identified reading comprehension difficulties did not attempt to complete any further entries in their vocabulary notebook once the guided instruction was completed.

7.7 Conclusion

The title of this chapter asks the overarching question: Can the complexities of developing students' literacy skills around physical science concepts benefit from a singular approach to teaching academic vocabulary? On a simple level, the answer to this overarching question is a qualified 'yes'. On a more complex level, the answer is that the benefits gained depended on multiple influential factors related to the processes of teaching and learning. These factors included:

- the pedagogical approach chosen and its alignment with student meta-cognition of the purpose and requirements of activities;
- the level of student engagement and students' motivation to participate in activities, including the effects of the overall classroom culture;
- time limitations which might restrict the use and practice of vocabulary terms in appropriate scientific contexts;
- the inherent and varied linguistic difficulties associated with the use of academic terms; and
- students' language backgrounds and literacy levels.

Results of this study suggest that effective vocabulary teaching cannot be solely reliant on following a single method of instruction without consideration of these factors.

7.7.1 Implications for Future Teaching Practice

Through conducting this case study, the teacher-researcher developed a better awareness of the factors which might influence a student's acquisition of language skills in general. The results of this study reinforced the teacher-researcher's intention to make language use consistently explicit in the science classroom and has broadened his repertoire of strategies to do so. Student production of multi-modal representations, facilitated through the pre- and post-tests and maintenance of a vocabulary notebook, have highlighted the possibilities of how scientific concepts can be conveyed by students.

In comparing the student and teacher perceptions of the strategies implemented, the teacher-researcher identified that some activities required further refinement in their design and implementation to achieve their desired outcomes. In particular, the 'What If' problem solving task might have been suitably engaging and challenging for all students, if students had prior experience of similar, scaffolded tasks. During interviews, students suggested that more time spent on discussing and reviewing the scientific meanings and explanations for some of the vocabulary terms would have been beneficial. The teacher-researcher agrees that this was one area which particularly suffered due to time constraints impacting on decision making for the sequencing of lessons. It is expected that further use of the Marzano six-step approach by the teacher-researcher would lead to refinement of activities and more effective use of the time made available for a topic sequence. This study has highlighted the need for the teacher-researcher to be particularly aware of finding opportunities to review vocabulary terms throughout a lesson sequence, rather than on conclusion of a topic, and for the provision of relatively equal amounts of time to practice the use of each selected term after its introduction.

7.7.2 Implications for Future Research

The Marzano six-step was developed as a singular approach to explicit vocabulary instruction. The results of this study suggest that there are several aspects of this approach which would benefit from further research. This case study research was undertaken over a short period of time (4 weeks) and for one topic only. Implementing a longitudinal study of the use of the Marzano six-step approach would contribute further to identifying factors related to the successes and challenges of integrating vocabulary instruction in the science classroom. Beyond its use as a singular approach, the Marzano six-step approach provides both a structure and a guide to potential learning activities that could be embedded into a wider ranging approach to investigating explicit literacy instruction in science education, such as demonstrated by the Pacific CRYSTAL project (Anthony et al., 2010; Tippett & Anthony, 2011).

This study suggests that the Marzano approach alone is not sufficient in and of itself to cater to students with low literacy skills. Specific linguistic processes and a student's cultural and language skills background may have had a considerable impact on the outcomes of vocabulary instruction provided during this case study. Jozwik and Douglas (2017) have found that multicomponent vocabulary instruction, which incorporated explicit instruction, self-regulation procedures and specific collaborative learning experiences, provided positive support for ELL students to read and define academic vocabulary. It would be worthwhile to conduct research which investigated the incorporation of the Marzano six-step approach within the context of multicomponent literacy instruction for the support of students with low level English literacy skills to develop and communicate their scientific understanding.

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Chapter 8
Investigating Students' Self-Efficacy and Self-Concept in Science Through Collaborative Inquiry: Unpacking the 'Hidden' Complexity Within Data

Debra Panizzon, Bruce White, Katrina Elliott, and Alex Semmens

Science, technology, engineering and mathematics (STEM) is currently a national priority for Australia and many other countries with a skilled workforce in the area considered a high priority (Organisation for Economic Co-operation and Development [OECD], 2017). Underpinning much of this focus is the need to produce a future workforce with the intellectual capacity, knowledge and employability skills necessary to ensure economic prosperity for a competitive global economy (Australian Government, 2015; Becker & Parker, 2011). Aligned to this global STEM focus, the national government in Australia implemented the *National Innovation and Science Agenda* to drive smart ideas that create economic growth, local jobs and global success. It focuses on four key pillars:

1. Culture and capital
2. Collaboration
3. Talent and skills
4. Government as an exemplar (Australian Government, 2015).

It is this agenda that has driven funding for major STEM initiatives across Australia in the last four years (Panizzon et al., 2015). A key emphasis within the educational sphere is to enhance the participation and ongoing engagement of students in STEM at all levels of schooling.

While we acknowledge such workforce aspirations, it is imperative to recognise that education in STEM is valuable and important for all learners in its own right. STEM allows learners to develop foundational understandings, skills, ways of

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thinking and insights about our world that are a necessity for all citizens. An emphasis on STEM in the early years, primary and secondary schooling is about much more than optimising a future workforce. However, supporting, nurturing and challenging our learners to attain their full potential in STEM is also extremely complex given that a ‘one size fits all’ or ‘quick fix’ approach is non-existent (Breiner et al., 2012).

This chapter explores some of this complexity using data obtained from a Year 7–8 STEM Collaborative Inquiry project undertaken by the Department for Education in South Australia. In this chapter we focus on students’ self-efficacy and self-concept in science because these dispositions are recognised as impacting students’ participation and ongoing interest in the sciences (Jansen et al., 2015). Initially, we describe the aims and nature of the STEM inquiry project, which provides the educational context for the chapter. This is followed by a brief overview of the literature pertaining to self-efficacy and self-concept in science. Next, the methods used to collect, analyse and interpret data to determine the impact of the project on students are presented. Finally, we highlight the importance of unravelling these data at a number of levels to gain an insightful understanding of what actually occurred so that we can more adequately support our students in their STEM education.

8.1 STEM Project Context

A major project entitled the STEM Collaborative Inquiry project was completed from 2016–2018 and involved 250 teachers, 2037 students, 49 principals, and 39 schools. The aim of the project was to support five school networks to design, trial and evaluate innovative STEM learning across Years 7–8. Each network consisted of a minimum of one secondary school and four primary schools. Targeted project outcomes included:

- Alignment of pedagogy across Years 7–8 to ensure greater continuity of learning in science, mathematics, digital and design technologies from primary into secondary school;
- Collaboration with industries, academic providers, local councils, and community organisations to design and solve real-world problems relevant to the local context using complex thinking;
- Integration of science, mathematics, and technologies using inquiry and engineering problem-based processes so that students applied their learning to an unfamiliar context;
- Enhancement of teachers’ pedagogical content knowledge to improve student engagement and interest in science, mathematics or digital and design technologies for their future lives; and,
- Improvement of students’ self-concept and self-efficacy in science, technologies and mathematics while reducing mathematics anxiety.

At the time of initiation of this project, Year 7 students were 'housed' in primary schools with relocation into secondary schools being planned. The inquiry project was not designed to be a transition project although it did provide an opportunity for Years 7 and 8 students and teachers to work together on common STEM projects.

School participation in the project was open to all networks that could provide evidence of emerging or established STEM-related learning opportunities and collaborative practices between the primary and secondary schools. Networks for involvement in the project were selected ultimately to represent students from different geographical locations and socioeconomic and cultural backgrounds.

In order to collect evidence of impact of the project, a research study was designed based around four questions:

1. What impacts on students' understandings and dispositions around science, technology and mathematics are evident from their involvement in the project?
2. What changes in teachers' curriculum, pedagogies and/or practices are evident from involvement in the project?
3. What key collaborative structures are identifiable within and between the participating networks? What were the enablers supporting these collaborations? What were the challenges in establishing and maintaining these collaborations?
4. How did engagement with industry/university or other stakeholders enhance the outcomes of the project for each network?

The aim of this chapter is to report and discuss findings in relation to RQ 1 with a focus on students' self-efficacy and self-concept in science only.

8.2 Impact of Students' Self-Efficacy and Self-Concept in Science

Student self-efficacy and self-concept are often associated positively with student engagement and achievement (Jansen et al., 2015). Self-efficacy is described as a student's perception of their ability to complete a task (Bandura, 1997; Bong et al., 2012), while self-concept is the student's personal evaluation of their ability in a particular domain (Bong et al., 2012). Both constructs are generally accepted to be domain specific (Jansen et al., 2015) i.e., related to science or mathematics. While the two constructs appear to be quite similar, they are generally considered to be distinct and conceptually different in describing a student's beliefs in their competency within a discipline (Jansen et al., 2015).

The early work of Bandura (1997) highlighted a link between self-efficacy and achievement, which has been corroborated by more recent research (Bircan & Sungur, 2016; Thomson et al., 2017). However, the relationship is considered highly complex with motivation and engagement contributing as mediators between self-efficacy and achievement (Lee et al., 2016). Furthermore, the link between self-efficacy and achievement may actually be reciprocal with achievement affecting self-efficacy and self-efficacy then influencing achievement (Hwang et al., 2016). Self-concept in science has also been reported as being a possible indicator of student achievement in science (Oliver & Simpson, 1988) although not as consistently as self-efficacy.

Student self-efficacy and self-concept varies across gender with male students generally demonstrating higher self-efficacy and self-concept than female students (Thomson et al., 2017; Webb-Williams, 2018). The 2015 Trends in International Mathematics and Science Study (TIMSS) survey included items that explored students' confidence (a concept closely related to self-efficacy and self-concept) with results indicating that Australian Year 8 male students scored significantly higher than female students. Importantly though, these gender differences were non-existent for Year 4 students (Thomson et al., 2017).

As such, research also indicates that students' self-efficacy and self-concept are impacted by age (Beghetto, 2007; Huang, 2013; Lofgran et al., 2015) with a general decline in both dispositions with age. Bong et al. (2012) suggest that this decline is because students provide a more accurate view of their competency with both dispositions as they age with younger children often over-estimating their capabilities. Adding to the complexity around these dispositions, Lofgran et al. (2015) found that the observed declines in self-efficacy and self-concept were more heightened at major school transition points, such as the move from elementary to middle school. Hence, both dispositions are central to any discussion of impact for the Years 7–8 STEM Collaborative Inquiry project.

8.3 Research Design

The data corpus included:

- Disposition surveys developed by the Department for Education with self-efficacy and self-concept items extracted from the PISA 2015 survey (OECD, 2015);
- Interviews with teachers;
- Focus group interviews with students in each school comprising a network;
- Interviews with principals; and,
- Observation of teachers' lessons related to the STEM project.

8.3.1 Participant Selection

A summary of the participants involved in the first year of data collection (2017) is provided in Table 8.1. The surveys were completed by all students and teachers collaborating in the school-based projects. Purposive sampling was used to select students and teachers for interview (Wiersma, 1995). This sampling ensured

Table 8.1 Research participants Year 1 of project

Surveys		Interviews		
Students	Teachers	Students[a]	Teachers[b]	Lesson Observations
1299	88	60	25	10

[a]Conducted as focus groups of five or more students
[b]Individual interviews

representation of the diversity of participants across the networks (i.e., secondary school and primary school; geographical locations).

8.3.2 *Data Collection and Analyses*

Collection began at the beginning of the year with disposition surveys completed by teachers and students. Focus group interviews were then undertaken with small groups of teacher-selected students along with teacher interviews. The process was replicated in late October to capture post-project data from the same students and teachers facilitating direct comparisons.

Lesson observations of individual teachers or of teaching teams were conducted as they worked with students as part of their STEM project. All data were analysed appropriately using a mix of quantitative and qualitative methods. The surveys consisted of Likert scales with five options: Strongly disagree, Disagree, Neutral, Agree and Strongly agree. Each option was allocated a number, one for Strongly disagree to five for Strongly agree. Non-parametric tests (e.g., Mann-Whitney U) were used to identify significant differences for students' self-efficacy and self-concept in science across year levels, gender and the five networks (Shapiro & Wilk, 1965). Direct statistical comparisons between Years 7 and 8 were not attempted given the changed wording used in the surveys to suit the two groups of students.

Content analysis was used on all the interview transcripts and electronic open responses captured from students and/or teachers to build up a series of discrete codes to develop "conceptual categories that reflect commonalities" (Harry et al., 2005, p.4). These analyses were used to interpret the statistical results providing a greater understanding of the impacts of the project.

8.3.3 *Interrogating the Data*

A discussion of the findings for self-efficacy and self-concept are provided separately. Initially, a general pattern of the pre and post survey responses is presented, followed by an analysis of gender in two different ways. The first method involves a comparison of pre and post responses for females and males quite independently to track any change emanating from the project. The second compares the pre and post data across female and male students to observe whether one gender flourished over the other. Finally, the impact of each network on students' self-efficacy and self-concept around STEM are explored.

8.4 Self-Efficacy in Science: What Changes Were Evident?

The representation of the overall results for Year 7 students (Fig. 8.1) shows slight variations between the pre and post survey responses for some items. A statistical analysis identified one significant increase ($p = 0.005$) for: *When I leave school I will need science for my future*. This finding suggests that involvement in the project may have helped Year 7 students develop a greater understanding of the applicability of science to life beyond school.

In terms of impact on females and male students, a within gender comparison between pre and post survey data (Table 8.2) found no statistical differences (see columns 1–2). However, the bolded figures in the table highlight a number of statistical differences ($p = 0.05$) from a comparison of the pre and post survey data across genders (see columns 3–4).

For the items: *I am good at science* and *I learn science quickly*, the means for the post survey for male students were significantly higher than female students while no significant differences emerged from the pre surveys. With the item: *Knowing science will help me make good decisions in the future*, male students again demonstrated a significantly higher mean than females but only for the pre survey. This suggests that male students rated their ability for this item more highly than females prior to immersion in the project with this difference disappearing in the post survey responses. Collectively these findings identify that self-efficacy for female Year 7 students did not change from participation in this project although there was evidence of enhancement of the self-efficacy of male students.

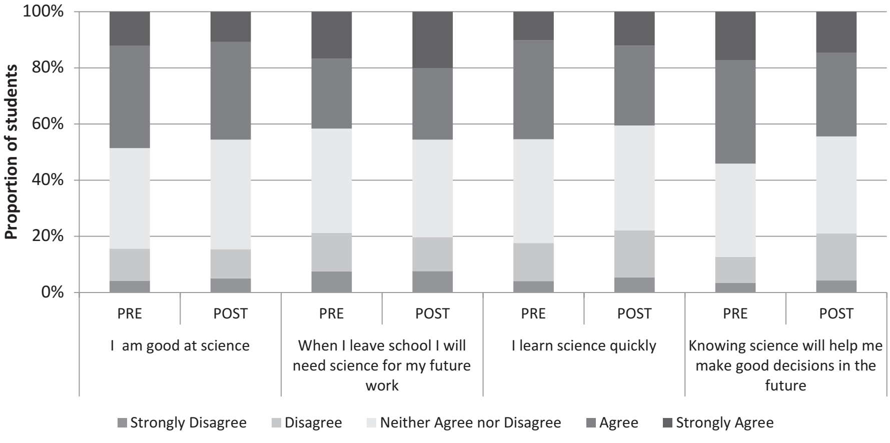

Fig. 8.1 All Year 7 students' self-efficacy in science ($N = 640$)

Table 8.2 Year 7 students' self-efficacy and gender comparisons in science

	Within gender comparisons $(\overline{X})$				Across gender comparisons $(\overline{X})$			
	Female		Male		Pre		Post	
Survey item	Pre	Post	Pre	Post	Female	Male	Female	Male
I am good at science	3.58	3.38	3.59	3.64	3.34	3.47	3.29	**3.53**
When I leave school I will need science for my future work	3.45	3.46	3.57	3.61	3.23	3.36	3.48	3.46
I learn science quickly	3.4	3.26	3.63	3.52	3.28	3.40	3.18	**3.43**
Knowing science will help me make good decisions in the future	3.59	3.51	3.66	3.55	3.43	**3.65**	3.50	3.59

Bolded figures highlight significant differences

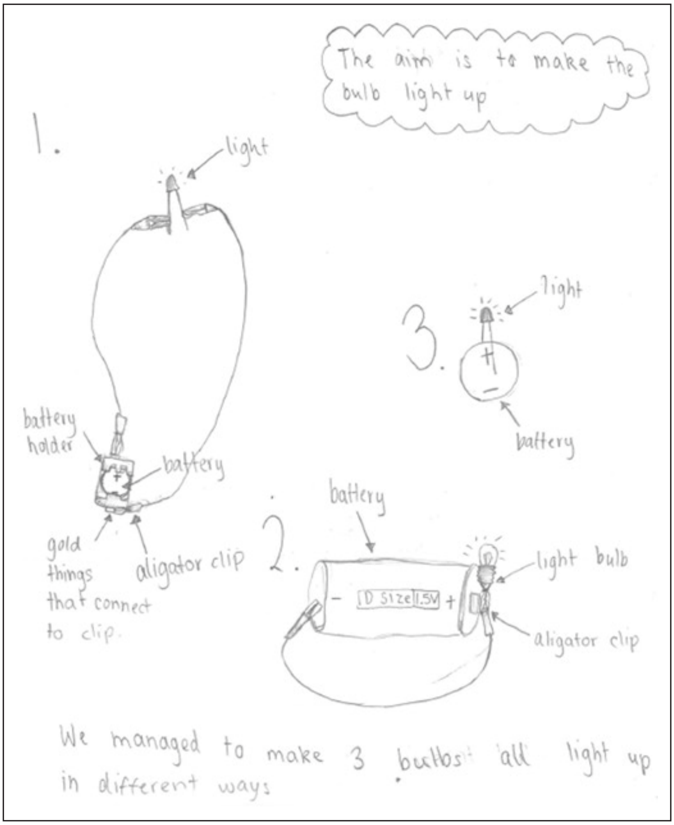

Fig. 8.2 All Years 8 students' self-efficacy in science ($N = 659$)

In terms of Year 8 students, Fig. 8.2 provides a summary of the overall trends in these data. As observed here there was some movement away from the Strongly disagree and Disagree options to Strongly Agree and Agree. Only one significant increase ($p = 0.008$) was identified for the item: *I would consider a career in* *science*. Again, this is a positive outcome indicating that more Year 8 students were prepared to consider careers involving science as a consequence of their involvement in the project.

A within gender comparison (see Table 8.3) identified one significant difference for males ($p = 0.05$) for the item: *I would consider a career in science*. This is because more males selected either Strongly agree or Agree for this item in the post rather than pre survey and represents a positive impact of the project. In contrast though, no significant differences were found for an across gender comparison.

8.5 Self-Concept in Science: What Changes Were Evident?

An overview of Year 7 students' self-concept as gauged by the pre and post survey responses is provided in Fig. 8.3. What is particularly interesting about these results are the items that attracted higher proportions of Strongly agree and Agree options. Looking at the five items it seems that this cohort of Year 7 students considered that science was not overly difficult for them (see item 1), felt positive about solving

Table 8.3 Year 8 students' self-efficacy and gender comparisons in science

	Within gender comparisons $(\overline{X})$				Across gender comparisons $(\overline{X})$			
	Female		Male		Pre		Post	
Survey item	Pre	Post	Pre	Post	Female	Male	Female	Male
I feel good about myself when I do science.	3.34	3.48	3.4	3.4	3.27	3.41	3.33	3.36
I would consider a career in science	2.57	2.83	2.49	**2.89**	2.6	2.59	2.75	2.86
I can usually give good answers to test questions on science topics	3.43	3.48	3.35	3.37	3.27	3.28	3.35	3.36
Knowing science will help me make good decisions in the future	3.54	3.58	3.48	3.6	3.37	3.46	3.49	3.49

Bolded figures highlight significant differences

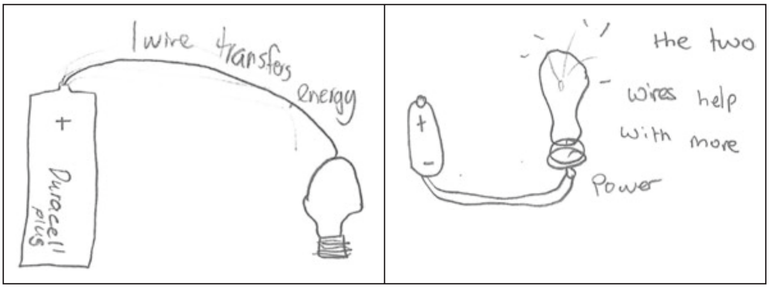

Fig. 8.3 All Years 7 students' self-concept in science 2017 ($N = 640$)

Table 8.4 Year 7 students' self-concept and gender comparisons in science

	Within gender comparisons $(\overline{X})$		Across gender comparisons $(\overline{X})$		Female		Male		Pre survey	
	Post survey	Survey item	Pre	Post	Pre	Post	Female	Male	Female	Male
I can understand most subjects well, but science is difficult for me										
2.68	2.74	2.43	2.33	2.76	2.60	**2.82**	2.52	I am sure I can solve challenging problems in science	**3.47**	3.19
3.61	3.45	3.41	3.50	3.32	3.43	I get good marks in science	3.64	3.6	3.57	3.45
3.48	3.39	3.49	3.41	I have always believed that science is one of my best subjects	2.82	2.74	3.07	3.25	2.65	**2.91**
2.68	**3.12**									

Bolded figures highlight significant differences

problems (item 2) and getting good marks in science (item 3). But these students did not consider science as one of their best subjects (item 4). However, no significant differences were identified suggesting that no substantive variations occurred in Year 7 students' self-concept as a result of this project.

Analysis of these data in relation to gender produced the results summarised in Table 8.4. In terms of within gender comparisons (columns 1–2), little change occurred in male responses between the pre and post surveys. The only significant negative change was for female students for the item: *I am sure I can solve challenging problems in science* ($p = 0.02$). This result signals that females were more positive about their ability in the pre surveys than the post surveys.

In contrast, across female and male pre and post survey responses (columns 3–4, Table 8.4) produced two significant differences ($p = 0.003$). For the item: *I can understand most subjects well but science is difficult for me*, more female students selected the Strongly agree and Agree options than male students in the post surveys. This finding aligns with research indicating that females are less confident about their abilities in science than males. Of course, this is a perception and it may be that the female students actually do better than they perceive. This view is reinforced with the statistical results ($p < 0.001$) for item: *I have always believed that science is one of my best subjects.* These results signify that more males selected Strongly agree and Agree options for the item than female students in both the pre and post surveys. Clearly, the self-concept of male Year 7 students appears higher than for female students.

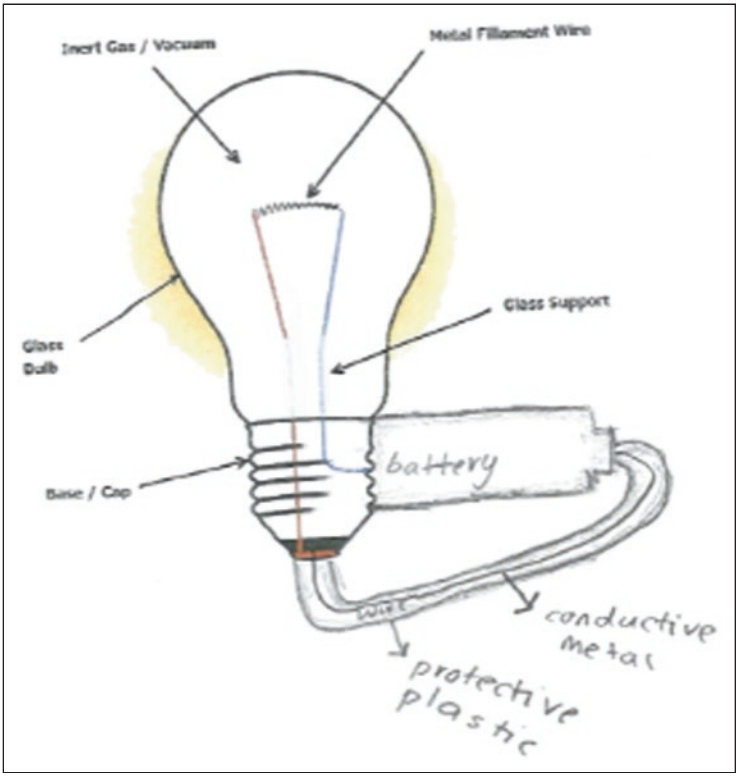

Fig. 8.4 All Years 8 students' self-concept in science (N = 659)

Moving to Year 8 students, Fig. 8.4 provides a summary of responses for the pre and post surveys. While there are some shifts in option selection between pre and post responses, it is more compelling to ponder the pattern across the items. As a cohort these students considered science not to be overly difficult for them (item 1), demonstrated mixed views about being able to do advanced science (item 2), agreed that they understood the science concepts well (item 3) and felt they obtained good marks in science (item 4). A statistical analysis of the items revealed only one significant difference for: *I can understand most subjects well, but science is difficult for me* ($p = 0.00$). This result is because a higher proportion of students selected Strongly agree while fewer chose the Disagree options in the post survey.

A comparison of the pre and post survey findings within each gender (columns 1–2, Table 8.5) identified statistical differences for three items: *I can understand most subjects well, but science is difficult for me* ($p < 0.001$); *I am sure I could do advanced work in science* ($p = 0.002$); and, *When I am being taught science I can understand the concepts very well* ($p = 0.04$). These results indicate that a higher proportion of female students selected Strongly agree and Agree options in the post surveys. While at first glance this might seem a highly positive outcome, each item must be considered separately. For example, greater agreement with finding science

Table 8.5 Year 8 students' self-concept and gender comparisons in science

	Within gender comparisons $(\overline{X})$				Across gender comparisons $(\overline{X})$			
	Female		Male		Pre survey		Post survey	
Survey item	Pre	Post	Pre	Post	Female	Male	Female	Male
I can understand most subjects well, but science is difficult for me	2.21	**2.78**	2.44	2.73	2.47	2.62	2.9	2.88
I am sure I could do advanced work in science	2.81	**3.13**	2.79	2.97	2.8	**3.0**	3.03	3.01
When I am being taught science I can understand the concepts very well	3.38	**3.58**	3.42	3.38	3.17	3.33	3.37	3.33
I get good marks in science	3.69	3.78	3.47	3.47	3.46	3.37	**3.56**	3.34

Bolded figures highlight significant differences

difficult (item 1) is a negative outcome while female students agreeing that they could do advanced work in science (item 2) and being able to understand the concepts (item 3) is positive.

When gender was compared across females and males (columns 3–4, Table 8.5), two significant differences were highlighted. In the pre surveys, male students indicated ($p = 0.03$) that they were more confident in doing advanced work in science (item 2) but this difference had disappeared in the post surveys. The improvement in the self-concept of Year 8 female students mentioned above was evidenced further in the findings to the item: *I get good marks in science* ($p = 0.02$). While there was no significant difference in the pre surveys between males and females, females showed improvement in the post survey responses.

Reflecting upon the overall results for students' self-efficacy and self-concept in science, these findings indicate that primary school students demonstrated a greater significant improvement over the duration of the collaborative inquiry project than secondary school students. These changes were more in favour of male rather than female students thereby corroborating prior research findings.

8.6 Impact of the Networks

Having explored the possible changes in students' self-efficacy and self-concept, the next step might be to consider the impact of the various networks. In this discussion, comparisons are made within each network (i.e., pre versus post surveys) rather than across the networks. The reason for this is that each network represented quite a diverse educational context in relation to student socioeconomic status and geographical location.

Focusing on Year 7 students, Table 8.6 summarises the means for all self-efficacy items (1–4) and self-concept items (5–8) from the pre and post surveys across each of the five networks identified as A-E. It is quite clear from these data that the majority of statistical differences ($p = 0.05$) occurred within Network A with one

Table 8.6 Year 7 students' self-efficacy and self-concept in science across networks

	Network A		Network B		Network C		Network D		Network E	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Self-efficacy										
I am good at science	3.23	3.49	3.32	3.08	3.10	3.27	3.53	3.39	3.50	3.60
When I leave school I will need science for my future work	3.05	**3.62**	3.28	3.10	3.18	3.42	3.48	3.60	3.25	3.47
I learn science quickly	3.23	3.30	3.24	3.10	3.27	3.19	3.41	3.31	3.35	3.45
Knowing science will help me make good decisions in the future	3.26	**3.72**	3.45	3.18	3.55	3.38	3.68	3.66	3.49	3.62
Self-concept										
I can understand most subjects well. but science is difficult for me	2.43	2.55	2.77	2.76	2.90	3.01	2.62	2.52	2.65	2.59
I am sure I can solve challenging problems in science	3.37	3.57	3.39	3.18	3.33	3.22	**3.52**	3.31	3.50	3.55
I get good marks in science	3.05	**3.66**	3.58	3.51	3.07	3.12	3.62	3.40	3.53	3.63
I have always believed that science is one of my best subjects	2.36	**2.85**	2.64	2.65	2.72	2.64	2.84	2.98	2.93	3.11

Bolded figures highlight significant differences

difference identified for Network D. So what do these findings portray regarding impact? In terms of Network A, each of these differences demonstrates that in the post surveys a higher proportion of students selected the Strongly agree and Agree options. When considered in relation to each of the items, this result is extremely positive indicating that the network has contributed to the enhancement of Year 7 students' self-efficacy and self-concept through their participation in the STEM inquiry project.

Alternatively, the statistical significance found for Network D for the item: *I am sure I can solve challenging problems in science* suggests a negative outcome. It demonstrates that a higher proportion of students selected Strongly agree and Agree options for this item in the pre surveys than the post surveys. As such, it seems that students felt less able to solve challenges in science after the project than they did going into the project. However, it could be argued that students' understandings of what challenging problems look like in science has actually shifted from their involvement in the inquiry project.

The same form of analysis was completed for Year 8 students (Table 8.7). It is immediately clear that there is not one network that stands out in terms of a pattern of statistical differences as emerged for Year 7 students. The first significant difference occurred for the item: *I would consider a career in science* due to an increase in Strongly agree and agree options in the post survey for Network C. The second set of differences arose for the same item: *I can understand most subjects well but science is difficult for me.* As observed here, more students across three of the networks chose Strongly agree and Agree responses in the post than pre survey for this item. While this is a negative outcome in one sense, it raises the question as to why more students acknowledge science as being difficult the second time around? It

Table 8.7 Year 8 students' self-efficacy and self-concept in science across networks

	Network A		Network B		Network C		Network D		Network E	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Self-efficacy										
I feel good about myself when I do science.	2.66	2.88	3.11	3.16	3.24	3.40	3.52	3.45	**3.58**	3.31
I would consider a career in science	2.23	2.35	2.64	2.33	2.66	**3.04**	2.74	2.86	2.58	2.75
I can usually give good answers to test questions on science topics	2.81	2.82	3.20	3.56	3.14	3.21	3.54	3.49	3.36	3.34
Knowing science will help me make good decisions in the future	2.84	2.71	3.09	3.47	3.44	3.56	3.59	3.60	3.56	3.41
Self-concept										
I can understand most subjects well but science is difficult for me	2.47	2.47	2.51	2.93	2.70	**3.16**	2.45	**2.80**	2.50	**2.76**
I am sure I could do advanced work in science	2.56	2.65	2.87	3.09	3.01	3.19	3.06	3.06	2.78	2.85
When I am being taught science. I can understand the concepts very well	2.73	2.88	2.91	3.38	3.27	3.27	3.40	3.41	3.37	3.42
I get good marks in science	3.08	3.18	3.52	3.53	3.36	3.39	3.54	3.48	3.48	3.48

Bolded figures highlight significant differences

might be that the project has raised their awareness about their abilities in science so that they have a more realistic view of their capabilities. Without access to more qualitative forms of data it is not possible to offer any further insights.

So, what can be gleaned in general from these findings about the impact of the five networks? Network A had the most obvious impact on nurturing the self-efficacy and self-concept of Year 7 students involved in the project. However, this was not the case for the Year 8 students in the same network. For those of us involved in this project, this finding is not surprising given the enthusiasm, commitment and expertise of the Year 7 teachers working in the primary schools comprising the network. Interviews with these Year 7 teachers (who were all female) unearthed a group of highly competent teachers with solid backgrounds in both science and mathematics while being 'technologically savvy'. They were confident in teaching these subjects and were able to incorporate the problem-based challenges that were part of the broader inquiry project into their classroom teaching. It appeared as though the Year 7 teachers collectively were directing and leading the focus of the project within this network.

An interesting feature of this network is its educational context. Located in the South-East of South Australia in a regional/rural locality, many of the nearby towns were struggling as local industries experienced either 'boom or bust' conditions. As such, the socioeconomic status of students was not high given that unemployment was variable within the region. Of importance though is that there was a degree of stability of Year 7 teachers across the network even though a number of them were teaching part-time. In contrast, the high school in the network experienced a high degree of STEM teacher turnover and changes in STEM leadership over the years leading into and during the project.

The data presented in this chapter provides a very interesting narrative. Taken at one level, statistical differences either emerged or not in relation to year level and gender. However, without collating and analysing the data for the schools comprising each of the five networks, the important contribution made by Network A would have been overlooked. Yet, if data are going to be used to monitor student progress and teacher impact, care must be taken to interrogate any data from different perspectives and at a number of levels otherwise only parts of the picture emerge.

8.7 Conclusions

The chapter set out to investigate RQ 1: *What impacts on students' understandings and dispositions around STEM are evident from their involvement in the Years 7 and 8 STEM Collaborative Inquiry Project*? There is evidence that the self-efficacy and to a lesser extent the self-concept of some students was enhanced with their involvement in this project. Of interest is that the positive outcomes emerged for Year 7 students (i.e., primary school) with little overall change identified with Year 8 students. When considered more closely in relation to gender, the Year 7 differences tended to be male students in most instances. This is not a surprise with the literature (OECD, 2013) suggesting that males demonstrate a higher self-efficacy and self-concept than females in these early adolescent years (Huang, 2013). But what was a critical insight was that the positive differences with Year 7 students aligned predominantly to Network A.

High stakes data has become a key focus in educational discussions of teacher impact and school effectiveness. But schools, students and teachers, learning and teaching represent a highly integrated symbiotic relationship that is quite complex. What is demonstrated in this chapter is that care is required in unpacking data around complex settings such as this so that it actually provides the different lenses through which to accurately interpret educational findings. Without considering the impact of the network in this instance only part of the story would be told. The value of any data are that they provide evidence – not just for its own sake but because the results can be used to help plan, design and implement more targeted programs or ventures into the future. However, for this to truly benefit our students, teachers and schools we need to become immersed in the detail.

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Chapter 9
Complexity in Primary Children's Representations of Science and Mathematics Concepts

Christine Preston, Jennifer Way, and Eleni Smyrnis

9.1 Introduction

This chapter explores 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. In Science and Mathematics, representation theories hold that representational competence is integral to disciplinary knowledge and practice involving a blend of visualisation, reasoning and externalised representations including models, symbols, verbalisations and diagrams. We 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.

Increased emphasis on the integration of STEM education in Australian primary schools entails an array of pedagogical issues for teachers. Whilst primary teachers are familiar with interdisciplinary teaching and learning in general, they typically lack approaches for deep learning in STEM disciplines, especially science. Given the strong STEM Education agenda in Australia (OCS, 2014), greater research is required to "… *make STEM connections more transparent and meaningful across disciplines*" (English, 2016, p.3) with an emphasis on conceptual understanding. Exploring the similarities of 'knowing and doing' across STEM disciplines is a laudable research direction. A feature of the study reported in this chapter is that it investigates parallels in children's thinking about scientific and mathematical concepts derived from their self-constructed representations.

Our research takes the stance that representations are 'thinking tools' used mutually for internal (mental) and external (visible) conceptualisation and model building (Goldin & Kaput, 1996; Prain & Tytler, 2013; Tytler et al., 2013), and therefore

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concentrates on primary students' self-created representations rather than instructed representations or the interpretation of adult created representations. However, the activity of representing does not necessarily produce the most effective or productive representations for a particular situation. This implies the existence of levels of competence in representation, and the need for creativity, reflection and adaptation of representations. Such characteristics are referred to as meta-representational competencies (diSessa, 2004). In science education there has been an increase in research showing that representational fluency, built on meta-representational competencies is critical to developing conceptual understanding in Year 6 and older students (for example, Jee et al., 2014; Nichols et al., 2016). Studies specifically examining children's representational drawings, particularly in mathematics are few in number (Bobis & Way, 2018). This chapter provides evidence that younger children need to be supported to develop these representational skills through drawing their own representations.

Children's drawings are known to be conduits for expression and communication. Drawings can potentially convey levels of conceptual understanding as well as support knowledge construction (Chang, 2012). Pictorial drawings, viewed as free-form depictions of emergent understanding (diSessa, 2004), are distinct from standard scientific or conventional mathematical diagrams. Diagrams, stripped to essentials (ideas and structures) and constrained by subject norms, can be problematic for students to interpret (Preston, 2016). As pictorial drawings may include superfluous details or omit essential elements (Diezmann & English, 2001), their potential for supporting conceptual learning has been undervalued. Indeed, some strong arguments have been presented that the best pathway to conceptual understanding and reasoning is by supporting children's emergent models through developmental steps towards formal models (Gravemeijer, 1999). Some Science and Mathematics education researchers argue that teachers should overtly focus on developing students' representational competence, enabling diagrams to become beneficial thinking tools (Goldin & Shteingold, 2001; Prain & Tytler, 2013; van Garderen et al., 2012). Research focusing on the affordances of self-constructed representations in science indicates "the approach has been successful in demonstrating enhanced outcomes for students" (Hubber et al., 2018, p.57). In relation to our own research, we propose that an explicit focus on developing competence in drawing as a representational form in STEM experiences may assist students to understand key concepts and relationships for knowledge building and deep learning.

While developing competence in diagrammatic representation is important in Science and Mathematics, such representations do not exist in isolation, but are part of complex, interrelated systems of representations. Internal cognitive representation includes, among others, *verbal/syntactic systems* (language) and *imagistic systems* (spatial structures and mental images), which extend to kinaesthetic encoding such as gestures and body movement (Goldin & Shteingold, 2001). Internal representational systems are manifested in various combinations as external representations. Representational gestures seem to be particularly useful for spatial thinking and are often activated through the use of other representations such as drawing

(Elia et al., 2014; Thom & McGarvey, 2015), and verbal description (Alibali & Nathan, 2012; Logan et al., 2014).

Our research is founded on the premise that primary students' self-generated representations (primarily drawings), can offer insights about their emerging conceptions in science and mathematics. The main project collected data from 50 children (Years 2, 4 and 6) from six primary schools in the state of New South Wales, Australia. This chapter is centred on data collected from one school to begin the exploration of age-related trends in children's evolving conceptual understanding and representational competence in science and mathematics involving observation of a dynamic event.

As part of an ongoing study, this chapter addresses two research questions:

- What science and mathematics conceptual understandings are demonstrated through children's representations?
- What developmental differences are evident in children's drawings across the 7–12 year age-range?

9.2 Methodology

The six participants for this study were drawn from a small, regional primary school. Teachers were asked to recommend children who would be comfortable with interacting with the researcher in an individual interview situation. Two children from three different year-levels agreed to participate, with parental permission: Year 2 (approx. 8 years old), Year 4 (approx. 10 years old) and Year 6 (approx. 12 years old). Younger children were not included in order to minimise the chance that the children had not yet begun to create representational drawings. The two-year gap between age-levels was intended to increase the likelihood of detecting developmental differences in the children's responses.

Task-based Interview is a methodology particularly suited to the exploratory nature of our study, with its intention to infer student cognition from their external representations. Maher and Sigley (2014) portray the purpose of task-based interviews to make opportune observations as individual participants react contextually to a problem situation or engage with a task, to infer their mathematical (or scientific) thinking. As the task design is pivotal, it must be suitably open-ended to enable a gamut of responses, be age appropriate in its conceptual content and interesting enough to facilitate creation of rich representations for inferential analysis (Goldin, 1993). Researcher-participant discourse must be warily contemplated to avoid the possibility of questions, prompts and responses overly influencing participants' thinking. However, it is acknowledged that it is likely that the student's interaction with the task and with the interviewer will naturally result in changes in thinking, which constitutes learning.

Qualitative data were collected, using multiple techniques, directly from children's drawing, talking and gesturing as they engaged in active investigation with a toy car and ramp assembly. Each child participated in a simple 'experiment' involving a toy car freely moving down a ramp (See Interview Protocol). The child made predictions about, and viewed the actions of the car, prior to developing self-created representations, focused on the production of one or more drawings about the observed phenomenon. In this study, 'drawings' are considered to be an externalisation of imagining and concept construction (Woleck, 2001; Wright, 2007) and are dynamics processes, not just static products. Revealing children's understandings in complimentary, verbal and non-verbal modes is considered to be important when researching children's thinking through drawings (Macdonald, 2013). Wright (2007) explains the combined modalities enable children to use different forms of representational thinking to consider various interpretations, extend understanding and form new meanings during the act of constructing and relating their drawings. To capture the connection between drawing and narrative, a 'show and tell' digital pen (*LiveScribe*) with an inbuilt camera and microphone was used for drawing. The data digital from the *LiveScribe* pen is saved in a form that enables the dynamic episode of combined verbalisation and sign making (drawing) to be replayed by the researcher for analysis. This technology therefore increased reliability during analysis by synchronising drawing and utterances as intrinsically linked elements of meaning-making.

In addition to capturing the draw-and-talk episode via the digital pen, video-recording was used to capture the broader meaning-making context. The gestures that naturally accompany speech potentially convey additional thinking or express ideas more easily than words or drawn figures (Garber & Goldin-Meadow, 2002). Videoing captured dialogue, facial expressions and gestures throughout the interview, including predictions and discussion before completion of the drawing, and additional dialogue afterwards. McNeil's (1992) classification scheme articulates that language and gesture are inseparable from the integrated communication system, where two of the four gestures (i.e. deictic and iconic) are the focus for this study.

9.2.1 Interview Protocol

9.2.1.1 Equipment

The protocol required specific equipment including a purpose-built ramp assembly of a 5-step 'ladder' and a ramp platform (Fig. 9.1) that could be positioned on any step with a small, free-wheel toy car. Marker sticks were used to locate where the car stopped on the floor, and a tape measure was available should a child choose to make an actual measurement.

9.2.1.2 Procedure

The task was introduced with the following instructions: I am interested in finding out what children think about how toys work. We are going to do an activity using this ramp and car (show equipment) and I would like you to do a drawing of it and

Fig. 9.1 Toy car and ramp assembly

tell me what you think about what happened, and why you think it happened. I would like you to talk about what you are thinking while you are drawing it. We are going to see what happens when we start this car from different heights on this ramp. The following sequence of steps was then enacted:

(a) The ramp is set on the lowest level. The researcher places and holds the car at the top. Researcher – "What do you think will happen to the car when I let it go?" The car is released, the child observes and is invited to place a labelled marker where the car stopped. Researcher – "Let's see if the same thing happens again". Car released from the same height.
(b) The ramp is set on the middle level, then the highest, and step a) dialogue is repeated.
(c) The child is shown how to turn on the pen and start it recording. Researcher – "Draw some pictures (with words if you want) to show what you saw and why you think this happened. Please talk about your drawing as you are doing it. I might ask you some questions as you draw."
(d) The researcher asks questions to clarify, elicit more information or to encourage further thinking. Prompts for talking while drawing included:

- Please tell me about what you are drawing
- What have you drawn so far?
- What are trying to show?
- Why have you drawn the ……?

Probing questions included:

- Can you tell me more about…..?
- What was different? What was the same?
- Why do you think this happened?
- You said ….. happened. How have you/can you show that in your drawing?

9.2.2 Data Analysis

A multi-layered analysis approach was applied to the data. The first layer of analysis concentrated on individual student responses. An analytical framework as shown in Table 9.1 was used and consisted of four main components including drawing, verbal, video/audio and significant sequences/conceptual shifts. In this study, 'conceptual shifts' refers to the identification of a point in the interview where the child demonstrates a noticeable change in thinking, such as redrawing their representation to show something different, or changing their verbal description or explanation to communicate a new concept. The components (Table 9.1) were collaboratively formulated by the research team, then independently tested by all three researchers. Each researcher employed the framework to analyse the recorded data from the same interview. A three-way discussion was held to discuss and justify any varied interpretations of both the analysis criteria and the student's responses. Subsequent adjustments were made, resulting in a corroborated analytical framework that could be applied with reasonable confidence by a single researcher. To increase validity, the completed analysis for each student was reviewed by a second researcher, who made any required minor amendments before adding an interpretive summary.

The second-layer analysis focused on identifying differences between the representational responses produced by each age level. A summary table of the key characteristics of each year level results was compiled to facilitate comparisons across year levels to suggest a possible developmental sequence.

A third layer of analysis looked for similarities and differences between the types of responses. This analysis was guided by questions such as, 'Does the child/age-level communicate different concepts or thinking using different modes of

Table 9.1 Analytical framework

Component	Data source	Aspects
Drawing	Digital pen	Perspective and features Sequence of construction Type (procedural, descriptive, explanatory) Concepts and relationships Annotations
Verbal	Digital pen	Terminology Clarification of drawing Additional information Type (procedural, descriptive, explanatory) Concepts and relationships
Video and audio	Video camera	Student's predictions Gestures Additional information
Significant sequences or conceptual shifts	All data sources	Extracts that record sequences of significant meaning-making (such as dialogue between the researcher and student and/or changes to the drawing)

representation?'. For example, were the drawings and verbal explanations both explanatory in type, or were the drawings descriptive and verbalisations more explanatory?

9.3 Results

Each student's representational responses are presented first, with a focus on the key features of the drawings, supplemented with verbal and gestural data. Student names are pseudonyms. A brief year level summary is also provided. The outcomes of a comparative analysis across year levels are then presented to suggest developmental trends within the students' drawings and in the science and mathematics concepts they demonstrated.

9.3.1 Year 2 Representations

Brett's single, front-view drawing shows the ramp platform in the foreground and the steps of the 'ladder' only in the background (Fig. 9.2 left). His drawing includes three marker sticks to show the relative distances travelled by the car after leaving the end of the ramp. Brett did not draw the car but showed the path the car travelled from beginning to end of the ramp using four, equal-length, straight dashes. A fifth, longer 'line' shows the transition of the car from the ramp to the floor. Although Brett's drawing only shows the highest ramp (step 3) it is partially explanative as it implies a relationship between the height of the ramp and the distance the car travelled.

Janey's drawing (Fig. 9.3) comprised two parts. On the left side of the page she drew the marker-sticks showing the relative distances the car travelled on the floor

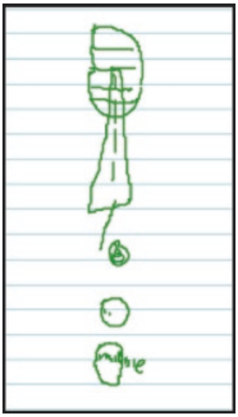
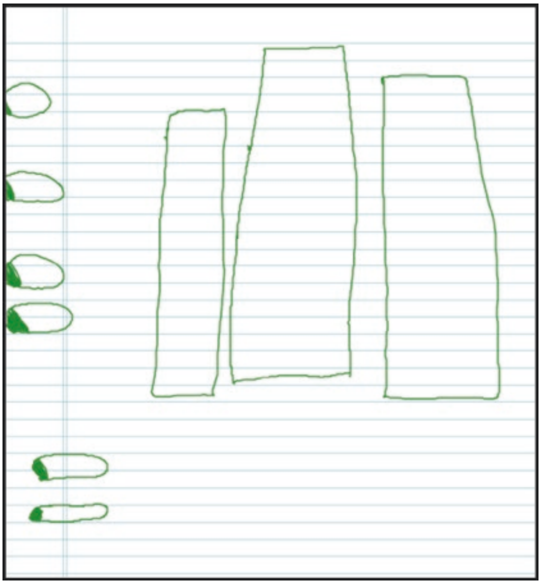


Fig. 9.2 Brett's drawing (Year 2)

Fig. 9.3 Janey's drawing (Year 2)



after exiting the ramp. However, her descriptive drawing did not show the end of the ramp as a reference point. In the second part, Janey tried to show the different ramp heights. She chose to draw the ramp only (without the 'ladder'), and as she indicated verbally, used proximity to the top of the page to indicate the differing heights at the top of each ramp. The highest ramp was drawn first in the centre of the page. The lowest ramp was drawn to the left, then the middle-height ramp was drawn to the right. When asked why the ramp height made a difference to where the marker-sticks were placed, Janey explained: *"The further you go up, the more it's gonna go out"* and used her hands to show height and horizontal distance.

In summary, both Year 2 students' front-view drawings focused on the distance travelled by the car. The students used gesture and spoken words to make connections between ramp height and the distance of travel but did not make such connections through drawing. Interestingly neither child drew the car, focusing instead on drawing the position at which it stopped on the floor.

9.3.2 Year 4 Representations

Bruce made two drawings (Fig. 9.4). The first attempt on the right side of the page was abandoned when there was no room to show, *"… on each height it was going down faster*". He then drew three front-view figures depicting each ramp height (labelled 'top', 'middle', 'bottom') and a symbolic car to show where it stopped each time. Bruce explained, *"Then it goes from the top level, it's going to go further because it's going steeper and picking up more speed."* This statement indicates a

Fig. 9.4 Bruce's drawing (Year 4)

causal relationship between ramp height and distance travelled with an associated change of speed. Bruce added the words 'faster' and 'slower', in response to the prompt, "How can you show the difference in speed?" Continued discussion about the highest ramp revealed, *"… gravity makes it fall faster."* Bruce thought gravity also affected the lowest ramp but "… not as much" and was unable to show gravity in his drawing.

Josie's six-part isometric (i.e. corner view) drawing (Fig. 9.5) was structured within a grid, sequenced left to right across the top row, then across the bottom row. For each ramp height she showed the car in its starting position at the top of the ramp, followed by a drawing of two marker sticks (depicting the first and second trials). For the lowest ramp the sticks were positioned to the left side of the grid-square, close to the base of the ramp. The sticks for the middle and top ramp heights were drawn successively further from the left side of the grid-square. She included both descriptive (procedural) text and labelling arrows to show each ramp was tested and recorded twice. She also wrote explanative (causal) text relating gravity to change in speed. Josie also gestured with her hands as she explained: *"It went further because of the vertical change, that made it go steeper and then wheels went down because of gravity".*

In summary, the Year 4 students' representations consisted of multiple components, including all three ramp heights, the car and the relative distances it travelled. Both students talked about how gravity and speed were related to ramp slope (steeper). While Bruce only alluded to slope verbally, Josie's isometric view drawing allowed her to depict the difference in angle for each ramp and connect it with differences in the distance travelled by the car.

Fig. 9.5 Josie's drawing (Year 4)

9.3.3 *Year 6 Representations*

After stating, "*I am not very good at drawing*", Bob drew the highest ramp at the bottom of the page (Fig. 9.6), depicting an isometric viewpoint and said, "… the higher it gets, the car will go further". He drew the car part-way down the ramp and a long curved line to show that the car "… rolled down the ramp." Bob drew three short, parallel 'lines' behind the car to show "… that it's moving". Next Bob drew a lower ramp above the first figure, with a shorter, curved line in front of the car to show "… it didn't go as far". He drew shorter 'lines' behind the car to show less speed. When asked why the car didn't go as far, Bob said, "… because it was at an angle like that (gestured with arm) so it has more speed so it could go further…and faster". He then added more 'whoosh' lines to the first drawing to emphasise its greater speed. Asked if he could 'show the angle', Bob drew the ramp board from a corner 'angle', representing its third dimension (thickness), possibly misinterpreting the question. 3-dimensional ramp end face-on that emphasised the thickness. Then, near the top of the page, he drew a series of three side/top-view ramps at slightly different angles saying, "… the next one might be this and then it just keeps going higher" (Fig. 9.6).

Jenny drew a side-view of the car on the ramp, with no 'ladder' included (Fig. 9.7, left drawing). She drew the highest ramp labelled 'faster', and the lowest ramp labelled 'slower'. She added the words 'ramp' and 'car' after the prompt, "So tell me the parts of your drawing." Specific prompts of, "What are these lines?" and, "What is the difference between the high and low one?" led to the comment "… difference in angle" with hand gesturing and adding more labels. Verbalisation provided reasoning about the causal relationship between gravity, "… there's more gravitation as less……one's faster because it's got more gravitation hitting and that one's got less."

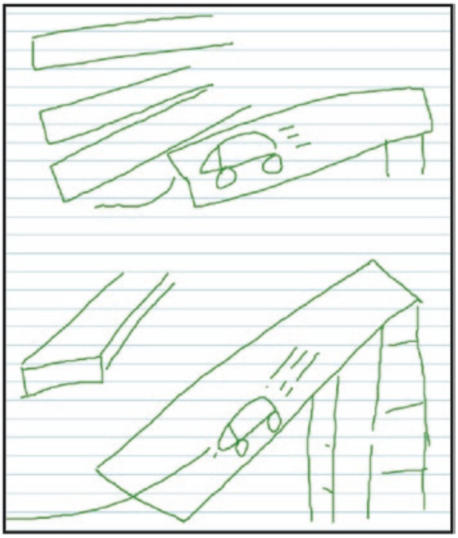


Fig. 9.6 Bob's drawing (Year 6)

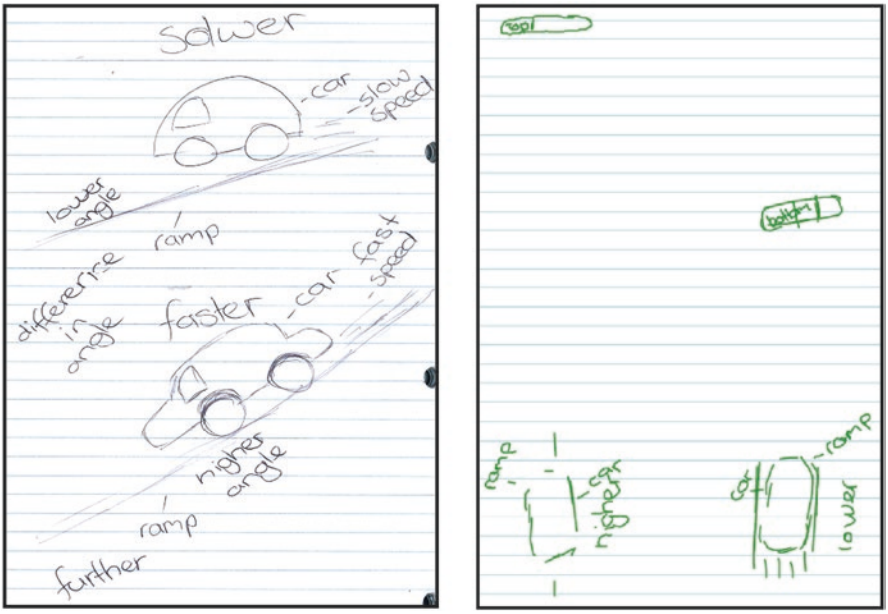


Fig. 9.7 Jenny's two drawings (Year 6)

Jenny started another drawing on a new page to try to show that "… one went further because there's more speed" (Fig. 9.7, right drawing). The second drawing shows a top-view of the cars on the ramp, with marker sticks (towards the top of the page) indicating the distance travelled by the car. She also explained that "It has more speed because it's going down at a high angle …The bottom angle, it just goes a little far because it doesn't have the thrust".

In summary, both Year 6 students created multiple drawings and drew from various perspectives, which enabled the casual relationships between ramp angle, car speed and distance travelled to be depicted. They both gave spoken explanations explicitly connecting the changes in ramp height and angle with car speed and the distance travelled. Interestingly, they both drew 'whoosh' lines behind the car on the ramp to indicate movement and difference in speed. Rather than draw all three ramps both students selected the highest and lowest to illustrate the relationships they had noticed.

Comparative Analysis Across Year Levels

Several major themes of difference were revealed through making comparisons across the key characteristics of each year level's responses to the task using data drawn from all sources: (a) *Representational strategies* (type of drawing produced and its key features); (b) *Conceptual focus* (the main science and mathematics concepts to which they attended); (c) *Level of relational thinking* (complexity of connections and relationships between concepts); and also noted was, (d) *Formality of language* (every-day terms to more technical vocabulary). Table 9.2 contains a summary of differences across the 3 year levels in each of these themes.

Table 9.2 Summary of differences between year level responses

Themes of difference	Year 2	Year 4	Year 6
Type of drawing, key features	Descriptive Single perspective – one top view and one front view. Marker sticks included. No cars drawn No written labels	Descriptive – explanatory. One front view, one isometric view. Multiple drawings depicting all three ramp heights. Cars and their finishing positions depicted.	Explanatory Multiple perspectives and drawings (isometric, side view, top view). Only highest and lowest ramps included. Cars depicted and 'whoosh lines' to indicate speed.
Conceptual focus	Distance, height	Distance, height, speed, gravity.	Angle, height, speed, distance, gravity.
Level of relational thinking	Expressed a relationship between ramp height and the distance travelled by the car.	Expressed relationship between ramp height and distance in drawing and verbally. Mentioned speed and gravity and partially explained the connection between these and height and distance.	Expressed casual relationships between multiple variables, including gravity, and alluded to momentum.
Formality of language	General terms of direction, motion and comparison such a: goes up, moves down, further	A mixture of general terms and specific vocabulary such as: higher, steep, faster, vertical, gravity.	Greater use of specific vocabulary such as: angle, gravity, speed, thrust.

In all four themes, the characteristics of the students' responses become more complex, showing a progression in sophistication of science and mathematics understanding as the year-level/age increases. The progression from simple, single perspective drawings to more complex, multiple perspective drawings mirrors the increase in the number of conceptual relationships realised by the students. Interestingly the Year 2 students did not draw the car, focusing instead on the sticks that marked how far it went. Although the Year 2 drawings showed both the height of the ramp and the distance of travel, the relationship between the two variables was expressed more in their verbal explanations and gestures. Year 4 students' drawings depicted a clear relationship between height and distance by showing all three experiment situations making their drawings more explanatory. The causal factor of gravity was explained and included in textual labels (one child). Year 6 drawings conveyed a generalisation by including only the high and low ramps. They also focused more on causal factors such as gravity, angle and speed, referring less to distance. Year 6 students used icons (which we call 'whoosh' lines) to add the dynamic of speed to their drawings. The older students made multiple drawings which supported their conceptualisation of the dynamic event because they could effectively represent the idea of 'change' from one test situation to the next.

9.4 Discussion

The findings of the small-scale exploratory study reinforced the proposition that involving children in drawing dynamic events can provide insights into children's thinking and knowledge development (Wright, 2007), in science and mathematics. The car-ramp task provided a suitable stimulus for varied, multi-faceted responses from all age groups, and the use of multiple data-capturing techniques proved to be critical to the quality and completeness of the data. This aligns with the findings of Macdonald's (2013) study with preschool children. Narratives supported by gesturing showed evidence of the students' re-enactment of the dynamic event and revealed understandings that were not clearly communicated through drawing alone. Even the youngest students were able to explain the distance travelled by the car in relation to ramp height through verbal explanations and gestures, though they struggled to represent this relationship in their drawings. The opportunity to talk about what they were drawing assisted students to more comprehensively communicate their understanding of observations made during the dynamic event.

From a mathematical standpoint, the connections between each student's conceptual focus and the type of drawing they created is of particular interest. The Year 2 students focussed on the one-dimensional attribute of length, but, in the three-dimensional context of the task, had to consider length as both vertical height and horizontal distance, and somehow convey the relationship in a two-dimensional drawing. At this age level the skills involved in perspective drawings (projective geometry) are typically just emerging, so it is not surprising they chose to create a single-viewpoint drawing. In contrast, the Year 6 students attempted to represent the relationships among multi-dimensional physical attributes and concepts, such as angle and speed, and utilised their more developed repertoire of drawing perspectives. Thus, we see some connection between the complexity of the concept relationships perceived by the children and their capacity to utilise perspective drawings; an aspect that warrants further investigation. The data collected does not allow us to speculate about what mental images the children may have possessed, and whether or not their drawing competence inhibited or assisted the translation to external representation. Hast's (2018) discussion of research with 5 to 12 years-olds concerning changes in incline height on the motion of balls with different weights, declares younger children's mental images likely comprise disjointed knowledge (di Sessa, 2013) about motion down ramps, potentially limiting their drawing capacity. In contrast, the older students with more flexible knowledge structures, capable of coordinating different ideas (Vosniadou, 2013), have more sophisticated mental images to translate into drawings.

From a scientific perspective, students were able to generalise about the movement of the car in the three situations and relate it to the change in a single factor, height of the ramp, demonstrating scientific thinking. The mass of the car and the role of energy were absent from students' representations. An understanding of how the toy car moves involves translating between everyday observations and abstract concepts that cannot be directly observed such as contact force (friction) and non-contact force (gravity). This may account for the difficulties faced by children when attempting to visually represent the 'invisible' forces acting on the objects (such as gravity) and 'invisible' attributes of the objects (such as mass).

Gravity was mentioned as a causal factor by Year 4 and Year 6 students and reflects previous findings on students' ideas about gravity. The youngest students' views assumed 'natural motion' and the older students alluded to gravity as an 'unseen force' (Kavanagh & Sneider, 2007). However, understanding of the concept was lacking and the word gravity was used without elaboration. Terminology can be used by students as empty labels that potentially inhibit understanding (AAAS, 1993). Further, naïve understanding was apparent, through the view that there was less gravity acting on the car with the low ramp. An association was made between the height of the ramp and the effect of gravity, which students inferred was due to a difference in the amount of gravity (i.e. higher ramp has more gravity). This relates to the common alternative conception 'gravity becomes stronger the further you are from the ground' (Allen, 2014, p. 163).

9.5 Conclusion

The task of drawing a dynamic phenomenon is not a simple one, and the complexity of the cognitive demands placed on a child is perhaps often underestimated by educators and researchers. In our study, the children needed to activate and combine multiple representation systems to: (a) translate a dynamic event into a static depiction; (b) translate a three-dimensional scene into a two-dimensional representation;

(c) capture multiple variables and the relationships between them using invented drawing features; and, d) visually represent abstract forces and attributes of objects. In general, the children did not have sufficient representational competence to convey the full extent of their scientific and mathematical knowledge and reasoning through drawing alone. More sophisticated and complex understandings were revealed when additional representational systems, such as verbalisation and gesture, were utilised to supplement or elaborate on the drawn responses. However, classroom assessment processes frequently rely on student drawings as summative artefacts that demonstrate children's understanding. This raises a range of questions about what teachers can or should do to support the development of skills in representational drawing, particularly with the increased emphasis being placed on integrated STEM experiences in Australian primary schools. For example, What are the most effective approaches to increasing children's competence in scientific/mathematical drawing without disconnecting the drawing processes from their thinking processes?

Our research continues to work towards a deeper understanding of how to support the development of early primary children's representational competence in scientific/mathematical drawing to enable them to effectively utilise drawings as both formative 'thinking tools', and as summative communications of conceptual reasoning. When reflecting on our findings so far, we are struck by the paradoxical goal of (simultaneously) simplifying children's pictorial drawings towards diagrams, while enhancing their capacity to represent increasingly complex relationships.

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Part IV
Making the Complexities of Science Curriculum Content and Concepts Accessible to Learners

Chapter 10
Making the Complex History of Chemistry Accessible: Edgar Fahs Smith (1854–1928), Chemical Researcher, Administrator, Educator, and Student of Chemistry's History

William P. Palmer

10.1 Introduction

Edgar Fahs Smith was born in a log cabin in Pennsylvania. The start of his life was in very simple circumstances, yet he achieved a successful career in the complex field of chemical research.

His initial education proved him to be an excellent student; he completed his studies in Germany gaining a doctorate in chemistry at the University of Göttingen. He returned to the University of Pennsylvania to start his academic career. His research efforts were mainly devoted to the complexities of electro-chemistry. He was a much-loved teacher who guided his students in their difficult chemical studies by building up a collection of historical chemical items to engage his students' interests.

Edgar Fahs Smith had great success as an administrator, being elected Vice-Provost and then Provost of the University of Pennsylvania. One of the acts for which he will be remembered by historians of chemistry is founding the Division of the History of Chemistry of the American Chemical Society and for his collection of rare chemical books and chemical memorabilia which he left to the University of Pennsylvania. In his historical writing, he used a social, personal and cultural style in writing about chemists in the History of Chemistry.

As I have researched the life of this little-known chemist, I realise that his style of writing biographies of chemists is the style which I now try to follow. To encourage his students to understand the complexities of chemistry, his method was to tell the very human stories of scientists, illustrated by the apparatus which they used or the original books that they wrote. It is in large part due to the endeavours of Edgar

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Fahs Smith who used this simple idea that I and many other historians of chemistry attempt to follow his example.

Following the life of Edgar Fahs Smith in detail, as a case study, illustrates the assertion that the study of the complex concepts of chemistry may be assisted by using simple human stories and human experience. Smith's own philosophy and religious belief ensured that he emphasised simplicity in the way that he lived his life and the various biographical articles tend to show different aspects of that simplicity.

10.2 Sources

There is no autobiography of Edgar Fahs Smith, though he evidently wrote one which was not published. His secretary, Eva Armstrong, later curator of the history of science museum which Smith founded at the University of Pennsylvania, quotes from it stating that the quotations in the preface are from 'an unpublished autobiography by Edgar F. Smith' (Armstrong, 1937, p. 3). There is also an early partial biography of Dr. Edgar Fahs Smith from *The Wittenberger*, published at Springfield, Ohio, which was a sketch written by Rev. L. A. Gotwald, D.D. as was reported in the local newspaper (Reporter 4, 1887, p. 1). Edgar Fahs Smith was well-liked by many colleagues (Parsons, 1932, pp. 621–622) and much admired (Rogers, 1932, pp. 627) for his virtues of simplicity, modesty and caring. Probably the source, nearest to a full biography, is provided by G. H. Meeker, (Meeker, 1937, pp. 375–384). Personal stories about Smith when he was growing up are available through an article by his younger brother, Allen (Smith, 1932). Stories about his time with Wöhler obtaining his doctorate at Göttingen University are available through William McPherson (McPherson, 1928). The *Journal of Chemical Education* of April 1932, which was a Memorial issue dedicated to Dr. Edgar Fahs Smith contains several important articles about him. Edgar Fahs Smith is frequently mentioned in American scientific biographies, for example, in *American chemists and chemical engineers* (Miles, 1976, pp. 445–446) or briefly in two lines by Clark A. Elliott (Elliott, 1979, pp. 237–238) but less frequently in European chemical histories. It is perhaps pertinent to note that Edgar Fahs Smith does not receive a mention in J. R. Partington's monumental four volume *A history of chemistry* (Partington, 1965). This indicates that J. R. Partington did not see Smith's research as being of major significance.

10.3 Ancestry and Early Life

Edgar Fahs Smith was born on 23rd May 1854 in a log cabin on the banks of the Codorus Creek near York, Pennsylvania (Armstrong, 1937). His parents were Gibson Smith, who was a businessman owning a grist mill (Miles, 1976, p. 445) and Susanna Elizabeth Fahs (Ancestry).

Gibson Smith (1822–1887) was 32 years old when Edgar was born and he moved his family into York, where he became a grain, wood and coal merchant. He was a successful businessman and when he died, he left the family well-off (Meeker, 1937, pp. 375–384). His mother, Susanna Elizabeth Fahs Smith, was a devout Moravian and was responsible for much of Edgar's early education. Comparatively little is recorded about Edgar's elementary schooling. Edgar's younger brother Allen was born in 1863 and died in 1926 (Addison, 1940, p. 96). Allen told a story about Edgar that he 'upset a box of washing-blue upon my white head and attempted to wash it out… It would not wash out, and I remained for weeks a prominent figure in the local landscape from the efforts of the embryo chemist (Smith, 1932, p. 620)'. Edgar Smith attended York County Academy for his secondary education which he completed in 1872. Each year at Christmas, Edgar received only one book, but he supplemented this by earning money 'from strenuous toil in loading coal wagons, working on a farm during vacation periods and finally as a printer's devil' (Armstrong, 1936, p. 341), with which he purchased more books. Allen also mentioned Edgar's great interest in journalism and printing stating that Edgar 'established and for several years was in turn, or all at one time, editor, contributor, compositor, pressman, and financial agent of a youthful publication known as *Our Effort'* which was short-lived. With this publication Edgar wrote most of the articles that were devoted to science (Reporter 1, 1928, p. 6); this is thus an early effort at science communication which remained a lifelong interest. There were evidently several short-lived publications produced at different times such as *The Lutheran*, *Our Effort*, *Evening Star* and *The Poulterer*. A newspaper report said that:

> Their plan, was to put out an evening publication, setting up the type and doing everything connected with the publication of this wonderful daily after 5 o'clock each evening. Then about 8 o'clock they would go on the streets crying, `*Evening Star*—one cent? It lasted about 2 weeks when the two publishers involuntarily retired, physically worn out and financially bankrupt. (Reporter 1, 1928, p. 6)

All these factors were connected to Edgar's love of books. His brother said that Edgar owed his success to 'two persons – his mother and his old teacher, Dr. George W. Ruby, principal of York County Academy' (Smith, 1932, p. 620). Edgar joined the Junior Class of Pennsylvania College at Gettysburg, where he graduated with a Bachelor of Science degree in 1874. He was unsure what career to follow. His father wanted him to follow a business career, whilst he wanted to become a doctor (Kendall, 1928, p. 92) which was the career that his brother Allen chose. He was exceptionally interested in chemistry and mineralogy. His professor, Samuel P. Sadtler encouraged him to continue his studies in Germany and he followed that advice (Browne, 1928b, p. 376). He obtained admission at the University of Göttingen, spent the next 2 years, studying chemistry under Wöhler and Hübner and mineralogy under Von Waltershausen. He enjoyed his time at Göttingen under the supervision of the genial Wöhler, graduating in 1876 with the degrees of A.M. and Ph.D. with a thesis relating to trisubstituted benzene derivatives (Ihde, 1964, p. 826: Bogert, 1929, p. 559); he then returned to America.

Edgar Fahs Smith (1854–1928) married Margie Alice (Gruel) Smith (1860–1953) on 1st April 1879 (Ancestry); they had no children.

10.4 Early Career

He initially obtained a position as assistant in analytical chemistry to Professor F. A. Genth of the Towne Scientific School of the University of Pennsylvania (Browne, 1928b, p. 376) staying there for five happy years. At this time, he developed a series of lectures on the history of chemistry but scrapped them because they bored the students; he worked up new lectures which the students enjoyed. To achieve this he collected books, portraits, autographed letters, and memorabilia of famous chemists to exhibit to his classes and for research. This is the starting point of the Edgar Fahs Smith Memorial Collection (Miles 1976, p. 476).

In 1881, he was appointed as the Asa Packer Professor of Chemistry at Muhlenberg College, where he remained until 1883 (Taggart, 1932, p. 614: Reporter 5, 1881, p. 1). In 1883, he moved to Wittenberg College, Springfield, Ohio, as Professor of Chemistry, staying there until 1888. In 1888 he returned to the University of Pennsylvania, serving as the Professor of Chemistry until 1907, when he was appointed to the Blanchard Professorship of Chemistry. He retained this chair until 1920, when he retired; he was then granted an emeritus Professorship which he held until his death.

Apart from his chemical career, he had great administrative success. In 1898 he was elected Vice-Provost, holding the office until 1911 (Reporter 2, 1928, p. 25). Upon the retirement of Dr. Charles C. Harrison, he was elected Provost of the University of Pennsylvania in 1911 and he resigned in 1920. It is interesting to note that he was elected to this position due to his popularity. Various of his students and colleagues wrote about his excellent teaching and his kindly nature: five comments, typical of many, are recorded below:

1. I have never known an individual with a more magnetic, friendly personality than he. (Parsons, 1932, pp. 621–622).
2. It was my good fortune to be a pupil of Dr. Smith when he was only professor of analytical chemistry, before he was burdened with the cares of the department and long before he was overburdened by the vice-provostship or provostship. Then there was nothing for him but teaching and research. He had the qualifications of the ideal teacher … (Shinn, 1932, pp. 622)
3. As a teacher he had the ability of making the most difficult problems appear as <u>simple</u> and interesting as a fairy tale. As an associate he made one's endeavours to assume the magnitude of a wonderful undertaking. His kindly suggestions and encouragement made life worth living, and we all felt that, if for no other reason, we must make good for Dr. Smith. (Rogers, 1932, pp. 627)

4. His never-failing interest in his students, while they attended the institution and after they left it caused him often to be called 'the best-loved college professor in America (Reporter 2, 1928, p. 25)
5. A kindlier soul has never walked among us. Counsellor and friend to all who needed him, lover of the truth whether it lay hidden in the nature around him or in his fellow man, … (Venable, 1921, p. 106).

The following statement by Miles (1976) also illustrates Dr. Smith's popularity with the students:

> In 1911 the trustees of the university elected him to the office of Provost. When the results of the election were announced, Smith's popularity was so high that the students milled around Harrison Laboratory and built a bonfire in the street outside of his office. (Miles, 1976, pp. 445–446)

> Smith's simplicity of lifestyle has been presented as an obvious virtue as it may be expected that everyone would see his humility and simplicity as such. Meeker (1937, pp.131–132) tells of his disagreement with some alumni. They felt that Smith, as Provost of the University of Pennsylvania, should live in more opulent circumstances than 'his simple home', so they set up a fund to provide a mansion for Dr. and Mrs. Smith, collected the money and built the mansion. 'This did not please Dr. Smith; and he would not leave his simple apartment home'.

10.5 His Later Career

Smith's time as Provost of the University of Pennsylvania from 1911 to 1920 was extremely successful. Early in his provostship he divided the college into four departments: College, Towne Scientific School, Wharton School, and Education with a Dean for each school. During this time, the student enrolment and the teaching staff were doubled, the medical departments were unified and many other improvements were made. The Duhring bequest of more than one million dollars assisted in the process. Also, an increased emphasis was laid on research in every department (Addison, 1940, p. 41: Browne, 1928b, pp. 377–378: Taggart, 1932, p. 618). He retired from active administrative duties as Provost of the University of Pennsylvania in 1920 due to ill-health, being replaced as Provost in 1922 by Dr. Penniman (Reporter 3, 1922, p. 6). His friend, C. A. Browne wrote:

> Dr. Smith found greater leisure, as Emeritus Professor of Chemistry, for promoting an interest in the humanistic aspects of chemistry, which he felt were being neglected in the predominating industrial stress of American civilization. (Browne, 1928b, p. 378)

> Dr. Smith was a very generous man often giving to students in need. Recently, a book was auctioned on eBay that had been inscribed with grateful thanks by a person, who when a student, had received the book as an unexpected gift from Dr. Smith. C. A. Browne tells of Smith's philanthropy:

> Dr. Smith was in every sense of the word a philanthropist. He gave freely of his limited resources to every worthy cause and assisted many needy students to obtain an education.

> He might easily have amassed a fortune from the industrial utilization of his discoveries, but he chose rather to serve his fellowmen. (Browne, 1928a, p. 663)

Thomas D. Cope indicated Dr. Smith's qualities as a superb teacher in this brief extract:–

> Doctor Smith in person gave the demonstration lectures. During one of our years, he in person conducted the recitation-hour and he seldom failed to visit us during the laboratory periods. He would walk into the room unhurried, greet us with a smile, take in the situation, ask a few questions, confer with the instructor, and leave still unhurried.
>
> … Doctor Smith was a simple, genuine, wholesome, genial man. Dignity and good manners were natural to him. (Cope, 1947, pp.193–194)

Dr. Smith practised the mailing of 'cherry letters' (Christmas Greetings) to his students and former students at Christmas time each year even though the list of names always increased (Reporter 2, 1928, p.1). In 1926 a, statue of Edgar Fahs Smith was erected near his office at the Harrison Chemical Laboratory of the University of Pennsylvania (Kendall, 1928, p. 95).

Edgar Fahs Smith died of pneumonia on 3rd May 1928.

10.6 Chemical Research

The full catalogue of Smith's research is most easily found in the *Biographical memoir of Edgar Fahs Smith (1854–1928)* (Meeker, 1937, pp. 375–384) starting in 1877 with papers such as *New chlorine derivatives of toluene* (1877), written immediately after his return from Germany and with some of the other early papers in German such as *Ueber eine neue Dichlorsalicylsaure* (1878). It is interesting to observe that the local newspaper of York, where he had grown up, reported details of his progress through the academic world as shown below:

> We append the following list of Dr. Smith's successive publications: Analysis of a calculus found in a deer (1879): Detection of iron by means of salicylic acid (1878): Product obtained by the nitration of meta-chlor-salicylic acid, (1879): On a new base (1879): New results in electrolysis (1880): The electric method as applied to cadmium (1880): Synthesis of salicylic acid (1880). Scheme for detection or organic and inorganic acids (1878) … (Reporter 4, 1887, p. 1).

It is remarkable that a local newspaper would publish such a detailed account of Smith's chemical research papers. It is also noticeable that Smith's research seems to include all the major branches of chemistry, organic, inorganic and physical. Kendall (1928) summarises Smith's research efforts as follows: –

> An indefatigable research worker in the subjects of mineralogy, electrochemistry and analytical chemistry, Dr. Smith published more than two hundred original papers. His investigations upon the rarer metals have been of industrial as well as academic significance. (Kendall, 1928, p. 94)

Smith's most 'important research' contributions (Miles, 1975, p. 465) were in electrochemistry (Borman, 2012, p. 72), where his most notable experimental advance was the development of the rotating anode. He was an expert experimentalist and used electrochemical analysis to study many metals (Borman, 2012, p. 73). Fink (1935) described some of Smith's experimental work:

> Dr. Smith came upon the idea of rotating the anode. He discovered that by causing the anode to rotate at a high speed, greater current intensity and higher voltage might be applied with an attending, more rapid precipitation of the respective metals (Fink, 1935, p. 2).

It might be thought that the idea of using a rotating electrode was unsuccessful and was no longer an area for research. A comparatively recent paper (Gabe et al., 1998) in summarising the continuous nature of research in this area, stated that 'Electrodes have been rotated since at least 1905 to provide some quantitative control of solution convection'.

Smith and his colleagues determined the atomic weights of 18 elements using electrolytic and chemical methods with great accuracy (Miles, 1975, p. 465). His research on molybdenum and on tungsten and its compounds led to the greater use of these elements (Bogert, 1929, p. 560: Meeker, 1937, pp. 377).

10.7 Writing Chemical Textbooks

Smith wrote, translated and edited many textbooks. Smith's first translation was in 1878 when he translated with additions *Classen's quantitative analysis* (Meeker, 1937, pp. 382). He translated two textbooks written by Victor von Richter from German into English (Richter & Smith, 1883: Richter et al., 1899). Since new German editions were written every few years, Smith would be required to update his translations; so, work on this project was ongoing.

One early project with which Smith was involved was the publication in 1891 of a laboratory manual with a colleague Dr. H. F. Keller (Smith & Keller, 1891) which went through many editions until at least 1913. A review of the fifth edition (Smith & Keller, 1905) by William McPherson was favourable though brief; it stated:

> Smith and Keller's 'experiments' has deservedly reached its 5th edition. The experiments are well chosen to illustrate the principles of chemistry. (McPherson, 1905, p. 831)

Harry Frederick Keller was an alumnus of the University of Pennsylvania from 1881 and worked as an assistant in the Chemistry Department from 1888 to 1890. In 1890, he wrote a textbook (Smith & Keller, 1890) with Fahs Smith which was their first co-operative effort. Eventually he became head of the Central High School of Philadelphia Chemistry Department (Edmonds, 1902, p. 332). This meant that for much of the life of the laboratory manual, Keller and Smith would be able to co-operate closely in frequent revisions of the manual, which kept it relevant over a long period. They also produced a simplified manual (Smith & Keller, 1913) which was better suited to schools than the longer version. Smith was the sole author of several books such as *Theories of chemistry* (Smith, 1913) and his long-running textbook *Elements of chemistry, in lecture form* (Smith, 1918) which ran to ten editions (Palmer, 2017).

10.8 Writing the History of Chemistry

Dr. Smith was a prolific writer. WorldCat credits Smith with 214 works in 547 publications (see also Klickstein, 1959, pp. 20–30). Many of his books are biographies of early American chemists such as James Woodhouse (1917), Robert Hare (1918), James Cutbush (1919), and the story of Joseph Priestley whilst he was in America (1920). His more general histories included *Chemistry in America* (1914) and *Old Chemistries* (1927) which was published only in the year before he died. He published some 20 historical monographs about the lives of less well-known American chemists such as J. C. Booth, Franklin Bache, S. L. Mitchill, M. Carey Lea, John Griscom and J. B. Rogers. He also gave many public lectures that related to the history of chemistry and to chemical education (Browne, 1928a, p. 660). As may be seen from the titles of the books and monographs that he wrote, Dr. Smith was interested in the lives and social context of American chemists and perhaps should be credited with establishing this aspect of chemistry's history as a vital part of the subject, His friend and colleague C. A. Browne expressed Smith's achievement thus:

> While Dr. Smith's interests in the history of chemistry were general, the influence of local attachments induced him to limit his own investigations in this field to the developments of chemistry in America and more particularly within his native state. He disclaimed the title of historian and stated that the development of theories, the founding of industries, and the fixing of dates did not interest him so much as the personalities of the chemists who had promoted the growth of the science (Browne, 1928a, p. 660).

10.9 Adeline Jacobs Visits Dr. Smith

Adeline H. Jacobs, a local High School teacher, described how Dr. Smith showed her around his collection of historical items in the Harrison Laboratory. He revealed much about his character and the way in which he saw his historical collection being an aid to his teaching. Firstly, she described his office where his collection was held: 'pleasing rooms, with potted plants in the windows'. She sees this room as being suited to Dr. Smith's personality. Simplicity characterizes Dr. Smith. 'Plain living but high thinking'.

Dr. Smith showed Ms. Jacobs his collection which he called 'the great chemists of all ages and countries — the Living Dead'. He showed her portraits of Lavoisier and Priestley. He had a special affection for Joseph Priestley because when he came to America, he lived only 150 miles from Philadelphia. He showed her the balance that Priestley used, his portraits and a statuette of Priestley, a selection of books written by Priestley on a wide variety of topics, an original manuscript where Priestley heated mercuric oxide in his preparation of oxygen; he showed her a picture of Priestley's house where the men who founded the American Chemical Society (ACS) met in 1875 (Jacobs, 1935, pp. 502–503). He showed Ms. Jacobs an original Priestley manuscript and read it to her. She wrote:

> This seemed to me the pinnacle of inspiration. What could be more impressive? I had been lifted out of the world of the commonplace by this old teacher of my college days. I was thrilled! Reverently and thankfully I laid aside the Priestley manuscript. (Jacobs, 1926, p. 504)

Perhaps his obvious respect for these ‘Living Dead’ chemists was able to light a spark of enthusiasm in many of his students as well as to this visitor. His collection included letters and autographs from more recent chemists with Fritz Haber being one of his latest additions. All were filed with a photograph ready for use in the classroom. Dr. Smith explained his method of teaching to Ms. Jacobs:

> When I teach about the first synthesis of an organic compound from inorganic ones, I show my class this letter from Wöhler, who synthesized urea. It makes the subject more real to the student—these original letters and these portraits. (Jacobs, 1926, p. 504)

10.10 Preserving the History of Chemistry

Dr. Smith was a member of the ACS and was its President on three occasions (1895, 1920, and 1921) (Miles, 1975, p. 475). Another of the actions for which he will be remembered by historians of chemistry is his founding with C. A. Browne *The Division of the History of Chemistry of the American Chemical Society* in 1920 (Deischer, 1948, p. 12: Petkewich, 2007, p. 34).

Dr. Smith will also be remembered for his collection of rare chemical books and chemical memorabilia which he left to the University of Pennsylvania and now known as the Edgar Fahs Smith Collection (Klickstein, 1959, p. 19). Eva V. Armstrong addressed the Franklin Institute in Philadelphia on January 20th 1933 about the life of Edgar Fahs Smith. She pointed out that the process of collection ‘put flesh on the skeletons of pioneers of the science, making them living, breathing personalities’ (Armstrong, 1933, p. 358) so that Armstrong felt that the pioneers of the science had become real people for her. In order to explain how this historical collection started, she wrote:

> His love of books remained a solace and recreation throughout his life. He gradually assembled an outstanding library on the history of chemistry. Upon his retirement in 1920, after having served the University variously as Professor of Chemistry, Vice-Provost and Provost for more than 40 years, he accepted the invitation of the Trustees to retain his rooms in the University. (Armstrong, 1937, p. 8)

The generosity of Mrs. Edgar Fahs Smith allowed Dr. Smith’s office to be preserved as a memorial. A gift to finance the upkeep of the collection was also made (Miles, 1976, p. 446); his collections have thus been made freely accessible to all scholars interested in the history of chemistry (Browne, 1952, p. 476). By 1937, the collection had expanded to nearly 10,000 items due to frequent gifts (Anon, 1937, p. 472). In 1945, Dr. Browne presented nearly 450 items that related to the history of chemistry to the collection (Deischer, 1948, p. 13). Smith’s collection continued to expand until 1954, when the endowment began to run a deficit. A new chairman of the Department of Chemistry removed the collection from its original home, packed it away into crates, and left the crates in a storage room. A student newspaper raised the alarm, revealing the neglect of the collection (Manning, 2010). Criticism from chemists worldwide, helped to restore the collection, which was then placed in the Hare building.

10.11 Educational Method

The laboratory was most important to Dr. Smith and according to Shinn (1932, p. 623) 'The laboratory rather than the classroom was where he did his most effective teaching'. His rules were simple; there was only one rule for the way that the laboratory was run with which was 'Be fair' (Shinn, 1932, p. 626). He trusted facts and distrusted theories; he said 'Facts remain, theories may change overnight' (Shinn, 1932, p.614). He had an amazing memory which he used to good effect when questioning students, often using the historical information that he had amassed. This was done in a kindly way so that he motivated his students to do better and work harder. He, with his students, certainly did achieve great success.

During his long teaching career, 88 persons received their doctorates in chemistry from the University of Pennsylvania, all of them working under the personal supervision of Dr. Smith. As evidence of the later careers of these men, it may be mentioned that 42 of them are listed in "American Men of Science," and nine of these are starred. We have noted, further, that the list includes 16 professors of chemistry, seven industrial managers, superintendents, and directors of research, and five consulting chemists. (Hildebrand, 1932, p. 632)

Nonetheless, this measure of success was probably due to Dr. Smith's personality, hard work and the breadth of his accumulated knowledge more than the application of any specific educational methodology.

10.12 Conclusion

A problem with this study is that it sounds like a hagiography. No description of Edgar Fahs Smith when he was a boy or an adult has been found to be in any way negative about his work ethic, his personality or his interest in or care for others. He was well-behaved and hard-working as a student and competent both in science and arts subjects. He was well-liked as a junior lecturer and took a personal interest in the success of his students. He managed to simplify some of the complex areas of chemistry for his students by building a collection of historic chemical items which allowed him to capture his students' interests through using a 'show and tell' methodology. As a leader in chemical research he was excellent, though it is probably true that none of his many areas of research has opened important new areas of chemistry. Most remarkable is that he headed an important university which he led to greater success and he did this without alienating staff or students. In fact, when he wished to retire, his staff and his students all tried to dissuade him.

In this case study, Edgar Fahs Smith has been shown to be a prolific writer, an innovative researcher in complex research in the field of electrochemistry, a popular administrator and an exponent of using historical material as an educational tool to enthuse his students by telling simple human stories of great chemists.

He will perhaps be best remembered for establishing the Edgar Fahs Smith Collection for the History of Chemistry, which has grown in importance over time.

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Chapter 11
Teaching Electricity to Year 6 Primary Students Using Representational Pedagogies: From Simple Circuits to Complex Ideas

Peter Hubber and Christine Preston

11.1 Introduction

Electricity is very familiar to primary students and is mandatory learning in Year 6 in the Australian science curriculum (ACARA, 2019). There has been considerable research over several decades into children's understanding of electricity (Guisasola, 2014) in addition to research into pre-service and in-service teachers' understandings of electricity (Pardham & Bano, 2001; Otero & Nathan, 2008). Common and persistent alternative conceptions have been identified in primary (and secondary) students. They use terms such as electricity, current, power and energy interchangeably mirroring their use in everyday language. Frequently a 'sink model' (Fredette & Lochhead, 1980) is conveyed by students thinking the battery stores electricity / power / current, which flows to the bulb and gets consumed. The everyday phrases such as 'charging batteries' or 'batteries go flat' support this alternative conception (Hubber, 2017).

The physical act of circuit construction can be achieved without students necessarily understanding the underlying science. Previous research revealed many students "struggled to explain the concepts involved" in the functioning of circuits they had constructed in class (Prain & Waldrip, 2006, p. 1854). Explanatory accounts of electric circuits draw on abstract ideas (Chapman, 2014) and models. This creates difficulty in understanding the processes that underpin the operation of simple electric circuits for both students and teachers. The water reticulation and electric field models currently used at secondary school levels are not suitable for primary level students (Hart, 2008). These models to explain electric circuit behaviour draw on

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the sub-microscopic domain and are highly abstract. For these reasons, the teaching and learning of electricity at the primary level can be considered challenging (Jaakkola et al., 2011; Preston, 2017).

The topic of electric circuits can be made more accessible for learners by teaching at a phenomenological level only. Students merely explore *what* happens in electric circuits rather than seeking to understand why or *how* the observed phenomena happen (Chapman, 2014). The mandated curriculum behind the lesson sequence in this study required students to do both. Students explored the operation of simple electric circuits at a phenomenological level *and* provided explanatory accounts of electric circuit phenomena in terms of electrical energy transfer and transformation (ACARA, 2019).

The complexity of electricity as a topic might be simplified through the approach to teaching. Students initial undertaking of inquiry-based hands-on practical and simulation activities, related to real-world contexts, can gain insights into the macroscopic world of electric circuits (Aboagye et al., 2018). Students can then delve into the sub-microscopic world of electric circuits through using and constructing simplified analogical models of energy transfer and transformation (Chiu & Lin, 2005).

Inquiry-based approaches may lead to enhanced student engagement and learning of science (Chi, 2009; Furtak et al., 2012). This chapter describes how a primary school teacher adopted the Representation Construction Approach (RCA), a type of guided inquiry, in teaching electrical circuits to her Year 6 class. RCA has been developed and trialled over a 9-year programme of research. Through constructing and evaluating representations students are led to understand and appreciate, and productively employ scientific representations (Hubber et al., 2018; Waldrip et al., 2010). Whilst the study also explored student learning outcomes, this paper focuses on the teaching approach. The research question is: How can the RCA facilitate teachers making complex notions of electric circuits more accessible to students?

11.2 Methodology

A case study conducted over 2 years employed a design-based research methodology (Anderson & Shattuck, 2012). This comprised an iterative process of development and refinement of an intervention and evaluating outcomes involving the teachers as partners in the process.

The study was conducted in a single, non-government girls' school in Sydney, NSW. A science specialist teacher, Kate and science integrator Kira (names are pseudonyms) worked together to teach two participating Year 6 (11-year-olds) classes. Before teaching the topic, the teachers were engaged in professional learning with the researchers. This comprised an exploration of the key elements of the RCA, Pedagogical Content Knowledge (PCK) about electricity and familiarity with digital representations (animations). Particular attention was given to exploring simplified analogical models suitable for use by the students to explain their electric circuit observations. The professional learning drew on key elements of effective professional development:

- direct alignment with student learning needs;
- was connected to practice;
- focused on the teaching and learning of specific academic content, and;
- provided time and opportunities to collaborate (*cf*, Loucks-Horsley et al., 2010; Capps et al., 2012).

A similar professional learning approach has been successful in other studies (different science topics) implementing the RCA (Hubber et al., 2010; Hubber & Chittleborough, 2015).

The researchers and teachers jointly planned the teaching program with a representational focus. Consistent with design-based research, the intervention was evaluated and modified during and after the 7-week teaching sequence (1 h per week) in 2017. The modified topic was implemented a second time over six lessons in 2018 (90 min per week). The 2018 teaching program is outlined in the section below.

11.2.1 Data Collection

A range of data sources were used in this study to capture the teaching and student learning from different perspectives. Teacher practice was documented through videotaping of lessons to provide evidence of the pedagogic approach in action. Interviews with teachers gained their perceptions about the teaching experience. Student learning through the RCA was tracked through pre- and post-tests, artefacts (student journals, formative and summative assessments), classroom video capture of small groups, and focus group interviews. One of the researchers was involved as a participant observer and co-teacher during class lessons in 2017. Field notes were taken during lessons to assist with correlation of video data and student artefacts.

11.2.1.1 2018 Teaching Program

The 2018 teaching program was taught by the school's science specialist, Kate (assisted by Kira), in a dedicated science classroom. In addition to the science lessons the students sometimes engaged in reflective tasks associated with the topic during their STEM (Science, Technology, Engineering and Mathematics) class-time, which lasted around 30 min. These lessons were led by their classroom teacher.

11.2.2 Representation Construction Approach (RCA)

RCA is a directed inquiry approach that includes representational challenges which involves students constructing and critiquing representations (text, graphs, models, diagrams) to actively explore and make claims about phenomena. The students generate and negotiate their generated representations to discuss and explain the phenomenon and concepts. Students also negotiate the representations provided by the teacher. The set of principles that underpin the representation construction approach are broadly described as (Tytler et al., 2013, p. 34):

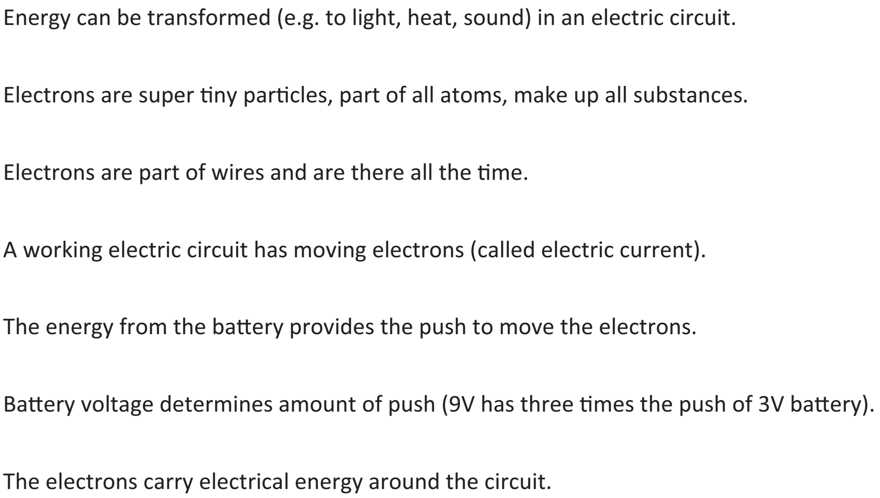
1. *Teaching sequences are inquiry-based and include representational challenges*: Students construct representations to actively explore and make claims about phenomena.
2. *Representations are explicitly discussed*: The teacher plays multiple roles, scaffolding the discussion to critique and support student representation construction in a shared classroom process. Students build their meta-representational competency (diSessa, 2004) through these discussions.
3. *Meaningful learning involves representational/perceptual mapping*: Students experience strong perceptual/experiential contexts, encouraging constant two-way mapping/reasoning between observable features of objects, potential inferences, and representations.
4. *Formative and summative assessment is ongoing*: Students and teachers are involved in a continuous, embedded process of assessing the adequacy, and their coordination, in explanatory accounts.

11.2.3 Identification of Key Ideas

A key feature of RCA is the determination of the key concepts at the initial planning stage of the teaching sequence. The key concepts, listed in Fig. 11.1 below, framed the representational activities that were to be undertaken.

11.2.3.1 Lesson Sequence

The lesson sequence using the RCA to teach the topic of electricity is outlined in Table 11.1. The sequence was premised on establishing ideas about energy prior to exploring electric circuits at a phenomenological level before providing explanatory accounts of electric circuit phenomena through the use of analogical models.



Energy can be transformed (e.g. to light, heat, sound) in an electric circuit.

Electrons are super tiny particles, part of all atoms, make up all substances.

Electrons are part of wires and are there all the time.

A working electric circuit has moving electrons (called electric current).

The energy from the battery provides the push to move the electrons.

Battery voltage determines amount of push (9V has three times the push of 3V battery).

The electrons carry electrical energy around the circuit.

Fig. 11.1 Sample key concepts from the teaching program

Table 11.1 Lesson Sequence (2018)

Lesson	Content
1	Introduction to forms of energy and their changes within familiar systems, such as toys. Class discussion of an interactive animated simulation (University of Colorado, 2009) which represents energy movement within a system through the use of symbols.
STEM activity: Students create a class electricity word cloud and student generated questions about electricity.	
2	Light globe challenge to create a working electric circuit with one wire, a battery and globe. Free exploration of electric circuits using wires, globes, batteries and light emitting diodes (LEDs). Students recorded their findings in learning journal.
STEM task: Create a diagrammatic representation to explain the solution to light bulb challenge.	
3	Drawing challenge: Introduction to the symbolic conventions of drawing electric circuits. Class discussion critiquing students' representations of circuits against the conventional symbolic form. Electric circuit challenges that incorporate multiple globes and batteries.
4	Switch challenge: Construction of a working switch. Introduction to the electron as energy carriers and exploration of virtual electric circuits (University of Colorado, 2009). Exploring conductors and insulators.
STEM task: Create representations to explain how switches work and the difference between conductors and insulators.	
5	Models of electric circuits: Rope, delivery, role-play that explain energy transfer via electrons and energy transformation at the battery and globe. Critique of models for what each does and does not show about electric circuits.
6	Summative assessment task challenge: Students are to construct a 3D model of an electric circuit using craft material. They are also to create an iPad generated video narration of how the model explains various aspects of electric circuits such as energy transfer and transformation.

11.3 Results and Discussion

There were several pedagogical implications and challenges faced by Kate in adopting the RCA to teaching the topic of electrical circuits to Year 6 students. The guided inquiry nature of RCA requires the teacher to generate classroom experiences whereby students are led to a scientific understanding of the canonical representations through initially generating and exploring their own representations. They then critique their own representations alongside the introduced canonical representations as to their efficacy for explaining and showing their findings, reasoning and understanding. This created a challenge for Kate to determine when in the lesson to introduce aspects of the canonical representations.

The commonly accepted explanations of electrical circuit behaviour rely on models of sub-microscopic domain that are highly abstract and inaccessible to primary students (Hart, 2008). Kate was consequently challenged to provide avenues for her students to gain insights into the complex domain of electrical circuits through the use of representations and analogical models with which her students might understand, generate and reason.

This section outlines the findings and discussion as they relate to the following themes:

- Guided inquiry through representational challenges and critique.
- Insights into the complexity of electric circuit phenomena through the simplicity of representations and models.
- Learning journals as a multi-model record of student learning.
- Sequencing the introduction and development of key ideas and skills.

11.3.1 Guided Inquiry Through Representational Challenges and Critique

The initial lessons had the students freely exploring the creation of electric circuits using a range of equipment as well as responding to a light globe challenge (Table 11.1). Students were also requested to record their findings in their learning journal (see Fig. 11.2 for a student example). From Kate's perspective:

> *"The exploratory style activities supported students to try out their ideas and figure out ways to explain their thinking rather than just be told by the teacher, was very effective…Every single girl has been engaged and you don't always get that kind of focusing on one topic."*

The bulb challenge was designed to address a common alternative conception, the 'sink model', found in 74% of the students' pre-tests (Fig. 11.3). In the sink model students believe that only one wire between the globe and the battery is necessary to light the bulb or that two wires provide more current or energy to the globe (Jaakkola et al., 2011). The challenge and following class discussion of the need for a continuous conducting path for a working globe circuit led the students to a

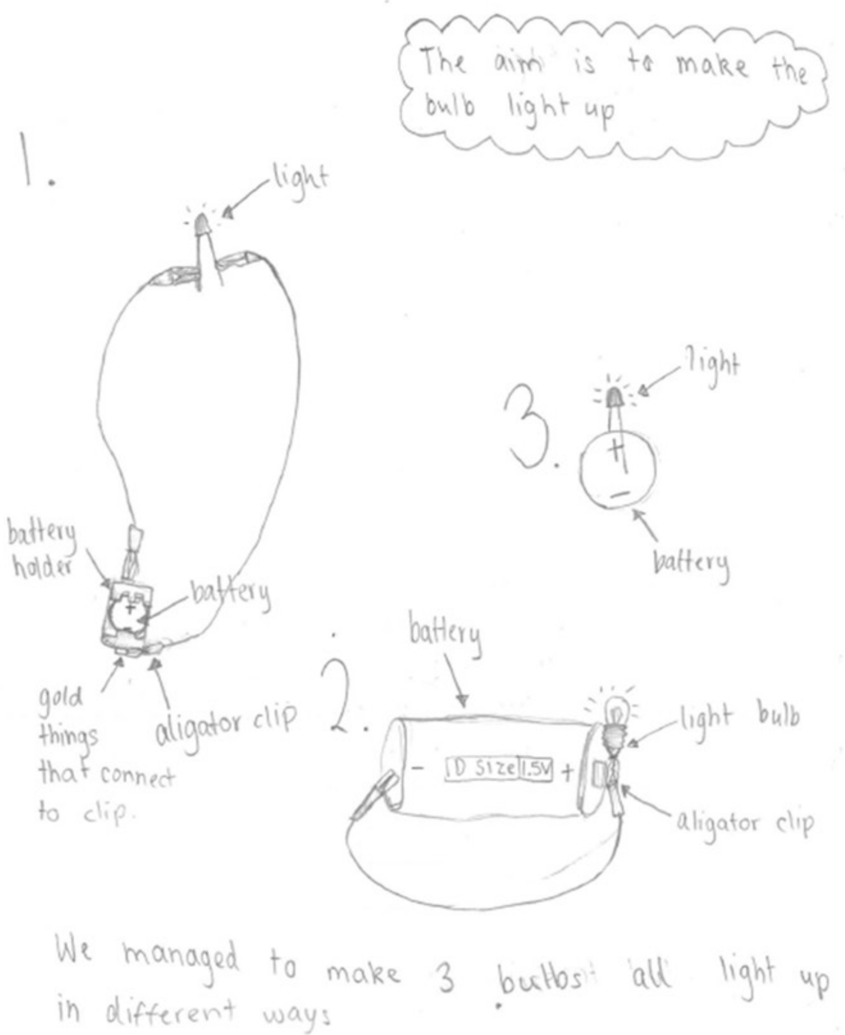


Fig. 11.2 Extract from students' journal

scientific understanding (see Fig. 11.4). The post-test indicated that all students had a scientific understanding.

From the students' perspective, the following quotes illustrate that the learning environment, whilst challenging at times, was preferred as it facilitated their learning and likened their investigations to the way scientists inquire about the world.

> *"So, at the beginning, to turn on the light bulb, I actually found it really hard. But then, I kept persisting and I actually got it to turn on, so it made me feel really good about myself and then I was very happy." [85]*
>
> *"At the beginning we actually did a lot with making our own circuits." [74]*

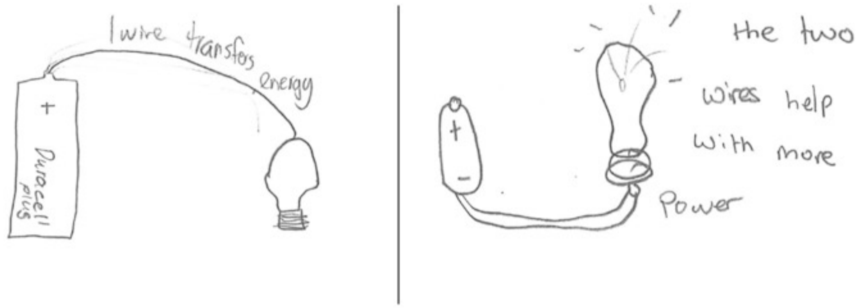


Fig. 11.3 Student pre-test responses that show how to light a globe

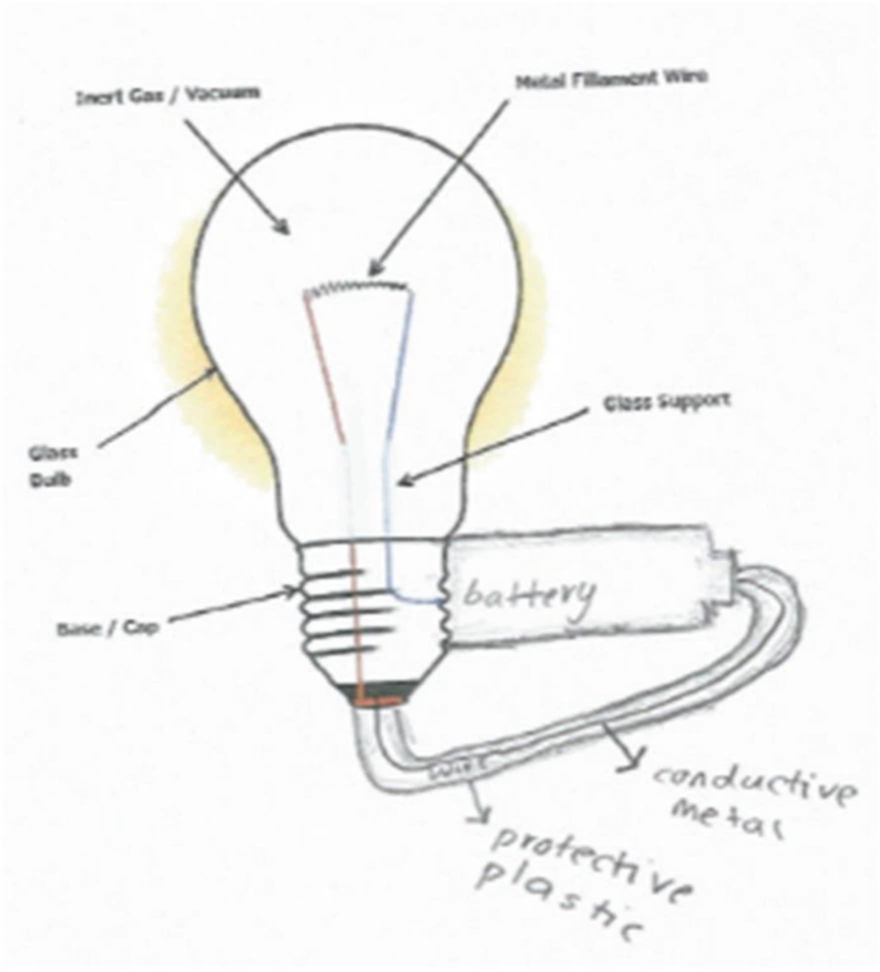


Fig. 11.4 Student's STEM task solution to the globe challenge

> *"I liked how they prompted us with questions, but they didn't give us the answer straight away. So, we had to find the answer ourselves which helped our learning." [71]*
>
> *"Because it's like trial and error and scientists they also don't get it on first go and they to keep working at it. They write stuff down, but they also interact with others which is more fun, I'm looking forward to coming to Science definitely more this year." [85]*

The main issue, as mentioned above, for Kate in relation to enacting a guided inquiry approach was when to hold back on giving answers and when to intercede in providing information. Through the 2017 teaching experience Kate realised that her role was the "*need to bring them to certain milestones of thinking.*" Following the 2018 teaching sequence Kate reflected:

> *"It's helped me so much and my confidence is definitely higher and I feel more comfortable being in that role of a constructivist's way of allowing the learning to happen and stepping in at the precise times to make sure that the actual understanding is there and the core understandings are there."*
>
> *"So, slowing down and allowing it to just linger there was probably my biggest achievement I think and I'm finding I'm actually using it in my other lessons."*

A key feature of RCA and challenges is the evaluation and critique of the students' generated representations, which then form a base for an understanding of more sophisticated levels of understanding the topic. For example, following the exploratory activities Kate opened classroom discussion that evaluated the students' journal entries against the conventional symbolic representations of electric circuits. This led students to appreciate the affordances and constraints of the scientific conventions. Figure 11.5 shows how a student used the symbolic representations with her own annotations to describe the outcome to a task.

A key feature of the learning sequence, advocated by researchers (Ametller & Pinto, 2002; Kress et al., 2001) was the use of multiple and multimodal representations that make the abstract processes that underpin electrical circuit behaviour concrete for the students. Figure 11.6 illustrates how the students were able to confidently express their understanding of the role of electrons in electrical circuits through different representational forms.

Nitz et al. (2014) argue that the development of abilities for dealing and reasoning with representations is crucial for learning science; a key element of RCA. Such abilities lead to what diSessa (2004) has termed metarepresentational competence and includes:

(a) the ability to invent novel representations;
(b) the ability to critique existing representations;
(c) knowledge of the functions that representations perform; and
(d) knowledge that facilitates the rapid learning of new representation.

Throughout the sequence the students showed evidence of aspects of metarepresentational competence listed by diSessa (2004). For example, evidence of students' ability to generate novel representations is shown in Figs. 11.2 and 11.3 where they represented their findings and provided explanatory accounts of electrical circuit behaviour. Further evidence is shown in Fig. 11.9 where in 2017, the students created group physical models of an electric circuit. In 2018, the students created personal physical models of an electric circuit as part of a summative assessment task.

representations of electric circuits. This led students to appreciate the affordances and constraints of the scientific conventions. Figure 5 shows how a student used the symbolic representations with her own annotations to describe the outcome to a task.

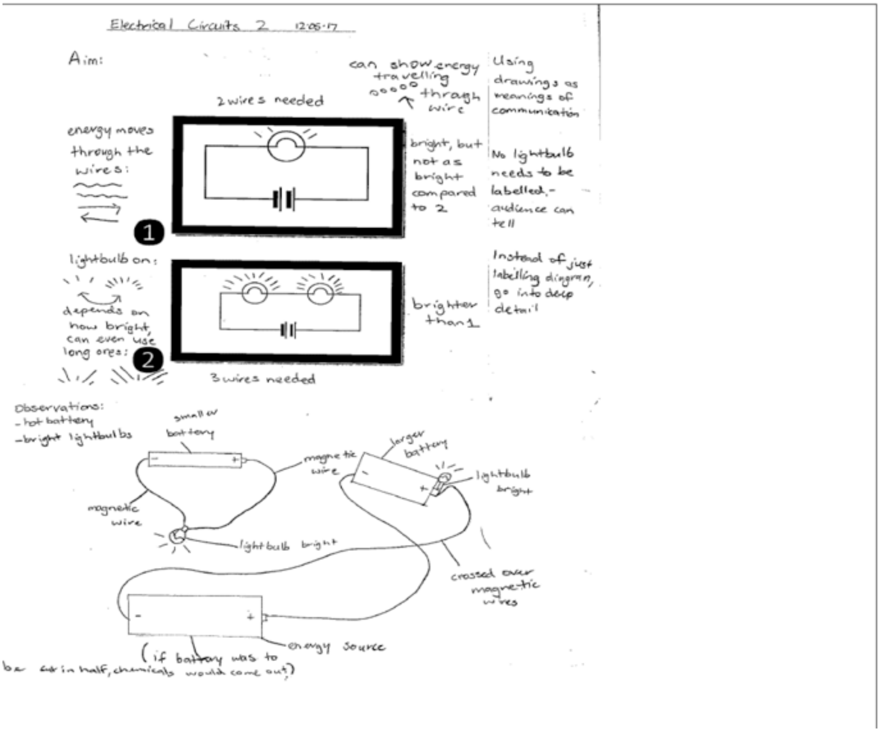


Fig. 11.5 Student's journal entry showing responses to circuit challenges

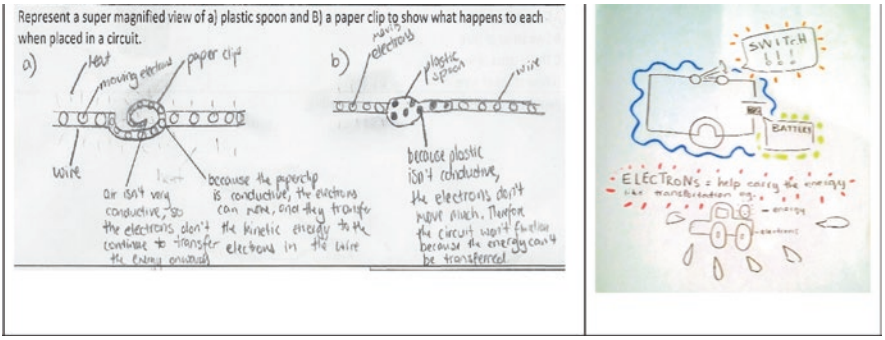

Represent a super magnified view of a) plastic spoon and B) a paper clip to show what happens to each when placed in a circuit.

Fig. 11.6 Students' representations of the role of electrons in electrical circuits

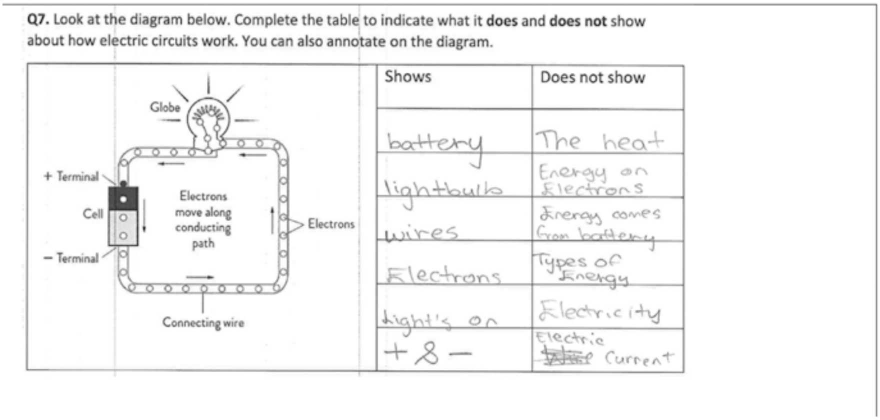
An example of the students' ability to critique representations is shown in Fig. 11.7. In a post-test the students were asked to indicate what a textbook diagram 'shows and does not show' about how an electric circuit works. Further evidence (discussed more fully in the next section) was the students' ability to critique the introduced analogical models to explain electrical circuit behaviour.

Insights into the complexity of electric circuit phenomena through the simplicity of representations and models

To simplify the complexity of explaining electric circuit phenomena Kate introduced representations and models that allowed the students to make concrete, the abstract concepts of energy, charge and voltage. For example, a symbolic representation of energy was introduced in the first lesson of the sequence (*Energy Forms and Changes* simulation, University of Colorado, 2008). The symbolism was used by students throughout the sequence in representing energy types, and their transfer and/or transformation within a system. Figure 11.8 shows a student's response to a post-test question. Students were asked to represent how electricity might be generated by one method.

Kate introduced the electron as the carrier of energy in an electric circuit through a class discussion of an interactive simulation (Construction Circuit Kit, University of Colorado, 2008). The simulation represented the macroscopic world and sub-microscopic world of electrons in creating electric circuits. The students then incorporated representations of electrons as circles (Fig. 11.8) in diagrammatic representation or as spheres or moveable beads in their 3D models (Fig. 11.9) throughout the sequence. Students explored electric circuits through virtual simulations as well as with physical equipment, a learning strategy supported by Jaakkola et al. (2011).

electric circuit works. Further evidence (discussed more fully in the next section) was the students' ability to critique the introduced analogical models to explain electrical circuit behaviour.



Q7. Look at the diagram below. Complete the table to indicate what it **does** and **does not** show about how electric circuits work. You can also annotate on the diagram.

Shows	Does not show
battery ✓	The heat
lightbulb ✓	Energy on Electrons
wires	Energy comes from battery ✓
Electrons	Types of Energy
Light's on ✓	Electricity
+ & −	Electric ~~[illegible]~~ Current

Fig. 11.7 Critique of textbook representation of an electric circuit

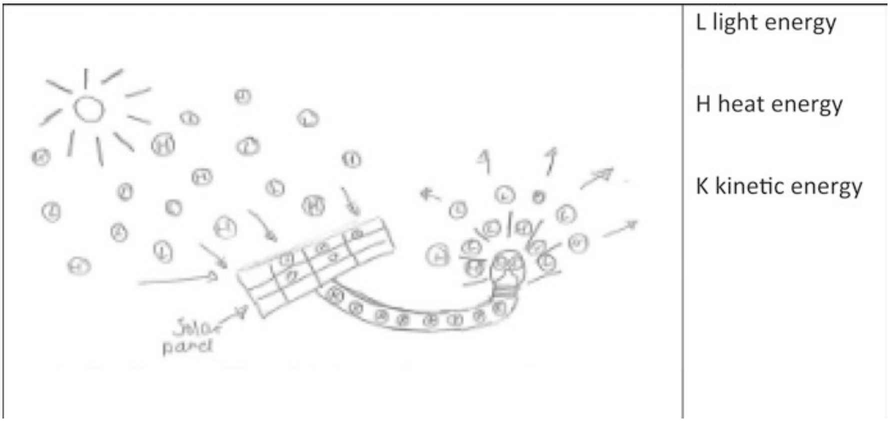


Fig. 11.8 Students' representation of energy changes in one-way electricity can be generated

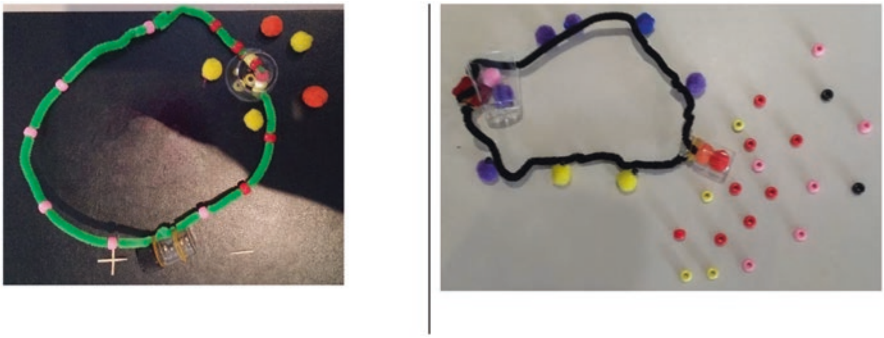


Fig. 11.9 Students' physical models of an electric circuit

In providing explanatory accounts of phenomena scientists generate models (Schwarz & White, 2005). Models do not appear from nowhere – the scientific community builds them from representations that are situated, multi modal, and often personal. In the teaching sequence rather than apply the sophisticated models used by scientists to explain electrical circuit behaviour, students developed simpler models that were more personal. In doing so the students were replicating the behaviour of scientists in constructing models to gain an understanding of the world.

Kate introduced three analogical models for the students to critique by identifying which aspects of electrical circuits were or were not represented in the model. Table 11.2 provides a brief description of the models with the links given between the target and analogue.

The students found the models were very beneficial to them in understanding simple explanations for the underlying processes of electrical circuits. Students were aware that the analogues used in the models were chosen to be quite familiar with their everyday experiences.

Table 11.2 Analogical models of simple globe circuit (2018)

Target	Loop model	Bakery model	Wet Ball Role-play
Battery that supplies energy	Student who pulls on the loop	Bakery that holds bread	Bucket containing water
Energy	Motion energy of the loop	Loaves of bread	Water
Electron as energy carriers	Sections of loop that have motion energy	Trucks that transport bread	Balls that a wet from being dunked in the bucket are passed around a circle of students
Globe transforms energy	Students who hold the loop feel the heat burn from the moving loop	Supermarket that takes the bread that are sold.	Students dry the ball through being passed around.

> *"They've made science way easier. I used to find it really hard to just do it on paper, and then once I did the models, it was easier to understand how it will work." [86]*
>
> *"We know about cars and houses and a road, you can learn about the circuits and about electrons…Yeah in the kid's perspective it's not like a whole bunch of things shoved in your face, it's really simple." [84]*

Students were encouraged to generate variations to the models that were presented. For example, one student created a delivery type model in commenting "*I did the sushi train… So, the sushi is like the bread but it's in a sushi train and the chef was like the battery.* [85]" The students were also aware that each model was limited in its explanatory power and multiple models were needed to gain a full understanding. This shows knowledge of the function that representations perform and is an aspect of meta-representational competence listed above. This is reflected in the following comments made by the students:

> *"I think all of them helped, because they kind of all like showed a different thing in a better way… So, like, if you used only one, then you wouldn't understand everything, because there's something missing. But then, when you used all different types of, like, models it shows different parts of it." [73]*
>
> *"I really liked it because if, say, I didn't get something in one model, and then we moved onto the next one, then I would get what it was meant to be." [86]*
>
> *"Each different model activity like that to show it, it sort of had a different way which you understand it and then when you bring them altogether it becomes a circuit." [81]*

As a final task to the learning sequence students were challenged to create a physical model to represent a circuit. In 2017 this was a formative task where students worked in small groups using an assortment of provided craft materials to make a model circuit. As the teachers (during class) and the researchers (student interviews) listened to student explanations (what each part represented and what the model showed about how circuits work) we realised this strategy held potential for assessing understanding of concepts and the representation itself.

While the task may appear simple, the students needed to think about the purposes of each circuit component and the relationships / interactions between them. They needed to be very clear in their ideas about energy, which included recognising different energy forms and distinguishing between energy transfer and transformation. Accordingly, the task became a reasoning tool as it assisted students' in consolidating their understanding.

In 2018 the task evolved to become an individual assessment task that incorporated digital technologies. In addition to making the model, students recorded themselves (using an iPad) describing how their model represents the circuit components and explaining the processes involved. This added an additional level of complexity, communicating to an audience (someone watching their video) and capturing and manipulating the model. Students were also directed to indicate what their model did not show. Figure 11.9 shows images of sample models that the students created.

The experiences had by the students in creating their own model of an electric circuit as a major summative assessment task was perceived by them as a very positive one. This is reflected in the following comments:

> *"I thought it was quite fun because you got to be quite creative… you sort of got to play around with tools and things." [81]*
>
> *"It didn't really feel like an assessment, so it got rid of all the stress and I just did it like how I'd want to do it. [82] It was the best assessment ever." [83]*
>
> *"I think it was good … you have to work with the materials you have. So, its problem solving and helping". [85]*
>
> *"It was hard trying to find the right things to represent. So, the people watching the video would understand what it means." [83]*

11.3.2 Learning Journals as a Multi-Model Record of Student Learning

The students were provided with record books, called learning journals, that only contained blank pages. They were encouraged to represent their personal and developing ideas in multiple representational forms (see Fig. 11.10).

One student commented that journaling allowed representation of her learning, "*… in your words and your own thoughts and ideas and you're allowed to put whatever you want on the page so you can do drawings or words. [74]"* The students overwhelmingly felt the journals and the journaling process enhanced their personal level of learning. From a metacognitive perspective, the journal created a personal record of learning, a view reflected in the following comment.

> *"So we record all of our ideas and drafts in our journals, so what we're thinking and why it didn't work, why the lightbulb didn't light up because we didn't always get it right first go, we had to try and experiment and we used all our experimentations in our journal book and that's where we stored all of our ideas, so later on we can just look back and reflect oh, that's what I thought but now I think this." [84]*

The journals, through their unique character, provided a resource for the students to share.

> *"And we can learn from each other because we have got different things from each book instead of just doing everything – everyone having exactly the same in their books." [74]*

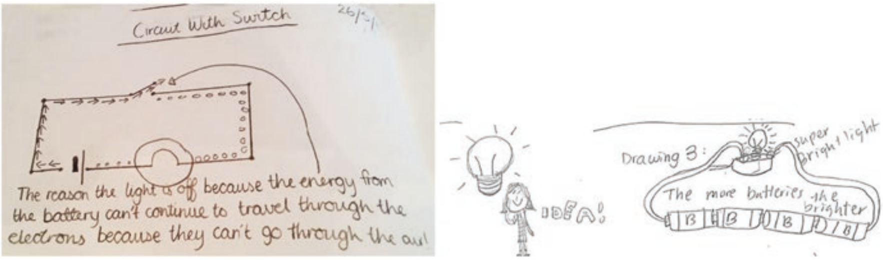


Fig. 11.10 Sample student journal entries

They also made reference to journaling as a process similar to what scientists do.

> *"Because it's like trial and error and scientists they also don't get it on first go and they to keep working at it. They write stuff down, but they also do interact with others which is more fun, I'm looking forward to coming to Science definitely more this year." [85]*

Scientists use journals in the process of creating scientific knowledge. The use of science journals in primary classrooms might provide students with insights into the way scientists operate in the field (Klentschy, 2010).

For Kate, the students' journals provided her with good insights into their developing ideas. She reflected that journaling "*is a kind of like a scrapbooking of their brain in a way*". Gilbert and Kotelman (2005) suggest that journals are a tool by which students might construct their own scientific understandings as they form a "central place where language, data and experience work together to form meaning for the student" (Klentschy, 2005 p. 24). From Kate's perspective, the flexibility of using different forms of representation, not only allowed the students to "*play to their strengths"* but also, the journaling is:

> *"Making them think more deeply. They've got to think well how can I show this in this simple picture, now that I've been taught the symbols, how can I make that work?"*
>
> *"Students say I want to write that down, so I don't forget…this is my memory of what I've learned from this activity."*

The use of different forms of representation allows, "Children to use science journals in ways that are both socially and cognitively appropriate to their developing understandings of science phenomena" (Shepardson & Britsch, 2001, p. 65).

11.3.3 Sequencing the Introduction and Development of Key Ideas and Skills

The teaching sequence was intentionally designed to explore energy ideas before the introduction of electrons. For Kate, "*There was a focus on just the energy rather than electrons. I think that was good and I think we, if we were to add to something next year might be a little bit more about different types of energy.*" Kate further added:

> *"So, you start off with linking obvious energy like movement and that and then show the students examples of that. And we did that with a PhET App the girl riding the bike. And the food that was really good, I could see some girls who have never really thought about the fact that you make energy in your body and that energy comes in food and gets transformed."*

As children hold on quite strongly, to the idea that *something* is used up in the circuit, energy transformation, not current, can account for what is 'consumed' (Summers et al., 1997). Consequently, energy should be introduced before introducing ideas about electric current.

The sequence also placed exploration of electric circuits at a phenomenological level before the introduction of explanatory accounts with models. This is consistent with the manner in which models are used in science as tools for explaining or visualizing scientific phenomena, and as thinking and communicating devices. They are used for specific purpose and are understood not to correspond with all the properties of the target phenomena (Cheng & Lin, 2015). For Kate:

> *"I think one of the big takeaways for the girls hopefully in this [sequence] is that models, the validity and effectiveness of a model varies and that they're, they're looking at things and going, Well that shows this well, but it doesn't show that well."*

11.3.4 Conclusion

This chapter has described the successful application of the RCA, a directed inquiry pedagogy to teaching the topic of electricity in Year 6 primary school. Success was manifest in student engagement with the topic, resolution of the 'sink model' alternative conception and evidence of students' abilities to show their understanding of electrical behaviour through using representations and simple models. Challenges in teaching and learning electricity due to the complexity of science concepts was discussed. We argue to teach the topic is not as simple as involving students in constructing electric circuits. The emphasis on representational generation and negotiation through adopting the RCA in this study provided a practical, focused way for the students to develop conceptual understanding and reasoning capacities in the topic of electric circuits. The RCA reflects the epistemic practices of knowledge construction by scientists. Such modelling enabled the students to participate in knowledge production methods aligned with scientific practice (Tytler et al., 2013). Put simply, students learnt about how a variety of representations are used by scientists to reason and communicate understanding through different modes.

The biggest challenge of the RCA for teachers and students was adapting to the change in teaching style. A less didactic approach positioning the teachers as guides rather than instructors. This meant teachers' influence was less visible to students who came to perceive they were learning for themselves. Initially teachers were uncomfortable about not answering students' questions directly. Nonetheless deferring to practical investigations that led students to discover their own answers, turned out to be highly engaging. Ultimately managing student learning through directed inquiry promoted student agency in learning. Students were highly engaged during classes, embraced opportunities to experiment during hands on investigations and felt a sense of accomplishment when problem challenges were solved. Two iterations of co-developing, implementing and refining class activities resulted in a synergistic mix of representational challenge, hands-on investigation plus journaling, and interactive discussions to consolidate understanding of concepts. Experience with the RCA increased the teachers' confidence in teaching what many primary teachers may consider to be complex concepts, with a high degree of success. Notably students in both high academically graded and mixed ability classes displayed an impressive depth of understanding of concepts. Student interviews also revealed strong positive dispositions towards science, scientific practices and future science learning / careers.

Key to developing understanding was teaching in ways that helped the students make sense of abstract concepts. The students became skilled at creating, negotiating and critiquing representations. They learnt to represent and reflect on understanding using multiple models which they acknowledge collectively helped piece together ideas about how electric circuits work. Exploring and explaining electric circuits from an energy perspective with electrons positioned as energy carriers, ensued as a productive strategy. Combining the *simple* – exploring electric circuits at a phenomenological level – with the *complex* – constructing and critiquing explanatory representations about electric circuits – resulted in conceptual understanding, especially regarding energy transfer and transformation.

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Chapter 12
Complexity and Simplicity: Looking Back and Looking Forward

David Geelan and Kim Nichols

This book began with a description of the eastern Australian bushfire crisis of the southern summer of 2019–2020. In the intervening time, that crisis has been supplanted in our minds by a much greater crisis – the COVID-19 pandemic which has, at the time of writing, infected more than 158 million people all around the world and ended the lives of more than three million. The global pandemic also dramatically challenged learning and teaching in science, with many schools locked down and students and teachers learning together through online videoconference. COVID-19 has been a dramatic illustration of the complexities and issues that face society and our students… and it does not displace the global heating challenge associated with the Australian bushfires and extreme weather events around the world, nor change the probabilities of a range of other natural and social disruptions facing science education, including the on-going disruption caused by the rapid adoption of information and communication technologies.

This chapter seeks to draw together the sections of the book and discuss the importance of the findings and ideas from each chapter, and to connect the themes discussed with some of the theoretical ideas and perspectives introduced in the opening chapter.

Chris Nielsen's study, which focused on scientific literacy development in the Year 7 physical sciences topic of astronomy, illustrated the importance of making language use explicit in the science classroom. The findings of the study suggested that consistent and repeated opportunities for time spent discussing and reviewing the scientific meanings and explanations of vocabulary terms is important for students to develop and demonstrate proficiency. Similarly, Panizzon, White, Elliott

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and Siemens demonstrated that students' participation in deliberative and collaborative inquiry learning had a positive impact on students' self-efficacy and self-concept in relationship to science and STEM knowledge. Moreover, this contributed to their interest in continuing to study science in senior secondary school and beyond. Preston, Way and Smyrnis elegantly showed a connection between increasing representational competence and growing conceptual understanding of observed complex physical phenomena. This outcome relied on the teachers' deliberative analysis of the complexities of children's self-created representational systems to explore their emerging conceptions in science.

It is important to consider briefly how the work collected here is related to the different levels of complexity outlined in the opening chapter. Briefly, these are:

Individual complexity – the external material conditions and internal, psychological features of the individual student and teacher

Classroom complexity – the webs of relationships and expectations between participants in a particular lesson and a particular classroom

School complexity – the ways in which the school community both formally and informally influences

Social complexity – the complex, dynamic interaction between schools (and the nested classroom and individual level complexities within them) interact with the broader society in which they are situated, locally, nationally and globally

This 'zooming out' emphasis on the multilayered nature of the complexity of the contexts within science is taught and learned has much in common with Bronfenbrenner's (1977; Bronfenbrenner & Ceci, 1994) 'ecological' model of child development and the micro-, meso-, exo-, macro- and chrono-systems he describes as mutually interacting with one another as developing children interact with all features of their environments, including but not limited to school.

Chapter 2 is focused on the nexus between social complexity and classroom complexity, mediated at the level of the school, as it explores the way in which the society-mandated curriculum is experienced, understood and implemented by teachers in classrooms. Ajayi Eyitayo discussed how curriculum and assessment policy documents in science education around the world are culturally oriented and value driven, and explored how the value-driven philosophies in these documents are strongly connected to socio-political and socio-cultural contexts. The study showed that Year 9 science teachers lacked a good understanding of what it means to equip students with values through the curriculum or why this is a critical purpose of curriculum enactment. Ajayi Eyitayo pointed to the need for initial teacher education programs that address these complexities of the curriculum. The author raised a number of important issues with regard to teachers' comprehension and interpretation of curriculum documents and proposed that efforts should be directed toward bridging the gap between the intended and implemented curriculum. He concluded by stating that all teachers should be required to explore the curriculum as a core component of their teacher training across the globe.

Chapters 3 and 4 are more directly focused on the nexus between school and classroom, as schools seek to support and prepare teachers for their classroom roles and activities. Dawborn-Gundlach's study of teacher retention and out-of-field teaching confirmed that the transition from learning to teach to practicing teaching is complex, with multiple types of support required. The support required needs to be timely to ensure that attrition from the profession is minimised, with the theory/practice divide reduced by observing experienced teaching in the classroom. The importance of both formal and informal mentoring was also highlighted. Dawborn-Gundlach concluded that ITE programs are a vital first step in ensuring teachers develop the requisite skills and knowledge to be ready to teach, however schools have the core responsibility for ensuring that early career teachers are supported in adjusting to teaching in practice and to the local school culture. Hobbes and Quinn explore what happens when secondary school teachers who have been prepared, in their teacher education degrees, to teach in one or more subject areas are required within a school to teach 'out-of-field' in subject areas in disciplines in which they may or may not have some content knowledge but in which they have not had sufficient education or opportunities to develop their pedagogical content knowledge (Shulman, 1986).

Chapters 5 and 6 are focused on the ways in which schools teach and seek to actively prepare students to engage with the greater complexities and 'wicked problems' of issues such as global climate change and biotechnologies. Skamp and his colleagues found that national culture has a complex association with, and a significant impact on, students' willingness to mitigate climate change through transport choices, energy usage and voting. A belief in the effectiveness of the actions taken was also strongly related to students' willingness to take action on the issue. This suggests that teaching and learning around these issues necessitates the opportunity to critically evaluate the measures proposed in light of the scientific knowledge being learning. Dawson and Venville's study provided evidence to support this claim. They found that argumentation, with the opportunity to construct an argument from evidence logically connected to issues and to evaluate arguments made by others, explicitly developed students' skills to think critically about climate change and gene technology.

Chapters 7, 8 and 9 in various ways and contexts explore students' use of language and representation in science learning, and the complex interactions occurring at the classroom level, mediated by the teacher, between students and the disciplines and conventions of science. Chris Nielsen's study, which focused on scientific literacy development in the Year 7 physical sciences topic of astronomy, illustrated the importance of making language use explicit in the science classroom. The findings of the study suggested that consistent and repeated opportunities for time spent discussing and reviewing the scientific meanings and explanations of vocabulary terms is important for students to develop and demonstrate proficiency. Similarly, Panizzon, White, Elliott and Siemens demonstrated that students' participation in deliberative and collaborative inquiry learning had a positive impact on students' self-efficacy and self-concept in relationship to science and STEM knowledge. Moreover, this contributed to their interest in continuing to study science in senior secondary school and beyond. Preston, Way and Smyrnis elegantly showed a connection between increasing representational competence and growing conceptual understanding of observed complex physical phenomena. This outcome relied on the teachers' deliberative analysis of the complexities of children's self-created representational systems to explore their emerging conceptions in science.

Finally, Chaps. 10 and 11 attend to the socioscientific dimensions of the social context and human activities of science, and the ways in which the various layers of complexity (or 'systems' in Bronfenbrenner's (1977) formulation) influence the actions and understandings of individuals in unexpected ways. Palmer presented an inspiring historical account of Edgar Fahs Smith, an important figure in the field of chemistry and presented a novel way to explore this strand of the curriculum in the classroom. Hubber and Preston discussed a classroom pedagogical approach and explored the ways in which it can make learning about electricity more accessible to students. They showed that supporting teachers in a collaborative way to adopt pedagogies that focus on the construction and discussion of representations is critical to making complex concepts accessible to learners.

The larger society continues to seek to direct and influence schooling in order to facilitate favoured outcomes, through budgetary measures, policy documents and parliamentary inquiries. Thirteen years ago Professor Bill Louden (2008) discussed the '101 Damnations' – the immense string of government inquiries into teacher education in Australia. At the time of writing this chapter in 2021, Federal Education Minister Alan Tudge has just launched yet another. Without taking a political stance, an approach to the complexity of learning and teaching that takes into account the material conditions of learners and their classrooms and schools – the resources needed to learn most effectively – may have the potential to reverse a trend toward an even stronger correlation between socio-economic status and school achievement (e.g. Chesters, 2019). Education, including science education, that seeks to provide opportunities for all students is an essential step toward both enhancing opportunity and enhancing the achievement of learners in a nation and more broadly.

We hope that the chapters collected here offer a range of research-informed perspectives on simplicity and complexity in science education that will be of value to the international science education research community as we collectively seek to enhance the educational experiences we offer students and the outcomes of those experiences in their lives and our society.

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