Tang Wee Teo
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Yann Shiou Ong *Editors*

Science Education in the 21st Century

Re-searching Issues that Matter from Different Lenses

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Introduction

Theme of the Book

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

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

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

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

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

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

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

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

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

Tang Wee Teo
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Contents

Part I Re-searching Science Curriculum and Teaching

Part II Re-searching Science Learners and Learning

Part III Re-searching Science Teachers and Teacher Education

Editors and Contributors

About the Editors

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

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

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

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Part I
Re-searching Science Curriculum and Teaching

Chapter 1
Conceptualizing Multiplicities of Scientific Literacy from Five Theoretical Perspectives

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

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

Introduction

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

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

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

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

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

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

Theorizing *Scientific Literacy*

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

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

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

Overview of the Chapter

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

Positivism and Scientific Literacy: Setting up an Argument

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

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

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

Constructivism on the Nature of Science and Scientific Literacy

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

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

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

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

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

Pragmatism on Argumentation and Scientific Literacy

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

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

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

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

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

Critical Theory on Power and Science

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

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

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

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

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

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

Poststructuralism and Knowing Science as Becoming

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

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

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

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

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

Discussion and Conclusion

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

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Chapter 2
Representations of Nature of Science in New Korean Science Textbooks: The Case of 'Scientific Inquiry and Experimentation'

Seungran Yang, Wonyong Park, and Jinwoong Song

Abstract Nature of science (NOS) is becoming a core component of both science education research and curriculum policy around the globe. In particular, how textbooks should portray NOS aspects have been of keen interest to science educators. This chapter outlines the background and motivations for Korea's new compulsory subject, scientific inquiry and experimentation (SIE), and analyses how textbooks for this subject present NOS aspects using historical episodes. The aim is to help textbook authors and policymakers by examining the opportunities and challenges of Korea's new NOS curricular initiative. The results indicate that textbooks tend to focus on the cognitive and epistemic characteristics of science, with a limited representation of social and institutional NOS aspects. While textbooks often included multiple NOS aspects that underlie each historical episode, in most cases, these aspects were only implicitly addressed without proper cues for students' reflection about them. Based on these findings, we discuss implications for textbook authors and science teachers.

Introduction

Korea has recently been drawing attention from the global educational community with its diverse science education reform initiatives. The Korean Science Education Standards (KSES) have been developed as the first official standards for science education in the country and were published in 2018, and the newly revised 2015 national science curriculum has been implemented nationwide in elementary, middle and high schools since March 2018 (MOE, 2015a). Korea is striving to incorporate

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new knowledge that emerges in rapidly changing science and technology into the curriculum while trying to emphasize content other than traditional scientific knowledge, such as scientific inquiry and nature of science (NOS), as important elements of the science curriculum. At the moment this chapter is being written, it has been three years since a new subject called scientific inquiry and experimentation (SIE) was first announced and seven months since it was first implemented to Grade 10 Korean students. The research literature has reported that science teachers have high expectation about this new curricular initiative and concerns about the radical shift in terms of assessment and teacher training (Son, 2016; Yoon & Kang, 2016).

Under the slogan of ‘science education standards for future generations’, KSES emphasizes scientific literacy as a key ability for the future society and states that NOS is an important constituent of scientific literacy (Korea Foundation for the Advancement of Science and Creativity, 2018). Furthermore, in the 2015 national science curriculum, SIE was introduced to facilitate students’ understanding of NOS through inquiring how scientific knowledge is produced and applied (Ministry of Education [MOE], 2015a). SIE deserves attention since it is the first curricular initiative in Korea—also among the first around the globe—to teach NOS and scientific inquiry as a separate compulsory school subject.

In many countries, science textbooks are the main teaching and learning resources for teachers and students (Chiappetta & Koballa, 2002). This is particularly true in countries such as Korea, where education is highly centralized and standardized, and teachers are thus asked to strictly commit to the curricular content (Pang, 2008; Song & Joung, 2014). Given that science textbooks significantly influence teachers’ practice of NOS instruction (e.g., Chiappetta, Sethna, & Fillman, 1993; McDonald & Abd-El-Khalick, 2017), it is important to examine how textbooks are representing the various NOS aspects. However, most studies to date have reported that representations of NOS in textbooks are insufficient and are expressed in an inappropriate manner (Abd-El-Khalick, Waters, & Le, 2008, Abd-El-Khalick et al., 2017; Rodríguez and Niaz, 2002). In addition, because most textbooks analysed so far have focused on science content knowledge rather than NOS itself, most NOS references in these textbooks were given in an implicit way (Abd-El-Khalick et al., 2008; Li et al., 2018; McDonald, 2017). This means that NOS was only implied in the text but not made ‘visible’ to students by explicit statements (Abd-El-Khalick et al., 2017). These research reports led us to ask two research questions, respectively, on the content and methods of SIE textbooks’ NOS representations: (a) What aspects of the NOS are represented in Korean SIE textbooks? (b) How are these NOS aspects presented in terms of the instructional approach?

Scientific Inquiry and Experimentation: A New Compulsory Subject

The 2015 national curriculum of Korea lists and defines ‘core competences’ that students are expected to develop through learning subjects that are essential in preparing students for the future society (MOE, 2015a). In particular, the science curriculum states that there are five core competencies: scientific thinking ability, scientific inquiry ability, scientific problem-solving ability, scientific communication ability, scientific participation and lifelong learning ability (MOE, 2015a, p. 4). The importance of learning through inquiry in science education has a long history (Anderson, 2002; Bruner, 1966; Schwab, 1963). However, despite the efforts by researchers and policymakers and the emphasis in science education documents, inquiry learning is being implemented only to a limited extent in school science classrooms, Korea not being an exception (Cho, Han, Kim, & Yang, 2008; Park, Kim, & Park, 2004; Stake & Easley, 1978).

The necessity of teaching inquiry as a separate subject arose from these considerations, along with the changing demands of the times.[1] SIE is introduced as a compulsory subject for Grade 10 students in order to help them 'recognize the value of science as well as its impact on scientific inquiry and social, technological development' by providing opportunities to experience authentic scientific inquiry activities. The ultimate aim of SIE is to assist students to 'raise scientific literacy and thus solve individual and social problems scientifically and creatively' (MOE, 2015a, pp. 111–112). To achieve this aim, SIE consists of three chapters: 'scientific inquiry in history', 'scientific inquiry in human life' and 'inquiry in frontier science'. The organization of SIE is presented in Table 2.1.

SIE textbooks are designed in a workbook style that contains inquiry activities such as experiments and observations (see Fig. 2.1). The excerpt shown in Fig. 2.1 (see the translation) encourages students to become Galileo and figure out the results of the thought experiment from which he discovered the concept of inertia.

The following describes Galileo's thought experiment on an object moving on a slope without friction. Based on Galileo's thoughts, let's figure out the results of a thought experiment
[Galileo's thought]
1. When the ball goes down the slope, the force acts in the same direction as the direction of motion, so the ball's speed becomes faster
2. When the ball climbs up the slope, the force acts in the opposite direction to the direction of motion, so the ball's speed becomes slower
3. What happens to the speed of the ball if the ball moves horizontally? If there is no friction acting on the ball, it could be rolling forever
[Thought experiment]
When the ball is rolled on a slope without friction, if the inclination of the opposite side is getting smaller, what will happen to the ball's motion?
1. The ball goes up to the same height
2. When the slope's inclination becomes smaller, the ball _________________
3. When the slope's inclination becomes even smaller and it becomes flat, the ball

____

(Textbook C, p. 9)

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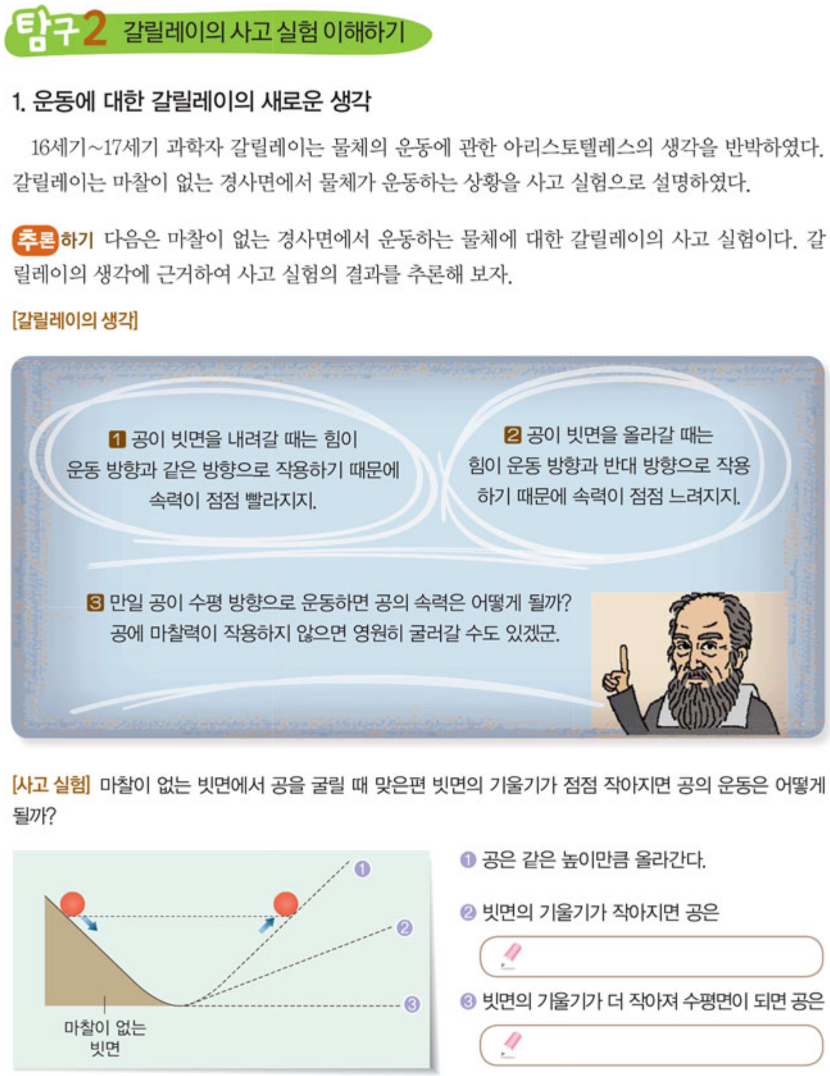
[1] The introduction of SIE lies in the context of a larger curricular move from the traditional two-track (humanity track and science track) system to an integrated system that allows students to experience diverse domains of human knowledge (MOE 2015b; Song and Na 2015). SIE serves this aim by bringing together the 'human' aspects of science, including its method, relevance and social impact.

Table 2.1 The organization of SIE (MOE, 2015a, p. 113)

Chapters	Key concept	Generalized knowledge
I. Scientific inquiry in history	Nature of science	Understand various aspects of the nature of science found in scientists' inquiry processes and experience the nature of science while practising scientific inquiry
	How scientists investigate	A variety of scientific inquiry methods are used depending on the topic
II. Scientific inquiry in human life	Scientific attitude	Through scientific inquiry and experimentation, students develop interest, curiosity and joy in science
		Scientific inquiry requires a variety of scientific attitudes, including interest, curiosity, cooperation and interpretation of results based on evidence
		Scientific inquiries include research ethics and safety precautions such as respect for life, research integrity and respect for intellectual property rights
	The process of scientific inquiry	Establish a variety of inquiry action plans based on the question of inquiry and situation characteristics
		Scientific inquiry activities consist of finding problems, establishing inquiry activity plans, conducting inquiries and displaying results
III. Inquiry in frontier science	Application of science	Apply science knowledge to life and various situations through scientific inquiry
		The outputs of scientific inquiry are shared and spread into various fields such as frontier science and technology



탐구2 갈릴레이의 사고 실험 이해하기

1. 운동에 대한 갈릴레이의 새로운 생각

16세기~17세기 과학자 갈릴레이는 물체의 운동에 관한 아리스토텔레스의 생각을 반박하였다. 갈릴레이는 마찰이 없는 경사면에서 물체가 운동하는 상황을 사고 실험으로 설명하였다.

추론하기 다음은 마찰이 없는 경사면에서 운동하는 물체에 대한 갈릴레이의 사고 실험이다. 갈릴레이의 생각에 근거하여 사고 실험의 결과를 추론해 보자.

[갈릴레이의 생각]

1 공이 빗면을 내려갈 때는 힘이 운동 방향과 같은 방향으로 작용하기 때문에 속력이 점점 빨라지지.

2 공이 빗면을 올라갈 때는 힘이 운동 방향과 반대 방향으로 작용하기 때문에 속력이 점점 느려지지.

3 만일 공이 수평 방향으로 운동하면 공의 속력은 어떻게 될까? 공에 마찰력이 작용하지 않으면 영원히 굴러갈 수도 있겠군.

[사고 실험] 마찰이 없는 빗면에서 공을 굴릴 때 맞은편 빗면의 기울기가 점점 작아지면 공의 운동은 어떻게 될까?

① 공은 같은 높이만큼 올라간다.

② 빗면의 기울기가 작아지면 공은

③ 빗면의 기울기가 더 작아져 수평면이 되면 공은

Fig. 2.1 Inquiry activity on Galileo's thought experiment (Textbook C, p. 9, reused with permissions from Dong-A Publishing)

Among the three chapters, Chap. 1, 'scientific inquiry in history', particularly focuses on the historical episodes to highlight different NOS aspects while engaging students in the inquiry process that scientists carried out in the past (MOE, 2015a). This curricular approach is consistent with the research evidence that using historical experiments can be useful to foster students' NOS understanding as well as their inquiry skills (Höttecke, 2000; Kipnis, 1998; Metz & Stinner, 2006; Park & Song, 2018). This use of experiments from the past is a means of contextualizing NOS.

While the curriculum explicitly lists the target NOS aspects as achievement standards, in terms of instructional approach, it encourages teachers to engage students in the experimental processes rather than just having teachers explain them (MOE, 2015a, p. 115).

Methods

Content Selection

We analysed the seven SIE textbooks authorized by the Ministry of Education of Korea. Chapter 1 was chosen for our analysis, since the national curriculum states that the key concept of this particular chapter is NOS (see Table 2.1). This chapter is designed to help students experience various NOS aspects through four historical episodes: Galileo's thought experiment, Mendeleev's periodic table, Mesozoic mass extinction and Pasteur's biogenesis. A total of 212 pages from the seven textbooks (24–34 pages from each) were subjected to analysis. Table 2.2 shows the achievement standards for each historical episode in the national curriculum.

Table 2.2 Topics and achievement standards for Chap. 1 (MOE, 2015a, p. 114, italics added)

Chapters	Topic	Achievement standard
I. Scientific inquiry in the history	Galileo's thought experiment	Students can understand the crucial experiments in the history of science that led to *paradigm shifts* and can explain the progress of science
	Mendeleev's periodic table	Students can conduct a historical experiment performed by *serendipitous discoveries* and explain the NOS found in the process
	Mesozoic mass extinction	Students can conduct inquiry through direct observation and explain the *inductive inquiry method*
	Pasteur's biogenesis theory	Students can perform historical experiments that employ hypothesizing and explain the features of the *deductive inquiry method*

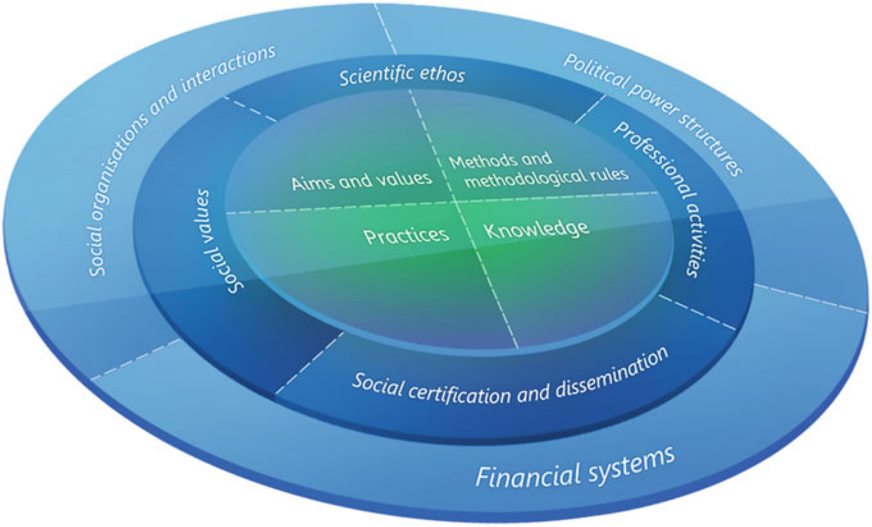


Fig. 2.2 FRA wheel: science as a cognitive–epistemic and social–institutional system (Erduran & Dagher, 2014, p. 28)

Analytical Framework

Erduran and Dagher's (2014) reconceptualized family resemblance approach (FRA)-to-NOS (RFN) was used as the theoretical basis for the textbook analysis. FRA is rooted in Wittgenstein's (1958) philosophy of language, and this concept has recently been rediscovered by several science educators as a theory to explain NOS in terms of similarities and differences among science disciplines (Irzik & Nola, 2011). Erduran and Dagher (2014) reconceptualized the theoretical discussion about NOS idea based on Irzik and Nola's (2011, 2014) proposal. In this approach, science is viewed as a cognitive–epistemic (innermost circle in Fig. 2.2) and social–institutional system (middle and outermost circles in Fig. 2.2). RFN has since been widely used as a useful lens for analysing how science curriculum documents and textbooks represent NOS (e.g., Kaya & Erduran, 2016; McDonald, 2017; Park, Yang, & Song, 2019; Park, Yang, & Song, 2020; Yeh, Erduran, & Hsu, 2019). Table 2.3 provides a description of the 11 RFN categories.

Analytical Procedure

First, we examined in detail all textbook elements such as text, inquiry activities, figures, photographs, sidebars and illustrations to identify whether the sentences included references to NOS. In this process, we identified to which aspect of the RFN framework an identified sentence as reference to NOS corresponds. Finally,

Table 2.3 Cognitive–epistemic and social–institutional NOS categories

RFN category	Description (Kaya & Erduran 2016)
Cognitive–epistemic aspects	
Aims and values	The key cognitive and epistemic objectives of science, such as accuracy and objectivity
Methods	The manipulative as well as non-manipulative techniques that underpin scientific investigations
Scientific practices	The set of epistemic and cognitive practices that lead to scientific knowledge through social certification
Scientific knowledge	Theories, laws and explanations that underpin the outcomes of the scientific inquiry
Social–institutional aspects	
Social certification and dissemination	The social mechanisms through which scientists review, evaluate and validate scientific knowledge, for instance, through peer review systems of journals
Scientific ethos	The norms that scientists employ in their work as well as in interaction with colleagues
Social values	Values such as freedom, respect for the environment and social utility
Professional activities	How scientists engage in professional settings such as attending conferences and doing publication reviews
Social organizations and interactions	How science is arranged in an institutional setting such as universities and research institutes
Political power structures	The dynamics of power that exist between scientists and within science cultures
Financial systems	The underlying financial dimensions of science including the funding mechanisms

each identified reference to NOS aspects was coded as an explicit or implicit representation. At the same time, we examined whether textbooks present each aspect of NOS, including reflective activity for NOS. An explicit representation of this NOS aspect is a general statement about science (e.g., ‘scientific knowledge is tentative’); an implicit representation of this NOS aspect is the presentation of historical cases, activities and so on from which relevant NOS views can be inferred and a reflective activity is the textbook part that prompts students’ understanding of NOS through activities such as explanation, discussion and speculation (e.g., ‘discuss why scientists work in collaboration’).

The unit of analysis was a sentence. However, when a series of sentences clearly indicated a specific NOS aspect, we coded them into one category. In addition, when two or more NOS representations were included within one sentence, they are coded into multiple NOS categories. To ensure intercoder reliability, in the beginning, two researchers independently analysed one randomly selected textbook from seven textbooks. After that, the analysis results were compared, and the differences were discussed until agreement was reached and coding criteria were refined. In the next phase, all seven textbooks were independently analysed by two researchers and then the results were compared and discussed until consensus was reached.

Results

Tables 2.4, 2.5, 2.6, and 2.7 describe each textbook’s representation of NOS aspects in the four historical episodes. In the table, *e* denotes an explicit reference to the target NOS category, and *i* denotes an implicit reference. An asterisk (*) was used to indicate the presence of reflective prompts (i.e., questions or student activities) for the NOS aspect being referred to either explicitly or implicitly.

The ‘Galileo’s thought experiment’ episode (Table 2.4) introduces the thought experiment that Galileo carried out to conclude that all falling objects are uniformly accelerated, which led to a paradigm shift in the field of mechanics. Scientific knowledge and scientific practices were represented in all seven textbooks through this historical episode, but the former was given stronger emphasis. Scientific knowledge was represented explicitly in all seven textbooks mostly with reflective activities (six textbooks), while scientific practices were represented explicitly with reflective activities in only two textbooks. In other categories, very few NOS references (one

Table 2.4 NOS representation in the ‘Galileo’s thought experiment’ episode

NOS aspect		Textbook						
		A	B	C	D	E	F	G
Cognitive–epistemic	Aims and values	e	–	–	–	–	–	–
	Methods	–	i	–	–	i	–	–
	Scientific practices	e*	i*	e	i	i*	i	e*
	Scientific knowledge	e*	e*	e*	e	e*	e*	e*
Social–institutional	Social certification and dissemination	–	i	–	–	–	–	–
	Scientific ethos	–	–	–	–	–	–	–
	Social values	–	–	–	–	–	i	–
	Professional activities	–	–	–	–	–	i	–
	Social organizations and interactions	–	–	–	–	–	–	–
	Financial systems	–	–	–	–	–	–	–
	Political power structures	–	–	–	–	–	–	–
	Other[a]	e*	–	–	–	–	–	–

*presence of a reflective prompt

[a] This ‘other’ category was used to refer to generic references to social–institutional NOS (e.g., ‘science is socially and culturally affected’), which could not be classified into one of the seven social–institutional NOS categories

Table 2.5 NOS representation in the 'Mendeleev's periodic table' episode

NOS aspect		Textbook						
		A	B	C	D	E	F	G
Cognitive–epistemic	Aims and values	e*	–	–	–	e*	e	i
	Methods	i	i*	i	i	e*	i	i
	Scientific practices	e*	e*	e*	e	e*	e	i
	Scientific knowledge	i	–	e*	i*	e*	e*	e
Social–institutional	Social certification and dissemination	–	–	–	–	–	–	i
	Scientific ethos	–	–	–	–		–	–
	Social values	–	i	i*	–	i	–	–
	Professional activities	–	i	–	–	i	–	–
	Social organizations and interactions	–	i	–	–	i	–	–
	Financial systems	–	–	–	–	–	–	–
	Political power structures	–	–	–	–	–	–	–
	Other	e*	–	–	–	–	–	–

Table 2.6 NOS representation in the 'Mesozoic mass extinction' episode

NOS aspect		Textbook						
		A	B	C	D	E	F	G
Cognitive–epistemic	Aims and values	–	e*	–	–	e*	e	–
	Methods	e*	e*	e*	e*	e*	e*	e*
	Scientific practices	e	i	i*	–	i	i	i
	Scientific knowledge	e	–	–	–	i	–	e
Social–institutional	Social certification and dissemination	i	–	–	–	–	–	–
	Scientific ethos	–	–	–	–	–	–	–
	Social values	–	–	–	–	–	–	–
	Professional activities	–	–	–	–	–	–	–
	Social organizations and interactions	i	–	e*	–	–	–	–
	Financial systems	–	–	–	–	–	–	–
	Political power structures	–	–	–	–	–	–	–

or two) were found. An excerpt in textbook F shows an example of an explicit reference to the tentative and revolutionary nature of scientific knowledge, followed by a reflective activity:

> Crucial moments in science come from new experiments and begin with other ideas. A system of theory, methods, and critical minds shared by people in a certain time is called a paradigm.

Table 2.7 NOS representation in the 'Pasteur's biogenesis theory' episode

NOS aspect		Textbook						
		A	B	C	D	E	F	G
Cognitive–epistemic	Aims and values	–	–	–	–	–	–	–
	Methods	*e**	*e**	*e**	*e**	*e**	*e**	*e**
	Scientific practices	*i*	*i*	*i**	*i*	*i*	*i*	*i*
	Scientific knowledge	*e*	*i*	*i*	*i*	–	–	*i*
Social–institutional	Social certification and dissemination	–	–	–	*i*	–	–	–
	Scientific ethos	–	–	–	–	–	–	–
	Social values	–	–	–	–	–	–	*i*
	Professional activities	–	–	–	–	–	–	–
	Social organizations and interactions	–	–	–	–	–	–	–
	Financial systems	–	–	–	–	–	–	–
	Political power structures	–	–	–	–	–	–	–

> However, when the phenomenon that cannot be explained by the existing paradigm continues to be observed and the contradictions accumulate, a new paradigm emerges to replace the existing paradigm, which is called the paradigm shift… Discuss with peer what changes have occurred since Galileo in the paradigm related to moving objects. (Textbook F, pp. 14–19)

On the other hand, textbook F addressed scientific practices and professional activities in an implicit manner. The example below shows how scientific practices such as experimentation contribute to theory formation and aspects that scientists can share scientific knowledge to academia or the public through professional activities such as the publication of books. However, these NOS categories were only implied in the text without any explication or reflective activities.

> Galileo's thought experiments on the fall of an object and his analysis of the motion of a horizontally thrown object are contained in his book *Discourses and Mathematical Demonstrations Relating to Two New Sciences*, published in 1638. In this book, Galileo analysed the motion of objects and concluded as follows. 'At the end of hundreds of experiments, I found that the distance of an object is proportional to the square of the time for which it travelled. In addition, the motion of a horizontally thrown object can be divided into vertical and horizontal motions. At this time, I found out that the movement in the horizontal direction is the same as a constant velocity motion and that in the vertical direction it is the same as a free fall'. (Textbook F, p. 19)

In the 'Mendeleev's periodic Table' episode (Table 2.5), all seven textbooks represented most of the 11 NOS categories. In addition, it was noteworthy that all four categories of cognitive–epistemic NOS were represented in four textbooks. Methods and scientific practices were represented in all seven textbooks, while providing details about the various method employed by scientists (e.g., Lavoisier, Döbereiner, Newlands and Mendeleev) in the discovery of the periodic table and explaining that serendipity can lead to the development of science by relentless effort. The nature of scientific knowledge such as its tentativeness was also represented in six textbooks. Aims and values of science were found in four textbooks. In terms of social and institutional NOS aspects, Textbooks B and E represented three (social values, professional activities, social organizations and interactions) of the seven social–institutional categories, while other textbooks addressed none or only one of them.

In the 'Mesozoic mass extinction' episode (Table 2.6), a dominant category was methods. Methods was represented explicitly with reflective activities in all seven textbooks, and it includes the details of the inductive inquiry methods used in finding the cause of the Mesozoic extinction event. Scientific practices were represented in six textbooks; only one of the textbook included explicit references to observations that contributed to the growth of scientific knowledge.

'Pasteur's biogenesis theory' episode (Table 2.7) focused on methods, scientific practices and scientific knowledge of NOS categories. The most central NOS aspect among these three categories was methods. Methods was represented explicitly with reflective activities in all seven textbooks while explaining the deductive inquiry method used in Pasteur's discovery of biogenesis. Scientific practices were represented in all seven textbooks but only implicitly, by addressing that the result of Pasteur's swan-neck flask experiment could be evidence of biogenesis. Scientific knowledge was represented in five of seven textbooks but as mostly implicit approach while presenting the tentative aspect of scientific knowledge through the confrontation between biogenesis theory and spontaneous generation theory.

Overall, one major trend that overarches the four episodes was that textbooks tend to concentrate on the cognitive–epistemic aspects of science, while social–institutional NOS was largely underrepresented. In each historical episode, most of the four categories of cognitive–epistemic NOS were addressed, but none or only one of the social–institutional NOS categories were addressed. In particular, there were no references to scientific ethos, financial systems and political power structures categories—which are gaining increasing importance in recent NOS research (e.g., Erduran & Mugaloglu, 2013; Kaya, Erduran, Birdthistle, & McCormack, 2018; Park et al., 2019). In terms of the methods of representation, cognitive–epistemic NOS aspects were usually addressed explicitly, often with reflective activities. However, in most instances, social–institutional NOS aspects addressed only implicitly.

Within each episode, the explicit representation and reflective activities were usually concentrated on one dominant NOS aspect. For example, the episode 'Galileo's thought experiment' addressed the scientific knowledge category in an explicit and reflective manner in most textbooks, but the other categories were addressed only implicitly, or not addressed. These specific NOS aspects were identical to the ones specified as achievement standards in the curriculum (see Table 2.2).

Discussion

Overall, the analysis revealed both the opportunities and challenges of Korea's new subject SIE in teaching NOS as a separate school subject. First, the NOS representations in the textbooks were concentrated in the cognitive and epistemic aspects of science, while social–institutional aspects of NOS were very limitedly represented. This could be partly explained by the fact that the national curriculum itself is composed of achievement standards that mainly concern epistemic aspects of science. Second, textbooks tended to focus on addressing one central NOS idea in each historical episode, which means that diverse NOS aspects were not represented in a holistic manner. Given that the components of cognitive–epistemic and social–institutional NOS interact with each other dynamically (Allchin, 2011; Erduran & Dagher, 2014; Hodson, 2014; Park et al., 2019), for students' richer understanding of NOS, textbooks should embrace NOS aspects that are as diverse as possible and reveal their dynamic interrelations within each historical episode.

Second, the way SIE textbooks addressed NOS aspects and prompted further reflection on them also carried significant implications. While many studies have reported that the explicit–reflective approach is more effective (e.g., Akerson, Abd-El-Khalick, & Lederman, 2000; Khishfe & Abd-El-Khalick 2002), most textbooks have been reported to lack explicit NOS references and reflective prompts (Abd-El-Khalick et al., 2008; McDonald, 2017). In this respect, most SIE textbooks gave students proper opportunities to develop NOS understanding by means of reflective activities. However, this effort was usually limited to the 'focal' NOS aspect emphasized in each historical episode. It would be necessary for textbook authors to include activities that can address multiple NOS aspects in one episode to maximize the NOS-learning potentials of historical episodes, by utilizing diverse epistemological and social lenses to look at the history of science (Park & Song, 2019).

Finally, the value of implicit NOS references merits more attention. Although the literature on NOS teaching methods has traditionally emphasized an explicit approach, this does not necessarily mean that the NOS given implicitly within a historical and social context is useless. Rather, implicit representation to NOS can be an important means of contextualizing NOS by linking the individual's scientific knowledge with the dynamics of human society surrounding the science (Allchin, Andersen, & Nielsen, 2014; Park et al., 2019). In order to exploit the learning potential of implicit NOS references, the teacher's role will be crucial. For example, while discussing the process where Pasteur presented evidence of biogenesis from his swan-neck flask experiment, in addition to describing each step of the procedure, a teacher can refer to the experimental practice in science by pointing out that 'experimental evidence contributes to the birth of new knowledge by supporting the hypothesis', which is implied in the episode. Along with this, teachers can bring up related NOS prompts such as 'Are there any other ways of supporting the hypothesis other than doing experiments?' 'What was the evidence in favour of spontaneous generation, and what was wrong with those experiments?' These would be good ways to deepen students' understanding of the nature of the experimental practice in science. It is also possible to address the social–institutional aspects of NOS by viewing the idea of biogenesis in connection with the religious and cultural worldview in Europe during Pasteur's time.

Not to mention, NOS is now a classical agenda in science education, with its rich history that spans over 100 years (Lederman, 2007). The uniqueness and importance of SIE as a NOS- and inquiry-oriented science education reform lies in giving them 'their own lives', instead of treating them as secondary to scientific content knowledge. Placing NOS and inquiry at the centre of the subject, SIE becomes an overture to many curriculum reforms that explicitly address these elements of science education. This means that analysing SIE textbooks is more than mere addition to the voluminous literature on textbooks' NOS representation; it allows us a fresh look to NOS. In this sense, the analysis presented in this chapter will be informative to curriculum makers and textbook authors around the world in embedding the history and nature of science into curricula and educational materials.

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Chapter 3
Pedagogical and Content Expertise in Team-Based Learning: Re-aligning Two Teaching Perspectives in an Undergraduate Medical School

Lishan Yang, Emmanuel Tan Chee Peng, and Preman Rajalingam

Abstract The Lee Kong Chian School of Medicine (LKCMedicine), an undergraduate medical school in Singapore formed from a partnership between Nanyang Technological University (Singapore) and Imperial College London (United Kingdom), has been using Team-Based Learning (TBL) as one of its main teaching strategies successfully for large student classes of up to 150 since its inception in 2014. Each TBL session is led by an interdisciplinary faculty teaching team, which consists of at least one 'Content Expert', who would have led the development of curriculum for the particular session and who hence would have subject matter expertise, and a 'TBL Facilitator', who manages productive student discussions during TBL sessions and provides pedagogical expertise before and during the educational sessions. This chapter discusses and compares the perspectives of content and process experts from the lens of the well-validated Teaching Perspectives Inventory. Using interview data and quotes from both parties, this chapter will illustrate areas of convergence and tension. In doing so, we provide a framework to enhance the teaching of science and its professional application in a large, interactive and collaborative classroom.

Introduction

The Lee Kong Chian School of Medicine (LKCMedicine), an undergraduate medical school in Singapore, was formed from a partnership between Nanyang Technological University (Singapore) and Imperial College London (United Kingdom). Its first cohort of students was admitted in 2013 and its bespoke medical curriculum was developed jointly by faculty from both institutions. The programme was planned

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as an integrated systems-based curriculum, with a focus on clinical presentations throughout. In keeping with modern educational practice, a decision was taken to move away from strict memorization of didactic materials and instead adopt principles of active learning with an emphasis on teamwork and application of knowledge (Partridge, 2013). Hence Team-Based Learning (TBL), a structured form of the 'flipped classroom' approach to teaching and learning, was established as the school's principle classroom learning and teaching strategy, dispensing with face-to-face lectures. TBL is used throughout the five-year MBBS programme, though most extensively in the first two years where around 60% of curriculum time is dedicated to TBL. The focus of these TBL classes is the development of foundational scientific understanding, and to contextualise the science to clinical presentations and clinical practice. In years 3, 4 and 5, learning is primarily practice-based in clinical settings. Students do however regroup for campus teaching, during which TBL classes provide a means to link clinical presentations with medical decision-making, potentially involving multiple disciplines. Class sizes are large, and enrolment is expected to grow year-on-year to up to 200 students per class.

At LKCMedicine, TBL was set up in concordance with established principles (Parmelee, Michaelsen, Cook, & Hudes, 2012). Students self-study before coming to class, work collaboratively in teams of six to complete in-class readiness assurance activities, receive feedback on these activities, and finally attempt to apply their knowledge to solve problems related to real-world medical scenarios. Students are able to delve deeply into the topics during team discussion, as TBL questions can be crafted around complex clinical and scientific scenarios (see Appendix 3.1: TBL Process at LKCMedicine). In addition, three critical factors enhance learning at LKCMedicine and enable consistent implementation of TBL across the five-year curriculum. These factors, as described by Rajalingam et al. (2018), are (1) 'team-centric learning spaces', to foster active, collaborative learning; (2) an 'e-learning ecosystem', seamlessly integrated to support all phases of the TBL process and (3) 'teaching teams' in which experts in pedagogical process co-teach with content experts.

This chapter expands upon the third factor, 'teaching teams', by comparing the teaching experiences and challenges from the perspectives of the Content and Process Experts who are involved in co-teaching. In order to enhance student learning in TBL, each session is led by an interdisciplinary teaching team. Each teaching team consists of at least one 'Content Expert', who would have led the development of curriculum for the particular session and who hence would have subject matter expertise, and a 'TBL Facilitator', who manages productive student discussions during TBL sessions and provides pedagogical expertise before and during the educational sessions. This system ensures that while the lesson content is delivered and clarified by at least one Content Expert in the classroom, constructivist pedagogical practices are established by the Facilitator, who plays the role of the 'Process Expert'. Content Experts at LKCMedicine are clinicians or scientists who are primarily involved in patient care and/or research, and who themselves were typically products of a more didactic mode of education. The Facilitator is a process expert trained in student-centred approaches to pedagogy. Furthermore, a particular Content Expert may contribute to only one or two TBL classes every year, whereas each TBL Facilitator is assigned between fifteen to forty-five TBL classes per year. This ensures that the Facilitators are able to build a relationship with the students over time. This team-teaching system combining subject matter expertise on the one hand and pedagogical expertise on the other ensures that constructivist learning principles are maintained fully in the TBL classroom—students can get closure for their lingering questions by the end of the session, but only after they have attempted to work through the problems in their teams through discussion and research. A willingness to engage with and be trained in TBL is a prerequisite for joining the School, and both sets of teaching staff appreciate the TBL format for creating a high level of student engagement (Rotgans et al., 2017). However, since the teaching roles differ, each party approaches TBL from different teaching perspectives. We will explore the perspectives of Content Experts and Facilitators through the lens of the well-validated Teaching Perspectives Inventory (TPI) (Collins & Pratt, 2011). Using TPI data and interview quotes from both parties, we discuss how contrasting roles and perspectives can result in complementary teaching practices. In doing so, we provide a framework to enhance the teaching of science and its professional application in a large, interactive and collaborative classroom (Fig. 3.1).

Fig. 3.1 Team-based learning in session at LKCMedicine. Reprinted with permission from LKCMedicine

Classroom Roles

Team-teaching is defined as a teaching context where ‘two or more persons are assigned to the same students at one time for instructional purposes’ (Gurman, 1989). In reviewing the literature published on team-or-co-teaching, there were no other examples of team-teaching which allowed for a Content and Process Expert—two individuals with differing expertise—to teach in the same classroom. With this article, we are extending the definition of team-teaching to encompass what is practiced at LKCMedicine. Typically, team-teaching has been described as a form of ‘co-teaching’, and most documented cases of co-teaching are of special education classrooms and mentoring situations. Friend and Cook (2004) describe six approaches to co-teaching (with team-teaching being specifically one of these approaches), but while team-teaching as defined by these authors bears the closest description to LKCMedicine’s version (‘tag team-teaching’), it is still not an exact match, since it is not the case that ‘both teachers are delivering the same instruction at the same time’, as defined by these authors.

There is a dearth of research on what an ideal ‘balance between content knowledge and pedagogical knowledge is and if so how can they be better integrated’ (Marshall, Horton, Igo, & Switzer, 2009). ‘Pedagogical knowledge’ in practice manifests as a set of skills, such as questioning techniques and the ability to design engaging learning activities, that comprise a process. While the purpose of each TBL session is for students to meet content-specific learning outcomes, the means to achieving this outcome is this inquiry-driven process backed by sound pedagogical principles. Separating the content and pedagogical expertise is LKCMedicine’s method of creating a balance between content knowledge and pedagogical practice.

At LKCMedicine, teaching roles are distinct in the classroom—the Content Expert handles students’ questions that concern content, whereas the Facilitator approaches the session with a mind towards optimising the TBL process. While it is the Content Expert’s role to listen to and respond to student questions, some of them, particularly the ones newer to teaching, are unsure as to when they should actually answer these questions. They are instructed, during pre-session TBL introduction workshops and in TBL written guides provided to them, to not be overly didactic, to encourage students to think critically about the topics, and to avoid giving away the correct answers to students until student teams have tried to solve the problems independently. For many Content Experts, their uncertainty lies in not actually knowing when to step in, which leads them to listening passively in the classroom until they are cued by the Facilitator to speak. On the other hand, there are other, more ‘seasoned’ Content Experts who play a more active role in questioning students and getting them to engage in TBL sessions, some to the extent that the Facilitator takes a more passive role instead.

An ideal TBL session would have Facilitator and Content Expert(s) work together seamlessly such that the Content Expert would step in when cued to and be able to pose content-based scaffolding questions as opportunities to do so arise, in order to engage students and draw them up to positions of cognitive understanding.

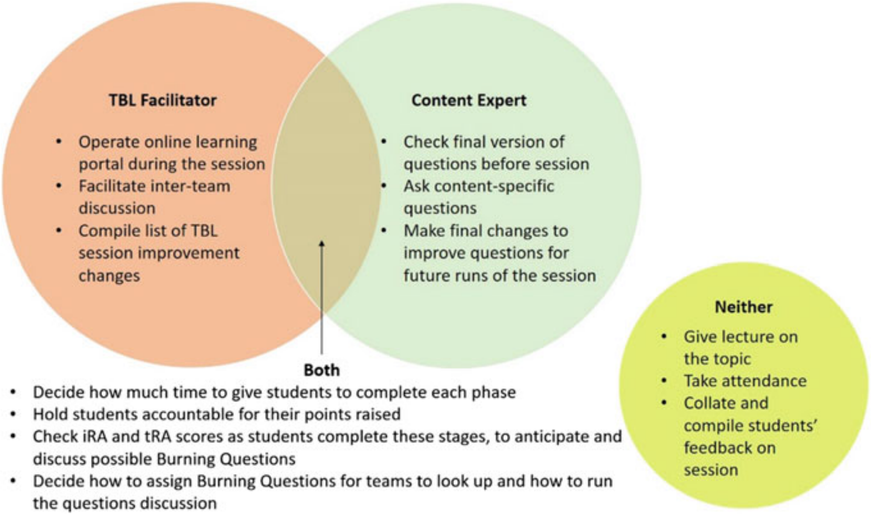

Fig. 3.2 Facilitator's and content expert's roles in LKCMedicine TBL

Figure 3.2 shows the scope of each party's role performed in the classroom—roles that are unique to each, as well as areas of direct collaboration. Administrative work such as attendance-taking and feedback collation are handled by a separate dedicated administrative department within LKCMedicine, and likewise the e-Learning system is maintained and supported by another department. Having this extent of administrative and IT support from other departments allows both Content Experts and Facilitators to fully focus on student-centred teaching in the TBL sessions.

Teaching Perspectives Inventory

A study was conducted where, after TBL sessions, Content Experts and Facilitators were asked to respond to the web-based Teaching Perspectives Inventory (TPI), which served as an indication of their pedagogical beliefs (Collins & Pratt, 2011). Participants were asked to share their TPI results. The TPI is a questionnaire that measures teachers' stands on five contrasting pedagogical perspectives (Pratt & Collins, 2001):

Transmission: Effective teaching requires a substantial commitment to the content or subject matter.

Apprenticeship: Effective teaching is a process of enculturating students into a set of social norms and ways of working.

Developmental: Effective teaching must be planned and conducted 'from the learner's point of view.

Nurturing:	Effective teaching assumes that long-term, hard, persistent effort to achieve come from the heart, as well as the head.
Social reform:	Effective teaching seeks to change society in substantive ways.

Upon completing the TPI, a chart is generated for the respondent. One (or sometimes two) perspective(s) would stand out for each individual, and this would be known as the dominant perspective (Pratt et al., 2016). The score that is significantly lower than the other four would be known as the recessive perspective. The next highest score to the dominant one is the backup perspective.

Aside from the TPI, both parties also responded to interview questions on their roles in team-teaching TBL sessions.

TPI and Interview Results: Findings and Discussion

Figure 3.3 shows the perspectives of four pairs of Facilitator and Content Expert. The TPIs are then plotted into line graphs. These represent actual Facilitator—Content Expert pairings in TBL sessions that had taken place. The TPI survey results revealed that all Facilitators indeed reflected predominantly Developmental teaching perspectives, whereas most Content Experts (save one—Content Expert B from Chart 2) displayed dominant Apprenticeship teaching perspectives.

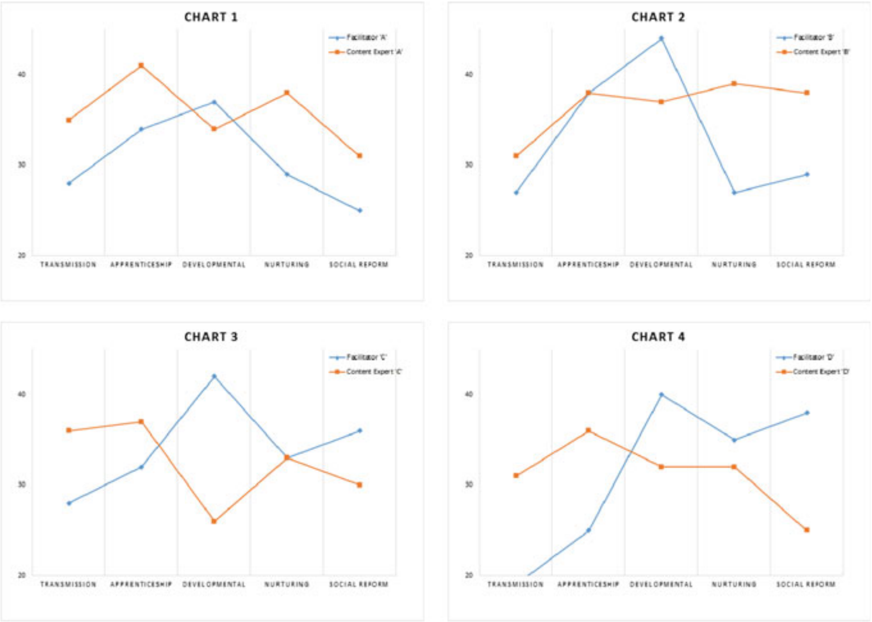

Fig. 3.3 TPI results

Across the Facilitators, the line graphs form an inverted ‘U’-shape, reflecting dominant Developmental perspectives, whereas the Content Experts’ TPI scores form an ‘M’-shape, reflecting dominant Apprenticeship perspectives. Within these general patterns, there are differences in the recessive teaching perspectives. The Developmental and Social Reform perspectives form the Content Experts’ recessive teaching perspectives. However, while Social Reform forms two Facilitators’ backup teaching perspective (Charts 3 and 4), it is the recessive teaching perspective for the other two (Charts 1 and 2).

Due to their training and experience in pedagogical methods, Facilitators primarily value the Developmental aspects of teaching. The nature of their work is after all to train students to be critically thinking individuals. All four Facilitators charted also take part in training potential Content Experts in pedagogical methods, being involved in faculty development, which would further account for their dominant Developmental perspectives. Their recessive perspectives, whether Social Reform or Nurturing, are likely attributable to their individual dispositions. Interestingly, the Facilitator who scored the lowest on Nurturing (Chart 2) attributes it to the fact that she had taken the TPI survey from a faculty development angle (rather than a TBL Facilitator angle; indeed this particular Facilitator’s job scope involves a greater proportion of faculty development than Facilitation), and ‘one doesn’t have to be nurturing towards one’s peers’.

On the other hand, Content Experts come from a professional environment where teaching is equivalent to training their future colleagues. As such, they would place a high value on Apprenticeship as a teaching model. Having Nurturing as their backup perspective also makes sense, as they would see their teaching roles as nurturing future colleagues. As a point of reference, from a sample of 116,621 teachers across all levels and fields of education, Nurturing was the most common dominant perspective (50%), followed by Apprenticeship (38%), Developmental (18%), Transmission (14%) and Social Reform (3%) (Collins & Pratt, 2011).

Content Expert A (from Chart 1) reported that without a Facilitator co-teaching, the session ‘may become didactic’. She further adds, ‘[the] Facilitator helps to facilitate interaction [between teams]. Content Expert’s role is to provide facts’. Content Expert D (Chart 3) sees her role as ‘listening to student discussion to resolve any misconceptions, and answering student questions’. She further adds that the Facilitator’s role is to ‘engage students, direct questions and facilitate discussion between students and Content Experts’. On a similar vein, a third Content Expert (C, from Chart 3) contends that the Facilitator’s role is to ‘surface the [students’] doubts’, whereas his own role is to ‘clarify the doubts’. The same Content Expert also reported that the most challenging aspect of TBL for him is ‘not knowing how to probe deeper into students’ understanding’, showing that the Facilitator’s role is invaluable when Content Experts are not completely confident in their questioning ability.

Content Expert B appreciates the Facilitator’s support because,

> having a Facilitator allows me to think while the students are responding and being challenged through the Facilitator’s questioning, so I can start formulating my thoughts and answers. It would be quite difficult to do both at the same time.

This shows that, in a large-class setting, being able to focus solely on the content of what the students are sharing in class helps Content Experts more effectively perform their function. He further adds,

> My role is to ensure that the students have understood the subject—it goes beyond the classroom and includes the preparation of materials for TBL. The Facilitator's role involves engaging the students in the learning process, stimulating them to think and express themselves, and guiding them in their discussions. The advantage of having regular Facilitators is that they know the students better and are able to engage those who are quieter.

Facilitators reported convergent views on their role vis-a-vis the Content Experts'. According to Facilitator A:

> I facilitate the discussion to ensure that learning takes place, by creating conducive learning environment, asking questions and probing understanding. I see the Content Expert's role as one in which he or she provides the content knowledge and expertise, especially when the discussion reaches an impasse, or when the students require some closure.

Facilitator B reported,

> My role is facilitating inter-team discussion, probing students for their rationales, and getting them to think critically about the other arguments they've heard in the classroom. Content Expert's role is to listen to students' reasoning in order to correct misconceptions, and to provide insights from a clinical perspective.

LKCMedicine's version of team-teaching has shown that content knowledge and pedagogical process knowledge being embodied in separate entities can in fact enhance their efficacy in the large, interactive and collaborative classroom.

Developmental perspectives are well-suited to creating a constructivist learning environment, while Apprenticeship perspectives signal teachers who are keen to share aspects of their professional practice as they close the knowledge loop for students. In an ideal TBL session, the Developmental perspective on the part of the Facilitator and Apprenticeship perspective on the part of the Content Expert(s) converge in this complementary manner.

Why Team-Teaching Works in LKCMedicine

Achieving effective team-teaching has been portrayed as requiring extensive development 'through the complex interaction of both external and interdependent partnerships' (Pratt, 2014). However, LKCMedicine's example has shown that team-teaching can be effectively implemented once the individuals with the requisite experience and training are placed in the roles of Content and Process Experts in the classroom. Essential to its success is a well-planned curriculum, clear roles for Content and Process Experts, and a targeted professional development programme.

While the literature has highlighted the importance of planning, design and assessment in team-teaching (Gaytan, 2010), at LKCMedicine the bulk of pre-session planning is invested in the TBL lesson plan. TBL was seen as an integral part of the curriculum right from the inception of the medical school, and the high level of commitment and investment from the start is what has led to successful implementation. New Facilitators undergo training, as do Content Experts, on student-centred pedagogical practices. Professional development for all teaching staff is a way to maintain pedagogical standards in team-teaching system (Walsh, 2012) and to keep everyone on the same page in terms of educational outcomes and ideals (Thompson et al., 2007).

Team-teaching may be helpful in teaching contexts where higher teacher–student ratios are required. In LKCMedicine's case, it came about because the implementation of a constructivist, student-centred pedagogical framework required teaching faculty to deliver content in a way that would encourage students to engage one another before they look to the Content Experts for closure. Additionally, 'large classes require effective and quite specific management skills' and 'most teachers find large class teaching a "performance", with the increased likelihood of stage fright' (Biggs & Tang, 2011). Even in a class of over 140 students, team-teaching in TBL creates a learning environment that is student-centred (rather than teacher-centred), since there is always someone familiar with classroom management processes to run the lessons. Both these factors combined ensure that even Content Experts newly drafted into teaching are unlikely to experience this 'stage fright' that new teachers may be prone to, due to Facilitator support.

The Way Forward

Having detailed the workings of a team-teaching approach in a TBL classroom context, this section discusses some possible applications of the findings and areas for future research. While the teaching context described in this chapter is undergraduate medicine, a significant portion of a medical student's education is essentially science education. Science educators and educational administrators in other contexts may also find the team-teaching approach a useful addition to their teaching strategy toolkits.

The addition of a Facilitator's teaching perspective may serve to consciously move a teaching session from didactic delivery to one which is more active and engaging. The presence of an experienced Facilitator could also help to support and frame the content delivery for beginning science teachers, creating more opportunities for active learning and open-ended questioning, thereby breaking the monotony of more didactic modes of teaching which teachers may default to when they are new to content delivery.

Currently, no other literature exists on this unique Facilitator-Content Expert team-teaching model. LKCMedicine's model could thus serve as an example of how it could be implemented in other teaching contexts.

Given the novel nature of the team-teaching approach, there are a number of future research areas. A separate but related study, coding and analysing the types of questions posed in the classroom by each party in order to better understand teaching scope undertaken by each party, has been undertaken and published (Yang & Rajalingam, 2019). Faculty development training, faculty buy-in and administrative support are important factors that led to the successful implementation of team-based learning (Thompson et al., 2007) as well as team-teaching at LKCMedicine, and these aspects could be further studied as well. Another interesting angle to examine is what each party feels they have learned from collaborating with the other, given the difference in their teaching perspectives.

While the TPI is not directly implemented at LKCMedicine in order to match teaching teams, perhaps other institutions that lack dedicated Facilitators and Content Experts in their teaching staff could employ the TPI as a tool to identify pairs of teaching faculty who could team up effectively. Studies could then be undertaken to determine which is more effective—having two similar perspective teachers team-teach (for example, two Developmental perspective teachers), or two contrasting perspective teachers (a Developmental and a Transmission). Further, additional factors that lead to successful team-teaching (such as communication styles, etc.) could be further examined.

Aside from the teaching team's perspective, future research could also examine the students' perspective, elucidating their perceptions of this teaching strategy. Our preliminary studies in this area (Rotgans, Rajalingam, Ferenczi, & Low-Beer, 2018) indicate that students think that Facilitators have greater direct impact on their learning than Content Experts, though Content Experts may have an important role in encouraging application of knowledge. This counterintuitive finding needs to be investigated further. What exactly are the ways in which each party guide students' learning? Do the students' resultant assessment scores and learning outcomes align with the teaching perspectives of the teaching staff? Additionally, future studies could perhaps investigate the efficacy of this approach in non-team-based learning or non-medical educational contexts.

Concluding Remarks: Tradition and Transformation

The study of effective teaching approaches remains ever relevant in the twenty-first century. Technological changes have had a profound effect on how and where learning takes place. Students today have almost unlimited access to information, and no longer need to physically attend lectures to acquire knowledge. Rather, preparation for class can be done literally anywhere; with information always literally at the fingertips, class time can be used more effectively on higher order learning activities, such as cementing understanding and solving problems. This development has necessitated a change in how teaching and learning take place. Teachers today need to engage students beyond simply transmitting information at them—students need to be guided in terms of how they seek and make sense of information.

In this chapter, we have proposed a new lens to frame the understanding of co-teaching. The study of co-teaching has been traditionally approached through examining how two or more teachers, transmitting the same instructional content, teach in the same setting. However, the model of LKCMedicine's team-teaching is unique, lying outside of existing frameworks. Beyond showing that two seemingly disparate teaching perspectives can fuse successfully in large-group tertiary-level teaching, LKCMedicine's model of team-teaching provides an approach that ensures students are nurtured to make sense of the oftentimes heavy content they learn, through working in teams. Rather than a discordant learning experience due to what at first may seem like mismatched teaching perspectives, Facilitator and Content Expert are instead able to collaboratively create a 'best-of-both-worlds' classroom environment for students.

Appendix 3.1: Overview of the TBL Process at LKCMedicine

The TBL process consists of three phases. TBL starts with the preparation phase which consists of individual learning activities undertaken before class, which may include reviewing journal articles, voiceover PowerPoints or other digital resources. The subsequent phases occur in class, with students allocated to teams of 6. In the closed-book readiness assurance phase, the intention is to ascertain whether students have acquired sufficient understanding of the subject studied and to provide clarifications where necessary. In the initial part of this phase (Individual Readiness Assurance Test or iRAT) students engage in an individual knowledge test, usually in multiple-choice question format, to assess the extent to which the learning objectives have been attained. In the second part of this phase (Team Readiness Assurance Test or tRAT), students repeat the same test, but this time in their teams. During the tRAT students discuss and come to a consensus on their team answers, and the correct answers are then revealed. This form of peer learning with subsequent feedback enables misconceptions to be clarified and knowledge gaps to be filled. Often the small group discussion leads to additional questions about the subject matter which can then be posed to the teacher(s), who provides the necessary clarifications through direct instruction. In the final application exercise phase, students working in their teams are tasked with scenarios—usually clinical problems—that encourage them to apply what they have learned in the previous phases. This application exercise phase is characterised by the '4S' principles (Michaelsen & Sweet, 2008): student teams work on the 'same' problem, which must be 'significant'. Student teams are required to make a 'specific' choice from a limited list of options and report their responses 'simultaneously'. The teacher(s) facilitates subsequent discussion and provides an expert's solution when necessary.

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Chapter 4
A Classics Reading Approach to Nurture Epistemic Insight in a Multidisciplinary and Higher Education Context

Kai Ming Kiang and Klaus Colanero

Abstract In this paper, we argue that classics reading, a traditional way of implementing general education, can be effective in nurturing epistemic insight in a multidisciplinary class setting in the higher education context. We think that epistemic insight is at the core of scientific literacy. The General Education Foundation Programme of The Chinese University of Hong Kong, which requires students to read science-related classics, was studied. The ways in which such classics are used to nurture epistemic insight are explained. Evaluation results show that the programme is, in general, well received by the students and is effective in nurturing scientific literacy through epistemic insight. We hypothesized that the success is due to the underlying presence of the nature-knowledge-value framework. Such a framework helps students to become aware of the different views about science (the first level of epistemic insight) and to reflect on the origin, the inter-relationship, the complexity and the limitations of such diverse views (the second level of epistemic insight). This second level is what we propose to be suitable for nurturing scientific literacy in tertiary students. We expect that the present reflection will be useful for developing innovative pedagogies for nurturing epistemic insight and for guiding in-depth studies on their effectiveness.

Introduction

Cultivating a more scientifically literate next generation has been one of the emphases of educational reforms in many countries in the last few decades (DeBoer, 2000; Organisation for Economic Co-operation and Development, 2007, 2016). Yet, what exactly is scientific literacy? Is it a set of skills in science reading (Norris & Phillip, 2003)? Is it the way of thinking in science that can be considered as the twenty-first century skills set used beyond science classroom (Hurd, 2000)? Or is it more

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about understanding some specific science knowledge and its relationship with the outside world (Roberts, 2007)? Recently, there has been a call to shift the focus of such educational reforms to developing students' *epistemic insight*, that is, the knowledge about knowledge, such as the understanding of the characteristics and limitations of knowledge (Billingsley & Hardman, 2017). What is the relationship between epistemic insight and scientific literacy? And how can we nurture it among diverse students? Based on the experience of the General Education Foundation Programme of The Chinese University of Hong Kong, we argue that *classics reading*, a traditional method of implementing general education, can be effective in nurturing epistemic insight as well as some other aspects of scientific literacy in the higher education context. In particular, through peer discussions on the core-issues raised by the classics, the perennial issues, students in a multidisciplinary class setting can be more easily inspired on how science relates to their individual disciplines and to the concerns of people living in the modern society.

Epistemic Insight

Epistemic insight, according to Billingsley (2017), is the knowledge about knowledge, i.e. the understanding of the nature of science, the understanding of the power, relevance and limitations of science in real-world and multidisciplinary arenas. We view epistemic insight as a concept located at the core of scientific literacy. *Modern science* is not a concept that just includes the theories, which are subject to continuous revision, nor only the experimental or mathematical techniques employed. It includes also the underlying epistemic assumptions and requirements (Popper, 1963; Gellner, 1974; Preti, 1968). Acquiring familiarity with the scientific theories and techniques without an awareness of the nature of the modern scientific knowledge, is equivalent to learning the strategies and the techniques of a game without knowing its rules and limitations.

Hence, epistemic insight is crucial for a scientifically literate person, as it develops the understanding of the interactions between modern science and the various other aspects of human life. It can be viewed as one core aspect of scientific literacy, which overlaps with dimensions 2 and 3 out of the four dimensions in the Organisation for Economic Co-operation and Development's definition (OECD, 2007, pp. 34–35), rather than a distinct idea outside the scope of scientific literacy. Such an aspect has an intrinsic value as it helps us to reflect on the limitations of what we know and how ourselves and our society could be affected by what we believe to be true. This can potentially contribute to making a more tolerant and rational society. Dimensions 1 and 4 of the OECD definition, on the other hand, are more related to the practical, immediate and extrinsic values of scientific literacy that helps us to improve the quality of our living and efficiency of our work. Hence, scientific literacy includes two aspects:

1. The epistemological aspect with an intrinsic value: the understanding and awareness of the characteristics of science and its inter-relationship with nature and human life.
2. The practical aspect with an extrinsic value: the understanding and use of scientific knowledge and the willingness to engage in science-related issues.

Hence, the call for epistemic insight is to remind us of the intrinsic value of scientific literacy: the epistemological aspect. It is interesting, however, to note that this call partly overlaps with what general education has been aimed at achieving in the last century, despite its very different roots.

Nurturing Epistemic Insight via Classics Reading

Reflection on the perennial issues is one important part of general education (Carson, 1997). Similarly, thinking about the big questions (Shipman, Brickhouse, Dagher, & Letts, 2002) is also considered an important means for nurturing epistemic insight (Billingsley, Taber, Riga, & Newdick, 2013). We argue that such perennial issues or big questions, such as "Where do humans come from?", "Who am I?", "What is the reality?", "What can we know and how?", are the common motive force for nurturing epistemic insight both in the context of general education and of science education. For this reason, we believe that reading classics, as an effective way of implementing general education curricula, can also be used to nurture epistemic insight in the context of science education. The difference lies only on what *classics* are to be read. As a starting point, we should consider *science classics* (Goodney & Long, 2003). According to Gjertsen's (1984), science classics are those texts that transformed science or produced a major intellectual revolution. However, we need not include only science classics that are considered correct from a modern perspective, such as Newton's "Principia" or Darwin's "On the origin of species". Doing so would exclude all other ways of exploring nature before the scientific revolution, such as Aristotle's understanding of nature or ways not originated from the West, such as ancient Chinese science. As Lindberg (2007, p. 3) argued, we should consider the origin of science, traced back to the antiquity and the middle age, "as this is the only suitable way of understanding how we became what we are". This would mean our selection should include also texts that are of conflicting views of nature, in particular not very scientific in a modern sense. We shall refer to this broadened selection as *science-related classics*.

From a pedagogical perspective, the advantages of reading science-related classics to nurture epistemic insight are, first, science-related classics, by definition, were written in response to the big questions and hence can be easily related to all students of various disciplines and backgrounds. Second, these texts are part of the history of the development of civilizations. They impacted the life, cultures and religions of different societies and provide opportunities for the students to explore the relationships between science and such areas. This is especially important when related to the similar questions raised by advances at the frontiers of modern science and technology. Third, reading them at its very least develops an awareness of great people and great ideas, which is a strong enough reason to expect engagement even by those students who have little interest in science.

General Education Foundation Programme

The Chinese University of Hong Kong in 2012 launched the General Education Foundation Programme (GEFP), which is comprised of two compulsory courses called "In Dialogue with Nature" and "In Dialogue with Humanity" (Wong & Chiu, 2010). These two courses require students to read respectively science-related and humanities classics as core texts. Through the reading of such classics, students can "explore the world of science and knowledge, and reflect on ideal society and good life" (GEFP, 2018, "Background"). The two dialogue courses have a common learning goal—"to build for students a common intellectual and cultural ground, from which sensitivity to the concerns of human existence may develop, and intellectual dialogues on these concerns may emerge" (GEFP, 2018, "Mission & Vision"). For each semester, there are over 3800 students concurrently taking the two courses. This sets The Chinese University of Hong Kong as an ideal testbed for the effectiveness of the classics reading approach, in particular on nurturing epistemic insight.

Besides requiring the students to read the classics, the effectiveness of the courses was enhanced by providing the students with a more inquiry-based setting rather than a traditional lecture setting (Martin, 2010; Odom, Stoddard & LaNasa, 2007). The courses are conducted via a 2-hour student-oriented tutorials, with classes of no more than 25 students from mixed disciplinary backgrounds, and a 1-hour lecture per week. The peer-discussion environment during the tutorial is deemed to be important as it challenges students' own assumptions or understanding with viewpoints from people of different academic backgrounds. This can then trigger them to reconstruct their understanding of the world and the nature of knowledge.

Including the two authors of the present paper, the 28 full-time lecturers of the GEFP were recruited from various academic backgrounds and were put together as a team into the same office to teach the two dialogue courses, share their pedagogies, and discuss the ideals of general education. In this way, the lecturers are very similar to the students in that their own assumptions or understanding are challenged with viewpoints from people of different academic backgrounds.

The list of readings for the course In Dialogue with Nature contains excerpts from science-related texts (see Table 4.1). These excerpts are compiled into the textbook of the course (Chan, Szeto & Wong, 2012). The list of readings comprises texts which are related to the ancient Greek philosophy of nature, ancient Chinese science and modern science. The texts are divided into three parts to address three main enquiries on Nature: Part I is about the human exploration of the physical universe; Part II is about the human exploration of the world of life and Part III is about our understanding of human understanding itself. It should be noted that the groupings

Table 4.1 Lists of readings for In Dialogue with Nature

Part I: Human Exploration of the Physical Universe
Text 1a—Republic/*Plato*
Text 1b—The Beginnings of Western Science/*David C. Lindberg*
Text 2—The Beginnings of Western Science/*David C. Lindberg*
Text 3a—The Birth of a New Physics/*I. Bernard Cohen*
Text 3b—The Principia: Mathematical Principles of Natural Philosophy/*Isaac Newton*
Part II: Human Exploration of the World of Life
Text 4—On the Origin of Species/*Charles Darwin*
Text 5—DNA: The Secret of Life/*James D. Watson*
Text 6—Silent Spring/*Rachel Carson*
Part III: Our Understanding of Human Understanding
Text 7—Science and Method/*Henri Poincaré*
Text 8—In Search of Memory: The Emergence of a New Science of Mind/*Eric R. Kandel*
Text 9—The Shorter Science and Civilisation in China/*Joseph Needham*
Text 10a—Why the Scientific Revolution Did Not Take Place in China—or Didn't It?/*Nathan Sivin*
Text 10b—Brush Talks from Dream Brook/*Shen Kua*
Text 11a—The Mathematical Universe/*William Dunham*
Text 11b—Elements/*Euclid*

are merely one way of organizing these texts and are not to be taken as the only meaningful order of teaching the course.

Similarly, the list of readings for the course In Dialogue with Humanity contains excerpts from humanities texts. These excerpts are compiled into the textbook of the course (Chiu et al., 2016). The list of readings comprises texts on moral and political philosophy, and on religion from the West and the East (see Table 4.2).

Table 4.2 Lists of readings for In Dialogue with Humanity

Volume 1
Text 1—Symposium/*Plato*
Text 2—Analects
Text 3—Zhuangzi/*Zhuangzi*
Text 4—The Heart of Understanding/*Thich Nhat Hanh*
Text 5—The Bible
Volume 2
Text 6—The Qur'an
Text 7—Waiting for the Dawn/*Huang Zongxi*
Text 8—The Social Contract/*Jean-Jacques Rousseau*
Text 9—On Liberty/John Stuart Mill
Text 10—The Wealth of Nations/*Adam Smith*
Text 11—Economic and Philosophic Manuscripts of 1844/*Karl Marx*

Epistemic Insight from in Dialogue with Nature

As mentioned, the use of classics as basis for discussion has at least one pedagogical merit towards developing epistemic insight: providing a context for discussing the big questions or perennial issues. Such a context helps the students to see the relevance of understanding the nature of science and its relation to the various aspects of life. This is important also for students who are not specializing in science or philosophy, as it is the case for a foundational general education course.

In this section, we shall now give examples of how the selected classics in the course In Dialogue with Nature are used to relate to the big questions or perennial issues and to nurture epistemic insight.

In Text 1 and 2 of In Dialogue with Nature, Plato's and Aristotle's philosophies of nature, unfamiliar to most students, are introduced. At the heart of their theories there is the perceived need to have some unchanging pattern behind the capricious world. Such a need can also be found in the Chinese Yin-Yang and Five-Elements theories, explored in Text 9 from Needham's great work. The in-class reflection leads to identifying the origin of such a cross-cultural need with the desire and struggles to develop a consistent and rational worldview, in contrast to a mythical one resigned to unpredictability. This way, students can acquire a first insight that the value of rationality or intelligibility, the root of scientific thinking, leads to assumptions and knowledge about our world.

The study of these ancient Greek philosophies of nature provides also an opportunity for comparison with Text 3 on Isaac Newton's masterpiece. Not just the theories are different, but their scopes are also different. For example, the purpose, the teleology of natural phenomena, which is central to ancient Greek philosophies of nature, falls outside of the scope of modern science. This is due to a change of value during the scientific revolution, a topic brought up in Text 10. Students can see the meaning of paradigm shift as suggested by Kuhn (1962) and can put into perspective Popper's (1963) requirement of falsifiability.

Text 6 also provides helpful opportunities to investigate and clarify other important interactions between values and knowledge. In Carson's text, scientific knowledge by itself is neither good nor bad, it is just knowledge. It can be used to produce very harmful pesticides and it can be used to develop sustainable agricultural methods. At the same time, Carson's reflections and attitude seem to raise the questions: can a responsible person neglect scientific knowledge when making decisions about nature? Or isn't there a moral duty in taking into account empirically testable knowledge?

In Text 7, Poincaré's reflection on the role of the sense of beauty and of the sense of usefulness in scientific discovery can help to clarify the often confused views about whether modern science is or not value-free. Modern scientific knowledge aims at non-subjective truth. But the subjective sense of beauty and the subjective sense of usefulness (practical, social, psychological, etc.…) can aid the development of scientific theories which will then be tested against non-subjective empirical observations.

Text 9, 10 and 11 raise the issue of cultural differences in knowledge (e.g. the ancient Greek vs. Chinese). Both the internal (the interest and concerns of the people) and external conditions (geographical constraints, politics, warfare, etc.…) of different civilizations can cause them to pursue different epistemological approaches. Reflecting on this cultural diversity, one could, for example, be inclined to believe that there are no absolute truths, resulting in relativism, and one could be inclined to believe in objective truth but with cultural subjective differences only in resource allocations. Either way, the students acquire greater awareness of the relationships between culture and knowledge.

These are just some of the most common epistemic issues discussed during the tutorials and as topics for reflective writing. The lecturers usually do not dictate a solution for these discussions. Instead, students are allowed to hear different views among themselves and to learn views of scholars introduced by the lecturers.

Results

Formal Evaluation

At the end of each semester, the students taking the two courses in the GEFP are given the opportunity to complete a Course and Teacher Evaluation (CTE) survey as a standard practice of the Chinese University of Hong Kong. Since the full launch of the programme, the two courses have been highly rated by the students in the CTE exercise. Such a response has to be considered together with two potentially negative factors. First is the compulsory nature of these two courses. Unlike free electives, it is compulsory for students to take these courses regardless of how much they like or hate them at the beginning. Second, the texts selected are mostly written in English, which is a second language to most of the students in Hong Kong. Given such negative factors, one should be able to see the difficulty of obtaining such a positive result.

The GEFP has also been externally assessed by the Association of American Colleges and Universities (AAC&U) in 2014 with highly positive feedback. This assessment led to the Exemplary Program Award for the Improvement of General Education in 2015 from Association for General and Liberal Studies. The award assessment criteria are described by Nichols, Mauldin and Gaff (2015).

Entry-Exit Surveys

In order to further evaluate the effectiveness of the programme, a preliminary investigation was conducted for two subsequent years, 2015/16 and 2016/17. Both sets of data followed the same procedure, which adopted the Input, Environment and

Output (IEO) model as our framework of assessment of students' self-perceived performance (Astin, 2012). IEO emphasizes the assessment of student learning outcomes and changes via the specific environmental factors provided to students. To investigate changes in student outcomes before and after studying the programme, we designed two student surveys, namely entry and exit surveys. The two surveys contain a common list of 17 items (see Table 4.2). Such a survey design allows us to measure the status of students at two different time points.

Generally, the two surveys were conducted during the first and the last lesson of the participating classes. The data gathered in the entry survey can act as a defined baseline while the data gathered in the exit survey can be considered as the final outcome. The surveys requested the students to fill in the last five digits of their student Identification (ID) numbers so that additional information related to the students could be retrieved. The surveys were of voluntary nature. The information was acquired with the consent of the student volunteers with a guarantee of having no consequences to their academic grade. The validity of using Entry-Exit surveys to measure student's perception was reported by Ng, Kiang and Cheung (2016). More details about the analysis of the Entry-Exit surveys have also been reported (Kiang, Ng & Cheung, 2015; Kiang et al., 2016).

The results of the academic year 2015/16 was reported and published in the proceedings of the International Science Education Conference 2018 (Kiang, Cheung & Ng, 2018). This study suggested that reading science classics can be an effective way to nurture scientific literacy at the higher education level.

To further study the effect with respect to the area of concern in this paper, i.e. epistemic insight, we further analysed the survey results in the academic year 2016/17. In this set of data, there were 99 tutorial groups surveyed for In Dialogue with Nature during the academic year. 51 groups were in Term 1, 46 groups were in Term 2 and 2 groups were in the Summer Term. There were 2155 students enrolled in these 99 groups at the end. 2133 students participated in the Entry survey and 1916 students participated in the Exit survey. The discrepancy in the participation numbers was mainly due to students' absence in the first or last tutorial sessions or late add-drop from the groups. Among all participating students, a total of 1646 were successfully tracked from the Entry and Exit surveys. The tracking rate is 77.17%. Some students were tracked unsuccessfully because they completed only one of the two surveys or because they did not provide sufficient information for tracking. The analysis in the present paper was performed on the data of the successfully tracked students.

Similarly, there were 60 tutorial groups surveyed for In Dialogue with Humanity during the academic year. 23 groups were in Term 1, 35 groups were in Term 2 and 2 groups were in the Summer Term. There were 1276 students enrolled in these 60 groups at the end. 1248 students participated in the Entry survey and 1076 students participated in the Exit survey. Among all participating students, a total of 993 were successfully tracked from the Entry and Exit surveys. The tracking rate is 77.82%.

The mean scores of these students at the Entry, Exit and the net changes of the two courses, measured in a 6-point Likert scale, are displayed in Table 4.3. Two-tailed paired t-test was performed for all the items of the two courses. For all 17 items, there were statistically significant positive changes of the students in the two courses,

Table 4.3 Entry-Exit Surveys' mean scores for the two courses

Intended-learning-outcomes related items	In dialogue with nature			In dialogue with humanity		
	Entry	Exit	Change	Entry	Exit	Change
Q1. I can analyze and evaluate arguments critically	4.24	4.75	0.50*	4.17	4.65	0.48*
Q2. I am open to new and different ideas	4.82	5.07	0.25*	4.78	5.02	0.24*
Q3. I can articulate clearly my ideas in writing	4.15	4.49	0.34*	4.16	4.41	0.25*
Q4. I can express clearly my ideas orally	4.03	4.41	0.38*	4.01	4.27	0.27*
Q5. I am confident in reading difficult texts in English	3.69	4.12	0.43*	3.63	3.88	0.24*
Q6. I am confident in reading science-related texts	4.04	4.37	0.33*	3.94	4.07	0.13*
Q7. I am interested in natural science	4.29	4.62	0.33*	4.08	4.16	0.08*
Q8. Scientific knowledge is important for my intellectual development	4.55	4.88	0.32*	4.36	4.51	0.15*
Q9. I understand the development of natural science	3.44	4.53	1.09*	3.55	3.91	0.37*
Q10. I understand the various features of scientific methods	3.68	4.67	0.99*	3.80	4.05	0.26*
Q11. I understand the contributions and limitations of scientific inquiry	3.88	4.72	0.84*	3.95	4.19	0.24*
Q12. I can assess the social implications of scientific inquiry	3.88	4.64	0.76*	3.92	4.21	0.29*
Q13. I am aware of major ideas that shape today's views of the good life and the good society	3.83	4.57	0.74*	3.95	4.66	0.71*
Q14. I appreciate diverse values about life and society	4.57	4.91	0.35*	4.54	4.86	0.31*
Q15. I can make informed judgments on what is a good life and what is a good society	4.14	4.65	0.51*	4.09	4.65	0.56*
Q16. I am interested in the discussion of values of life and social issues with others who hold different viewpoints	4.59	4.93	0.34*	4.63	4.89	0.26*
Q17. I believe that my life plan is meaningful	4.55	4.81	0.26*	4.43	4.65	0.22*

*$p < 0.01$ for paired t-test

indicated by the asterisks next to the net changes. This means that, while there could still be other uncontrolled factors that could influence the students, the most likely cause for the change of students' perception is arguably the effectiveness of the two courses (Schunk & Meece, 1992; Dinther et al., 2014).

These 17 items can be further categorized. Q1–Q7 can be considered as directly related to the practical aspect of scientific literacy as defined in the Section "Epistemic Insight". These items have changes of 0.25–0.50 for In Dialogue with Nature and 0.08–0.48 for In Dialogue with Humanity. On the other hand, Q8–Q12 can be considered as directly related to epistemic insight. These items have changed more significantly for In Dialogue with Nature (0.32–1.09) than for In Dialogue with Humanity (0.15–0.37) for the former is directly aimed at this purpose. On the other hand, for Q13–Q17, which are related to the more general human values and can be considered as the benchmark, the two courses scored similar changes (0.26–0.74 vs. 0.22–0.71). Overall then, In Dialogue with Nature have higher changes in scores than In Dialogue with Humanity for epistemic insight as well as for the practical aspect of scientific literacy. This result seems to support that reading science-related classics, under a general education programme in a multidisciplinary arena, can be effective in nurturing epistemic insight, and has some significant effect on developing also the practical aspect of scientific literacy.

Discussion

In the present section we discuss merits, limitations and prospects of using a classics reading approach for increasing students' epistemic insight.

Two Levels of Epistemic Insight

The problems more frequently discussed in the current literature on epistemic insight are the relation between scientific knowledge and religious beliefs, the meaning or purpose of the universe, of its existence and its behaviour, human consciousness and free will (Billingsley et al., 2013; Billingsley & Hardman, 2017; Billingsley, 2017; Owens et al., 2018; Konnemann et al., 2018). Students' attempts at addressing the above problems are diverse and of different degrees of complexity (Billingsley et al., 2013), but they can be grouped under four categories related to different attitudes towards scientific knowledge (Colanero & Redaelli, 2016):

(1) The modern scientific approach cannot provide answers about those problems, but other forms of knowledge can;

(2) The modern scientific approach can provide reliable and relevant knowledge, but those problems either go beyond the limitations of human knowledge or are a matter of values (not knowledge);

(3) Scientific method and knowledge have only a practical value. They cannot say anything about the fundamental human questions;
(4) What cannot be addressed through the means of modern science is irrelevant.

We suggest that becoming aware of the existence of the above four attitudes and of one's own inclination corresponds only to the first level of epistemic insight. There is a second level, which corresponds to the awareness of the assumptions, sometimes hidden, behind the above attitudes. Such awareness clarifies also the different reasons behind some of the views mentioned in the literature, such as the compatibility and incompatibility between modern science and religious beliefs (Billingsley et al., 2013).

The second level of epistemic insight is particularly relevant at the tertiary education level, where it is desirable and reasonable to expect that students go beyond the simple awareness of the basic problems and try to analyze the possible solutions. We believe that the course In Dialogue with Nature provides the soil for nurturing such a second level.

The Nature-Knowledge-Values Framework for Epistemic Insight

In order to explain the reason of the effectiveness of the course with respect to the second level of epistemic insight, we formulated a conceptual framework based on the interactions between nature, knowledge and human values (Colanero, 2015). Such a nature-knowledge-values framework is based on the reasonable heuristic assumption that all problems we address can be analyzed comprehensively from the point of view of the interactions between three fundamental aspects: (1) nature, the ontological aspect, (2) knowledge, the epistemic aspect and (3) human values, the axiological aspect. The ontological aspect consists of the observable facts of nature and ourselves and of our beliefs or assumptions about it. The epistemic aspect includes both the issues about the acquisition of knowledge as well as the actual knowledge that we have about the world. The axiological aspect consists of the human values, both personal and social, such as the purpose, the aims and the meanings of human actions.

It has to be clarified that we are not aware of any other proposal or application similar to our framework either for general education or science education. As far as we know, the few cases in which the concepts of nature, knowledge and values (or equivalently ontology, epistemology, axiology) are considered in conjunction, present only a definitional (Chesky & Wolfmeyer, 2015; Engle, 2008) or classificatory (Giroux, 1979; Eames, 1977) usage and do not focus on their interactions. Moreover, the ontological and epistemological aspects in those cases do not refer to nature, but to the defining features of the discipline they are considering. Occasionally it is stated, with good reason, that a philosophical, social or educational paradigm involves the views about the nature of the human being, our knowledge, and values, but without further elaboration, particularly without an explicit attention at the ways those three factors interplay within the issues under consideration (Giroux, 1979; Eames, 1977).

Acquiring a deeper epistemic insight about the relationships between scientific knowledge and human life issues means becoming aware of: how our idea of nature affects our view of the world and our values; how the acquisition of knowledge interacts with our values and how our human values affect the way we interact with nature and acquire knowledge. The main usefulness of this awareness consists of its potential to disentangle the complexity of reasons and beliefs behind one's own views on science-related issues. For example, science and religions include a different set of values and hierarchies of values (Preti, 1968; Colanero 2014; Colanero & Redaelli, 2016). It is often such a different ranking of values, or the lack of awareness about it that generates misunderstandings and conflicts. The different views may also involve different ontological assumptions and different attitudes towards empirical observations. Students should be lead to consider the ontological, epistemic and axiological components and their interactions in the issues at hand.

Limitations and Future Investigations

With respect to the first level of epistemic insight, the outcomes of the Entry-Exit surveys, as shown in the corresponding section, allow us to state with a high degree of confidence that the "In Dialogue with Nature" course is effective in developing awareness of the epistemic problems and of one's own views or inclinations towards them. With respect to the second level of insight we have not performed specific surveys to assess the course effectiveness. At this stage we can only observe that the type of discussion carried on throughout the course, as presented in the Section "Epistemic Insight from In Dialogue with Nature", does lead the students to reflect on the nature-knowledge-values interactions, whose understanding we associate with a deeper level of epistemic insight, as explained in the previous section. It also suggests that a future investigation, with both quantitative and qualitative methods to specifically test such an aspect, is worthwhile.

Conclusion

Epistemic insight is the understanding of the nature of knowledge, the relationship between different types of knowledge and the relationship between nature, knowledge and values. We argued that through reading science-related classics, students could be very effectively gaining deep epistemic insight. Through the multidisciplinary setting, students can appreciate the diversity of viewpoints. The epistemological issues were discussed with the underlying presence of what we call the nature-knowledge-values framework. All these readings and reflections in the presented framework help the students not just to be aware of the possibilities of different views related to science, which we call the first level of epistemic insight, but to understand and reflect on the origin, the inter-relationship, the complexity and the limitations of these views, which we call the second level of epistemic insight.

Evaluation results of the General Education Foundation Programme were presented. The evaluation results showed that the programme was, in general, well received by the students. It further revealed that students' self-efficacy in their epistemic insight related learning outcomes have had significant gain. The practical aspects of scientific literacy, such as their interests in science, their confidence in reading and communicating in issues related to science have also improved. We intend to have a more tailored and controlled evaluation to better understand and improve upon such a classics reading approach. It is expected that our study can be a first step towards wider use of this approach for nurturing epistemic insight in the higher education context.

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Chapter 5
Opportunistic Science Teaching and Learning ‘Outside’ the Classroom

Miguel Ison and Sharon Bramwell-Lalor

Abstract Science is often perceived to be conducted mainly in laboratories by scientists bearing stereotypical features. This is perpetuated in schools when science practicals are conducted in laboratory settings, using ritualized procedures requiring specialized and expensive equipment and for which the relevance of activities is not established. Using the lens of opportunistic teaching, this chapter highlights the experiences of pre-service science teachers and individuals who participated in practical activities, at a Research Days event held at a Jamaican tertiary institution. Visitors to the booths made and used coin batteries and ‘invisible’ ink. This multi-method study aimed at determining whether interacting with the activities impacted visitors’ chemistry knowledge, perceptions of science and understanding of science teaching. Survey findings from 101 student visitors revealed that after participating, over 60% of the responses to knowledge items were correct. Over 80% indicated that their impressions of science had changed and 90% reported a more favourable impression of science. These results suggest that engaging in authentic practicals ‘outside’ of the classroom had a positive impact on the participants’ knowledge and perception of science. The pre-service teachers learned that opportunistic teaching experiences engage learners and that effective science teaching may require improvisation. The findings imply that science teachers should provide more activities that relate to students’ experiences. This will likely contribute to their retention of information and heightened positive attitudes towards science. The authors recommend opportunistic learning as an instructional strategy that science teachers should use to promote student engagement and learning.

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Introduction

> The worst science teachers make no attempt at all to embellish the curriculum by taking their students out of the classroom […] and they make minimum effort to run practical classes. Indeed, their sole aim appears to be to cover the curriculum so that their students will achieve the highest grades possible in examinations, even by abandoning many of the practical classes if that should prove necessary.
>
> Dr. Brian Iddon MP, January 16, 2008

Practical work is endemic and indispensable to science teaching and learning and so its place is not debatable. It assists in developing manipulative skills, understanding science concepts and the process of scientific investigation (Woodley, 2009). In many Caribbean territories, science students are required to sit an external examination administered by the Caribbean Examinations Council (CXC). CXC stipulates that students' competency be assessed through theoretical *and* practical components. According to the CXC science curriculum guides, the hands-on activities aim to help students see the relevance of science to everyday life. The compulsory experimental component involving laboratory and/or fieldwork is a part of the School-Based Assessment (SBA). To facilitate the SBA, the CXC science syllabuses list materials and chemicals that schools *must* have to effectively deliver practical experiences. Additionally, the syllabuses prescribe a minimum number of practical activities and topic areas from which the tasks must be drawn. However, there have been many challenges in carrying out practical work universally and particularly, in the Caribbean context.

Although the CXC science curriculum guide opines that the aim of hands-on activities is to help students see the relevance of science to everyday life, this objective is often not fulfilled due to several systemic challenges in conducting practical work. There is a prevailing perception among science teachers that practical work must be confined to laboratory settings, requires specific equipment and ritualistic procedures must be followed (Osborne, 2015). Additionally, science teachers who have such perceptions, in turn, continue to practice it. Furthermore, in developing states with small economies, the acquisition of even basic specialized equipment, chemicals and facilities are sometimes hampered by prohibitive cost (Ogunkola, 2012). Additionally, because 'laboratory work' is a requirement for the high-stakes CXC exams, it is sometimes carried out in 'ritualized' ways to produce inert knowledge for the sake of passing examinations (SCORE, 2009). This problem is exacerbated by the exam-driven, results-focused culture in many Caribbean islands and other parts of the world (Stewart, 2015). Hence, if a science laboratory is not adequately equipped with resources, then very little hands-on activity may be carried out and science teachers may resort to duplicating notes from textbooks and implementing recipe-styled practical tasks that have been handed down from teacher to teacher over many years. This recipe-like approach is sometimes experienced by students as being boring, irrelevant and reduces their interest and engagement in science (Maharaj-Sharma, 2013; Shin et al., 2015). This decline in students' interest in science aligns with that reported by Osborne, Simon and Collins (2003).

One of the proposals for improving the quality of the science experience in the Caribbean classrooms is '…revolutionizing the methods of teaching…to make science fun and develop innovative hands-on approaches that stimulate curiosity without the use of textbooks' (Caribbean, Council for Science and Technology [CCST], 2007, p. 8). Hence, there is a justifiable reason for science teachers to explore opportunities for teaching and learning which may include contexts outside of those prescribed by the formal curriculum.

Practical work in science teaching then must be examined with new lenses with a view to constantly and intentionally finding ways of presenting it to ensure applicability to everyday life. The new lens through which practical work will be viewed is related to the perspective of informal science education that refers to the setting or programme structure used for learning Rennie (2014). In this chapter, we are proposing that practical work be viewed through the lens of opportunistic teaching. We define opportunistic teaching 'outside' the classroom as being conducted in settings outside of the classroom and its prescriptive curriculum and/or using materials that are a part of learners' everyday life.

This lens provides two perspectives for science teaching and learning. The first proposes that teachers look for 'ready-made' events that provide an avenue for science learning. These include science competitions, exhibitions and fairs, visits to science museums or centres and field trips. The second posits designing practical opportunities utilizing materials that are readily available in the learning environment—authentic learning tasks. Expensive, unavailable and specialized resources should not be a deterrent to science teaching and learning as it sometimes can be in many Caribbean secondary schools (Grades 7–11, aged 11/12–16/17) but should present opportunities for teacher's improvisation that is intentional.

This chapter describes an example of opportunistic teaching at an academic exposition (Research Days event) at a Jamaican tertiary-level institution held over a period of three days. Informal contexts such as Research Days events are useful in engaging both specialists and non-specialists with scientific content for a concentrated, short time (Bultitude, 2014) and helping students gain an appreciation for the processes of science (McComas, 2011). This preliminary and exploratory study sought to answer the following questions:

(i) What was the impact of participating in science practical activities on Research Days visitors' understanding of selected chemistry concepts and perceptions of science?
(ii) What understanding about the teaching of science (opportunistic teaching) was gained by the pre-service teachers' who facilitated the Research days activities?

Science Teaching and Learning Opportunities 'Outside' the Classrooms

Science learning outside the classroom or informal science learning experiences are designed to be engaging, enjoyable and personally relevant and are widely believed to foster scientific interest, scientific literacy and increased scientific knowledge (National Research Council [NRC], 2009). However, McComas (2006) cautioned that teachers might have to play an even stronger role to mediate students' learning and check for understanding in informal settings. If this is not done misconceptions can be constructed in the minds of the students. Fenichel and Schweingruber (2010) proposed four critical elements to maximize the benefits of learning in informal contexts. These elements are advance preparation, active participation by students, teacher involvement and reinforcement after the activity. These elements, if emphasized, could also provide a link between informal and formal learning in a prescribed curriculum. McComas suggested that teachers should not abandon formal science teaching and learning but should strive for a blend between formal and informal learning opportunities.

The National Research Council (2009) proposed a framework with six 'strands' of informal science learning that helps to formalize the type of outcomes that informal learning environments can support. The framework outlines the goal of informal science learning experiences:

(a) developing interest in science,
(b) understanding science knowledge,
(c) engaging in scientific reasoning,
(d) reflecting on science,
(e) engaging in science practice and
(f) identifying with the scientific enterprise.

Fenichel and Schweingruber (2010) identified 'interactivity' as an important strategy for supporting informal learning across the six NRC (2009) strands. They further explained that interacting directly with materials appears to have particular value. According to Fenichel and Schweingruber 'powerful learning takes place when an individual is able to find out for him- or herself that by correctly connecting wires to a battery, the bulb will light up…' (p. 40).

Most studies on informal learning focus on the affective dimension of learning (NRC, 2009—Strand 1). For example, research shows that informal science education increases students' interest, confidence, enthusiasm for learning science, attitude towards science and engagement in science (Krapp & Prenzel, 2011; Rennie & McClafferty, 1995; Tran, 2011). Furthermore, studies of informal science education impacts, also show that interest and enthusiasm are related to learning (Jolly, Campbell, & Perlman, 2004; Renninger, Hidi, & Krapp, 2014). There appears to be a paucity of studies on science students' knowledge gains from informal science education experiences (McMeeking, Weinberg, Boyd, & Balgopal, 2016) and the findings generally show limited knowledge gains (Campbell et al., 1998; Johnson, 2005). However, studies of students' self-reported learning are typically more positive (Falk, Moussouri, & Coulson, 1998; Korn, 2006).

Methodology

In accordance with the definition given by the editors of the Journal of Mixed Methods Research this research used a multi-method design (Fetters & Molina-Azorin, 2017), to explore science teaching and learning in a Research Days event held over three days at a tertiary institution in Jamaica. The authors are teacher educators involved in the preparation of science teachers for secondary schools. Final year pre-service science teachers assisted in preparing and troubleshooting the practical activities before the event, setting up the booths on the selected days, and interacting with the visitors by demonstrating the activities and inviting them to participate. The activities included: (i) making and using coin batteries and (ii) writing using 'invisible' ink. Both activities predominantly utilized everyday household, materials and chemicals.

The 'invisible' ink activity was based on principles of acid-base chemistry. Visitors to the booths wrote messages or drew simple images on paper using cotton swabs dipped in an ink mixture containing vinegar and phenolphthalein solution. Then, the paper was sprayed with a baking soda solution (alkaline) to reveal the message or image in a pink font/type-face. The messages/drawings were then erased by using cotton swabs soaked in ethanoic acid.

The 'coin battery' activity was based on the principles of oxidation-reduction (redox) reactions at work in the operation of wet cells (voltaic cells). Each cell was made from a circular piece of paper (paper towel or filter paper) soaked in a concentrated sodium chloride solution and sandwiched between a copper coin and a metallic zinc washer (disc). This was repeated to create four and five cell batteries. The battery was then used to power LED bulbs and a scientific calculator.

After participating in the activities, visitors who consented filled out a researcher-designed questionnaire. The instrument had a demographics section and ten items (5 Likert-type, 5 fixed choice—see Appendix), to ascertain the visitors' chemistry content knowledge of selected chemistry concepts, attitudes towards science practicals and their perceptions of science. Over the three days, 101 high school students (Grades 7–9, aged 11–14) completed the survey. In addition, semi-structured interviews were conducted with two adult visitors (Sandra and Ms Smith, psuedonyms) to elicit their views about the two activities.

To determine the understandings about the teaching of science gained by the pre-service teachers who facilitated the activities, a focus group interview was conducted with four female pre-service science teachers. The teachers were Racquel, Samantha, Tamara and Nadia (pseudonyms, aged 23–25). They were in their final year of the teacher preparation programme.

The data from the survey were analyzed using descriptive statistics (frequency, percentages) while the focus group interview data were audio-recorded, manually transcribed and verified by each researcher to ensure the accuracy of the transcription. The transcript was read and re-read to identify recurring words, phrases or issues as well as outliers, and noticeable absences. Theoretical and thematic memoing were done and initial codes were assigned. The initial codes were reviewed and converged into categories and themes and then analyzed using the six-strand framework of the NRC (2009) and the four elements proposed by Fenichel and Schweingruber (2010).

Results and Discussion

Research Question One

What was the impact of participating in science practical activities on Research Days visitors' understanding of selected chemistry concepts and perceptions of science?

From the 101 high school students surveyed, 58% of the responses to the chemistry knowledge items were correct. This result is encouraging in that student visitors were carrying out 'impromptu' practical activities in a five-minute time span involving concepts that they might not have been exposed to previously. These knowledge gains are consistent with the findings by Campbell et al. (1998) and Johnson (2005) for correctional studies. Additionally, Sandra, a tertiary level economics student who studied chemistry in High School up to Grade eleven (aged 16), visited the booth and did the activities. After she completed them and listened to the explanations by the pre-service teachers, she spontaneously started explaining the demonstrations to other visitors. When asked by Author 1 why she did this, she responded: 'I began to help with the demonstrations because I felt as if I learned something … sharing is a way to confirm learning' (Sandra, personal communication, February 2, 2017). While Sandra's content knowledge was not measured, her optimistic reporting on the acquired learning and her initiative and ability to competently teach other visitors provide evidence of this learning. This finding is consistent with research by Korn (2006) who found that student self-report about their learning in informal settings were usually positive. Moreover, this implies that informal learning can foster interest in science and increase competency, beliefs and desire to participate in science (Simpkins, Davis-Kean & Eccles, 2006). With respect to the perceptions of science, 95% of the 101 student visitors indicated that science was not boring, 90% of them had a more favourable impression of science and 98% of the students reported that they will likely try the activities at home. Ms. Smith an experienced high school science teacher visited the booth with her students. After watching the demonstrations, she said, 'I am going to try these experiments at school' (Ms. Smith, personal communication, February 2, 2017). When she was asked why, she responded, '…they are hands-on and make use of everyday, simple, easily accessible materials… My students loved it'. Ms. Smith's response showed that she had gained an understanding of how she could do practical activities in interesting and engaging ways. Ms. Smith further explained, ‘I liked the fact that you do not need expensive materials seen in textbooks to explain science concepts…the activities encouraged me to do practical work’.

These results suggest that the use of real-life investigations had a positive impact on participants’ knowledge and attitudes and their perceptions of science. These results are consistent with the finding of Renninger, Hidi and Krapp (2014) who showed that informal learning experiences positively impact affective engagement.

Research Question Two

What were the pre-service teachers’ understanding of science teaching from facilitating the practical activities in an informal setting?

The findings suggest that opportunistic teaching arouses learners’ interest in science and requires the teacher to be creative. The pre-service teachers had mixed expectations about opportunistic teaching. The excerpts below, taken from the interviews, with pre-service teachers who assisted with the preparation and presentation of the practical activities provide insights into how their responses related to the lens of opportunistic teaching.

> I feel that they [the students] were really excited about it [the experiments], they were like, “gee you using coins to generate power – like oh my god!” … when the students… realised that they could use objects and articles that were familiar to them … it piqued their interest more in that they want to learn more …(Racquel, interview, May 8, 2018).
>
> **The students loved it** [emphasis added] – they came and they wrote and they drew the heart and they were like, “come, come look”… that is the good thing about science – it pulls your attention and it will keep you engaged once it’s a hands-on experience. (Samantha, interview, May 8, 2018

Nadia stated, ‘I learned something, that I could actually use simple basic things in my house…’ (interview, May 8, 2018) and then Samantha added, ‘I realised that we don’t have to limit the experiments to what are already in the book … we can use household items to deliver a lesson [science]…’ (Interview, May 8, 2018). This is especially important if you end up working in a school that is not adequately resourced. Then the teacher must be flexible enough to use alternative approaches. According to Racquel such a school context, ‘makes you want to improvise …’ (Interview, May 8, 2018) meaning using other materials that are probably not [readily] available at the school. Tamara seems to agree when she opined, ‘you still have to be creative and think of other ways that you can get them [the students] to understand the different concepts’ (Interview, May 8, 2018). These findings are consistent with that of Jolly, Campbell and Perlman, (2004), who found that informal science education increased students’ interest and participation in science.

The above responses, from Racquel, Samantha and Nadia showed the positive impact of opportunistic teaching on pre-service teacher**s**. Nadia initially appeared to have had reservations about the effectiveness of the two activities. However, in the end, her doubts were assuaged. See the following excerpt:

> …for me it was pretty basic in preparation I never really thought it was something big 'cause it was Research Day and you going up against Medical Sciences … I wondered if these people [are] going to come and really find it interesting and we are in this little corner … **bu**t [emphasis added] then they came over and they were really interested. (Nadia, interview, May 8, 2018)

The above excerpt from Nadia seems to represent a paradigm shift for this young teacher trainee although her peers initially had high positive expectations: 'it was exciting yes… I really wanted to see the outcome and then I'd really want to see the look on the students' faces and the visitors faces when they come into encounter those two… experiments' (Racquel, interview, May 8, 2018).

Informal science education via opportunistic teaching stimulates learners' interest and enhances their participation (Renninger, Hidi, & Krapp, 2014) because they provide authentic learning experiences. These two opportunistic practical activities in this study caused the pre-service teachers to see how science can be implemented when they go into the classroom and they can look at their curricula with new eyes instead of seeing practical work as 'recipe' science. These types of activities are especially important in Grades 7–9 since greater learner enthusiasm for science can be fostered at a younger age. This experience at the university event made the science teacher trainees see that science practical tasks can be presented in new ways to make science learning engaging and so hopefully they can approach teaching with a different mindset. Additionally, the teachers realized that there is inherent value in the use of opportunistic teaching activities for the teacher. Similarly, the qualitative study by Schmidt and Kelter (2017) suggests value in science expositions as a teaching-learning tool for impacting content knowledge.

Conclusion

The importance of practical work in science is widely accepted. However, in developing countries with small economies, the availability of resources to carry out laboratory activities is a constant challenge for science teachers. The findings of this study suggest that the out-of-classroom practical activities utilized in this study had a positive impact on the participants' knowledge, interest and perception of science. Additionally, the four pre-service teachers learned that authentic, relevant and opportunistic teaching-learning experiences that are aligned with student life-experiences engage learners, and that improvisation is a characteristic of effective science teaching. Hence, they must pay attention to learning opportunities wherever they may be found, especially if they are out-of-school opportunities. These findings are in alignment with the first five 'strands' of the NRC (2009) framework for informal science education.

These findings have implications for teacher preparation programmes. These programmes should provide more avenues for pre-service science teachers to interact with their local curricula and infuse opportunistic teaching-learning activities to relevant areas. The findings indicate the importance of mentorship for pre-service teachers in practices that may be counter-cultural. Additionally, pre-service teachers need to become more adept in recognizing occasions for opportunistic teaching.

The findings in this study show promise in providing ideas for how science practical work could be more meaningful in contexts where conventional resources are not always readily available. This study used a post-test survey of participants and so future work may include a pretest-posttest design to increase rigour in order to determine a quantitative measure of the impact of the intervention—science teaching and learning 'outside' classrooms. It was difficult to interpret the knowledge gains in this study because of the heterogeneous nature of the visiting population sampled. However, future studies could include visitor variables such as prior science interest and selected content knowledge. Additionally, future work could examine the influence of learning in informal science contexts on students' science achievement in specific topics in the formal science context.

Appendix

Sample questions from the survey instrument

On what chemical principle was the disappearing ink based?
Redox reactions ☐ Acid-base reactions ☐ Redox and acid-base reactions ☐
I am not sure ☐

Are you likely to try either of these experiments at home?
Yes ☐ ☐ No ☐ Maybe

Science is boring.
Agree ☐ Strongly Agree ☐ Disagree ☐ Strongly Disagree ☐

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Part II
Re-searching Science Learners and Learning

Chapter 6
Scientific Argumentation as an Epistemic Practice: Secondary Students' Critique of Science Research Posters

Yann Shiou Ong, Richard A. Duschl, and Julia D. Plummer

Abstract Scientific argumentation has been an actively researched topic for almost 30 years. Predominant school science argumentation interventions focus on students constructing arguments using a component's template to produce good scientific arguments. In recent years, researchers have called for a shift toward interpreting argumentation as an epistemic practice comprising critique in addition to the construction of scientific claims. This chapter presents a study that looked at argumentation through a different lens—the epistemic practice approach to argumentation—that emphasizes students' critique of others' epistemic products (e.g., a science poster) as the trajectory for developing students' critical stance in argumentation. The study took place in a Singapore secondary school's inquiry course. Student-teacher discourse during a science research poster critique activity is examined between groups in two learning environments: student-centered critique (Class A) versus teacher-centered critique (Class B). Prior to the poster critique activity, Class A students experienced student-centered critique instruction and practiced critiquing literature using scientific soundness criteria (SSC). Class B students experienced teacher-centered critique instruction whereby the teacher proposed ideas for students' inquiry project, students reviewed literature by summarizing, and the teacher critiqued students' review. Findings on groups' productive disciplinary engagement in critique and construction (PDE-CC) practices and incorporation of PDE-CC guiding principles—problematizing, resources, disciplinary accountability, and epistemic authority—suggest the alternative approach of developing students' critical stance via engagement in critique practices using critique criteria is a promising approach to improve critique practices in the science classroom.

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Introduction

In the era of "fake news" and "alternative facts", it is pertinent for citizens to take an appropriately critical stance when making sense of claims and arguments that impact decisions ranging from personal to social, to national, and international levels. When presented with a claim, a person who takes a critical stance toward the claim would consider how and why it might not be credible or sound. Engaging students in scientific argumentation has been argued to support students' critical thinking by developing their reasoning and epistemic criteria for evaluating knowledge claims (Jiménez-Aleixandre & Erduran, 2007). While there is a general consensus among science educators that scientific argumentation is an essential part of science education, promoting a critical stance in science classrooms that value scientific argumentation remains a challenge (Henderson, McNeill, González-Howard, Close, & Evans, 2018).

A current issue with existing scientific argumentation research is the lack of framing scientific argumentation as an epistemic practice. Interventions typically provide students with tools for argument construction but pay little attention to the context which motivates the practice (Manz, 2015). Furthermore, although science education researchers acknowledge scientific argumentation comprising of both critique and construction practices, existing school science argumentation interventions overemphasize argument construction with insufficient attention on critique (Ford, 2008; Henderson, MacPherson, Osborne, & Wild, 2015). The study reported in this chapter addresses this gap by examining critique practices in a Singapore secondary school's inquiry course. Student–teacher discourse during a science research poster critique activity at the secondary two level is examined between groups in two learning environments: student-centered critique (intervention Class A) versus teacher-centered critique (comparison Class B). The study research questions (RQs) are: (RQ1) To what extents do groups demonstrate productive disciplinary engagement in critique and construction of claims? and (RQ2) To what extents are the guiding principles for fostering PDE-CC—*problematizing*, *resources*, *disciplinary accountability*, and *epistemic authority*—incorporated in the critique activity?

The chapter begins by reframing scientific argumentation through the lens of an epistemic practice. We introduce the productive disciplinary engagement in critique and construction of claims (PDE-CC) framework, based upon Engle and Conant's (2002) productive disciplinary engagement (PDE) framework. The PDE-CC formed the study's analytic framework and informed the intervention design in a larger research project (Ong, 2018) which the study draws upon. Next, we describe the study context and participants to situate our study, and outline the data analysis procedures. We then present our findings and discussions. The chapter concludes with implications from findings and suggestions for future research to drive the scientific argumentation research agenda forward.

Reframing Scientific Argumentation as an Epistemic Practice

A review of the classroom argumentation literature reveals researchers predominantly framed scientific argumentation as an epistemic tool use issue (Manz, 2015). Students learn to argue using scientific argument component scaffolds, such as the Toulmin Argument Pattern (TAP) (Osborne, Erduran, & Simon, 2004) or the Claims-Evidence-Reasoning (CER) framework (McNeill, Lizotte, Krajcik, & Marx, 2006). Studies evaluating students' argumentation skills based on the components in their arguments have identified students' inadequacies, such as their inability to select appropriate data as evidence (McNeill & Krajcik, 2007), lack of reasoning or considering scientific principles (McNeill et al., 2006), and inadequate rebuttals (Osborne et al., 2004). However, studies that attended to the social context of students' argumentation suggests students' arguments reflected what students considered as relevant components for the context rather than students' lack of argumentation skills (Berland & Hammer, 2012; Kelly et al., 1998). Thus, the research literature suggests a need to reframe scientific argumentation as an epistemic practice which involves epistemic tool use adapted to relevant contexts (Manz, 2015). Considering scientists' epistemic practices, scientific communities' main goal is to build sound scientific knowledge claims to explain natural phenomena (Driver, Asoko, Leach, Scott, & Mortimer, 1994). Science studies literature suggests this goal is achieved via epistemic practices of proposing, communicating, evaluating, and legitimizing knowledge claims (Kelly, 2016). Constructing claims (i.e., proposing and communicating claims) and critiquing or evaluating claims are both essential epistemic practices for knowledge building. Yet, critique is undervalued and rarely present in science classroom discourse (Henderson et al., 2015).

Productive Disciplinary Engagement in Critique and Construction

Findings reported in this chapter came from a larger study (Ong, 2018) aimed at designing an intervention to foster critique and construction practices. To design the intervention and evaluate its effectiveness, Engle and Conant's (2002) productive disciplinary engagement (PDE) framework was interpreted in the context of critique and construction practices, giving rise to the productive disciplinary engagement in critique and construction of claims (PDE-CC) framework. The PDE-CC framework's three dimensions—*engagement*, *disciplinarity*, and *productivity*—articulate what taking a critical stance toward scientific arguments looks like in group discourse. The three dimensions are elaborated as follows: *Engagement* concerns how and to what extent participants interact with others' ideas when critiquing or constructing claims. Synthesizing Walton's (1998) argumentation dialog types and the Interactive, Constructive, Active, and Passive (ICAP) cognitive engagement modes framework

(Chi & Wylie, 2014), the PDE-CC framework distinguishes the following discursive engagement levels. The highest engagement level is critical stance discourse, demonstrated in "critical discussions" where presented challenges are discussed extensively. "Joint idea-building" discourse involves adding and supporting ideas where challenges may be present but not further discussed. "Information-seeking" discourse comprises a series of questions and responses around an idea. The lowest engagement level is "exposition" discourse where one or more ideas develop in parallel.

Taking a critical stance in a *disciplinary* way means participants' critique and construction of scientific arguments resembles how and what scientists critique and construct. Hence, discourse is disciplinary if the discussion topic involves critical epistemic decisions that impact inquiry outcomes (Grandy & Duschl, 2007) and utilizes epistemic criteria valued by scientists, i.e., scientific criteria to support or challenge scientific arguments. Four critical epistemic decisions (EDs) (Grandy & Duschl, 2007) are: (ED1) What data to collect and how to collect them?; (ED2) What data to select as evidence?; (ED3) How to represent and analyze selected data; what models, patterns, or conclusions can be generated?, and (ED4) What is the most scientifically sound explanation for the model/pattern? Scientific criteria include: "justification" (whether a claim is justified), "internal coherence" (i.e., causal mechanism in scientific explanation; coherence among evidence, explanation, research question, and overall argument), "process reliability and validity" (i.e., use of control of variables strategy; whether measurements are valid indicators of variables), and "external source" (referencing sources other than what one knows/thinks). Non-scientific criteria include: "practicality" (whether the idea is feasible or applicable in real life), "agreement with personal experience" (i.e., anecdotal evidence), "communication goodness" (clarity and understandability of argument; appropriate use of scientific representations, e.g., diagrams), and "others" (any other non-scientific criteria).

Since an epistemic goal of scientific communities is to iteratively build sound knowledge claims through peer critique (Longino, 2002), the *productivity* dimension concerns whether group critique/construction leads to improvement of scientific claims or ideas valued by a knowledge building community (Scardamalia & Bereiter, 2003). Group discourse is "highly productive" if it leads to an "improved decision" with stronger justifications using scientific criteria, or a decision that overcomes identified error or problem. Discourse is "moderately productive" if it leads to "identifying an error" or problem in the initial decision/critique, or if the group "addresses the critique" by rebutting challenges or defending the initial decision/critique with non-scientific criteria, so the initial decision/critique holds. Discourse is "minimally productive" if it only leads to "making a decision" or making a critique.

PDE-CC's four guiding principles—*problematizing*, *resources*, *epistemic authority*, and *disciplinary accountability*—functioned as intervention design principles to support students' PDE-CC, as well as analytical principles for explaining the extents to which the three PDE-CC dimensions were observed in students' discourse. *Problematizing* refers to the extent to which the activity or problem taken up by students is genuinely uncertain and meaningful. Intervention critique activities were designed to scaffold students' critique of epistemic products, including the science research poster critique activity reported in this chapter. Such critique activities form the contexts for scientists' important epistemic practice. *Resources* refer to physical, technological, or conceptual tools that support students' critique. In the intervention class, three scientific soundness criteria (SSCs) relevant to reliability and validity in scientific inquiry were co-developed with the students as an epistemic tool to guide critique. The SSCs are: (1) use of accurate and reproducible data to answer research question, (2) conclusion is based on good data interpretation and inference, and (3) consideration of scientific concepts and methods accepted and used by recognized experts. *Epistemic authority* refers to shared epistemic authority among students and teachers to challenge ideas, resolve problems, and make epistemic decisions. Intervention critique activities were designed for shared epistemic authority among students and teachers to critique students' epistemic products. Finally, *disciplinary accountability* refers to holding students' ideas accountable to scientific criteria, i.e., challenging students' ideas and critiques based on scientific criteria. The intervention utilizes SSCs as an epistemic tool for students and teachers to hold ideas accountable to scientific criteria. The intervention's approach of holding students' ideas accountable to the discipline from the start follows Forman and Ford's (2014) conjecture that critique practices first occur on the interpersonal plane then the intrapersonal plane. That is, students, learn to critique peers' arguments before becoming better at critiquing their own arguments.

Research Methods

Detailed description of the study context and illustration of the analyses are reported elsewhere (Ong, 2018; Ong, Duschl, & Plummer, 2018). In the interest of space, details of the study context and participants, as well as the data analysis, are described in this chapter to the extent necessary for interpreting the findings.

Study Context and Participants

The larger research study spanned three school semesters in a highly selective Singapore public school that admits top performers in the national examination conducted at the end of primary school education (i.e., end of sixth grade). Students enrolled in the school are typically high achievers in math and science. The school offers an inquiry course for all secondary two/three (eighth/ninth grade) students. Two science classes, the intervention (Class A) and a comparative class (Class B) participated in the research study. Class A comprises Mr. Gan and groups A1 and A2. Class B comprises Ms. Lee and groups B1 and B2. All names are pseudonyms. The first author acted as a co-teacher, moving between both classes to facilitate the lessons and group discussions when the teacher was absent or when students requested assistance. Both teacher participants are physics teachers with prior experiences mentoring middle and high school students in science research and conducting physics research as undergraduates. Mr. Gan had longer teaching experience (seven years) while Ms. Lee (three years' teaching experience) had more extensive research mentoring experience as she had also mentored undergraduate students.

Each class met once a week for 1.5 h over 34 weeks. In semester one, student groups conducted a literature review and planned investigations relevant to their selected scientific inquiry project. Groups carried out their inquiry over semesters two and three. The intervention took place from lessons five to ten in semester one. Prior to the poster critique activity (lessons five to seven), Class A students—together with the researcher and Mr. Gan—co-developed the three scientific soundness criteria (SSC) and practiced using the SSCs to critique scientific literature (e.g., journal articles). In Class B, Ms. Lee introduced a good model of scientific inquiry research (in the form of a high-quality, student-produced scientific research presentation) and suggested relevant scientific concepts and research ideas for groups' consideration. Class B students reviewed literature (e.g., journal articles related to their inquiry project) by summarizing. Overall, Class A instruction can be described as student-centered critique instruction while Class B instruction can be described as teacher-centered critique instruction.

The science research poster critique activity required groups to select and critique one science research poster using a review handout. The posters were produced by students in the previous inquiry course cohort. Students were encouraged to select a physics-related poster or one that is relevant to their own inquiry project. Class A's poster review handout instructed students to "[e]valuate the scientific soundness of the poster using the scientific soundness criteria. Include the critical questions you used and the corresponding responses from the poster/presenter to support your evaluation". Class B's handout instructed students to "[e]valuate the poster. Say what is good about the poster and the research reported, and what is not so good about it". Class B's instruction was worded to convey the idea of evaluating the reported research, not just the poster design. Class B's instructions thus matched Class A's instruction without using the term "scientific soundness", which was unfamiliar to Class B students.

Data Analysis

To answer the research questions, event maps (Kelly, Brown, & Crawford, 2000) were created from reviewing the video recordings during the scientific poster critique activity in both classes to provide an overview of main classroom activities within the lesson. An event map is a tool that demarcates phases comprising thematic activities of students and teachers. A phase unit comprises concerted and coordinated thematic talk and action among participants; that is, a common focus for a segment of group exchanges (Kelly et al., 2000). Examples of phase units during Class A's poster critique activity include: (1) teacher gives instructions for poster critique activity and provides electronic copies of scientific posters to groups, (2) groups look through

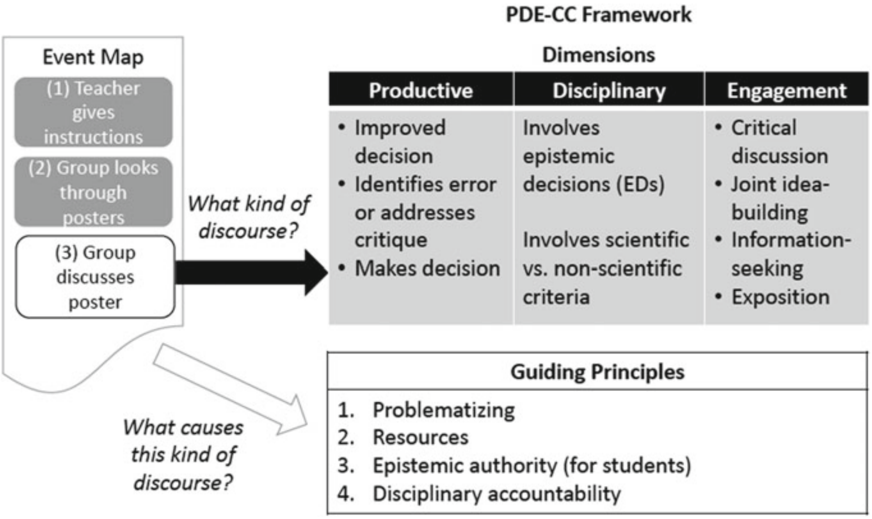

Fig. 6.1 PDE-CC as an analytic framework

posters, followed by (3) groups critique selected posters and fill in the electronic copy of a poster review handout. Phase units relevant to students' engagement in poster critique were identified and transcribed. Groups' poster review handouts were examined to clarify discussions.

To answer RQ1, each group's discourse transcript was analyzed for the levels of engagement patterns, disciplinarity extent, and productivity extent described in the PDE-CC framework section. To answer RQ2, evidence of incorporating each PDE-CC principle throughout the poster critique activity was sought: 1. *Problematizing*—Did students see poster as an epistemic product for critique and are the critiques meaningful? 2. *Resources*—What resources are provided to help students with critique? 3. Epistemic *authority*—Who challenges the initial critiques presented? and 4. *Disciplinary Accountability*—Are students' initial critiques held accountable to scientific criteria? Figure 6.1 provides an overview of using the PDE-CC framework, comprising three dimensions and four guiding principles, for analysis.

Findings and Discussion

For the purpose of this chapter, findings from A1 (comprising students Charles, Sue, and Xander) and B1 (comprising students Ariel, Norman, and Varun)'s poster critique activity are presented for PDE-CC comparison as both groups reviewed the same hovercraft poster. Both A1 and B1 demonstrated higher PDE-CC extents within their class. PDE-CC extents of the other two groups, A2 (students Jane, Kang, and Victoria) and B2 (students Audrey, Debbie, and Livie) are summarized. This is followed by a discussion on how PDE-CC guiding principles were incorporated during the critique activity, which could account for the different PDE-CC extents observed.

PDE-CC Extents Between Classes

In terms of *engagement*, groups A1 and B1 each demonstrated one instance of student-led "critical discussion" as their highest engagement level. A1's 'critical discussion' occurred as students disagreed over the problem with the poster. Sue opined the reported hovercraft inquiry "doesn't exactly answer the research question". Xander disagreed with Sue's characterization of the problem and instead framed it as a "reliability issue". Sue and Charles went on to persuade Xander the research question was not answered because the poster only reported the effect of a single position of the propellers on hovercraft speed. There was no comparison with other "examples", such as other positions or different numbers of fans (i.e., propellers). The propellers' position was not varied in the way experiments testing a variable ought to when investigating the variable's effect. A1's "critical discussion" occurred over 19 speaker turns. In comparison, B1's "critical discussion" occurred only over eight speaker turns. It started with B1 members trying to make sense of the hovercraft design, which led to Norman's critique: the poster did not explain how the hovercraft was created. Varun challenged Norman's critique, claiming the hovercraft was as described in the poster and did not require construction. Ariel pointed out the poster described cardboard with holes, implying cardboard with holes were not hovercrafts. Varun then corrected himself, stating nozzles were fitted in the cardboard to construct the hovercraft. Norman challenged the existence of nozzles. Varun and Ariel added details about the nozzles, which implies the poster did explain to some extent how the hovercraft was created, thus countering Norman's initial critique. The episode concluded with Norman stating, "the methodology could be clearer".

For *disciplinarity*, A1's main critiques focused on ED1: What data to collect and how to collect them. During their "critical discussion", A1 was concerned over the problem with the hovercraft poster's research design: whether it did not answer the research question or had a reliability issue. A1's other critiques involved the poster's lack of details around the data collection method, such as the poster did not specify the type of hovercraft used, precise propeller positions, and fan speed (a fan is used to move the hovercraft). A1's critiques utilized scientific criteria, including "justification" and "reliability and validity of processes". For B1, in addition to critique around ED1 exemplified in their "critical discussion" as described, discussions around other posters (while selecting one to review) focused on how well information was communicated and the appeal of the poster design. For instance, B1 students commented on whether a poster was "readable" with "no overly scientific words", whether pictures and diagrams were used and occupied an appropriate amount of space, and whether poster design was engaging. Overall, B1's critiques utilized a mix of scientific (referencing poster as "external source" of information to challenge Norman's claim during their "critical discussion") and non-scientific criteria ("communication goodness" and "others-aesthetics").

As for *productivity*, both groups' "critical discussion" were "moderately productive". A1's "critical discussion" led to addressing Xander's challenge to Sue's identification of the poster's research design problem. B1's "critical discussion" led to "identification of errors" in Norman's initial critique that the poster did not describe how the hovercraft was made. For the other two groups, A2 only engaged in "exposition" during their poster critique. Their critique involved their selected poster's lack of control of variables and was disciplinary as it focused on ED1 and involved the "reliability and validity of processes" scientific criterion. However, A2's discourse was "minimally productive" as it only led to the group making a critique. On the other hand, B2's highest engagement level was "information-seeking" over seven turns with their teacher. B2's discourse lacked disciplinarity as their critique focused on the poster's aesthetics and applicability of the research instead of focusing on the EDs. However, Livie did use the "internal consistency" scientific criterion to rebut Ms. Lee's critique by claiming the research design was still logical despite not reaching the intended application outcome (the brief rebuttal with no following discussion did not qualify as "critical discussion" engagement). Based on the student's rebuttal, B2's discourse was "moderately productive" as it led to the identification of an error in the initial critique. Overall, the main difference in PDE-CC between A1 and B1 and across classes lies in *disciplinarity*.

PDE-CC Guiding Principles Incorporation

Groups' PDE-CC demonstrated during the poster critique activity make sense in light of the extents to which PDE-CC guiding principles were incorporated. Evidence of incorporating all four PDE-CC guiding principles was found during A1's scientific poster critique activity. A1 students spontaneously looked for errors in their selected poster (*problematizing*). Sue cued the use of SSCs at the start of their critique activity (*resources*) by asking "what's the three criteria". Throughout the group discussion, Mr. Gan constantly held students' critiques accountable to the scientific criterion of "justification" (*disciplinary accountability*) and positioned students to *share epistemic authority* when critiquing ideas. Mr. Gan pressed Sue to justify her claim by providing specific examples and evidence, and directed students to engage in peer discussions instead of directing their response toward the teacher. Mr. Gan only modeled how to critique by providing his critique after students gave their initial critiques. Additionally, Mr. Gan supported Sue's points of view by evaluating them as "very, very important" and "very, very good points". Mr. Gan's support is important for achieving shared epistemic authority among students in view of previous lessons where Xander dominated critique within the group and among Class A students at times.

As mentioned, A2 achieved a low PDE-CC extent in terms of engagement and productivity. Evidence suggests *problematizing*, *epistemic authority*, and *disciplinary* *accountability* were not incorporated while evidence for *resources* was not observed during A2's critique activity. A2 members frequently engaged in off-task talk instead of the poster critique activity. Much of their off-task talk involved a math test all students had taken prior to the critique activity. However, the test was not mentioned as much in the other groups' discourse. Although students in all the groups had taken the test prior to the critique activity, it is possible the test only affected A2 significantly to distract them but not other groups from their critique activity.

For Class B, the main difference in B1 and B2's PDE-CC extents is B2 achieved a slightly lower engagement level (i.e., information-seeking) than B1. This is likely due to similar extents to which the four PDE-CC guiding principles were incorporated in both groups' poster critique activity. *Problematizing* was not incorporated in B1 and B2's critique activity as both groups initially looked for the best poster and highlighted only positive aspects of their selected posters. Class B students only started searching for errors in their selected posters upon Ms. Lee's request. *Epistemic authority* was not shared among students and teachers. During her interaction with B1, Ms. Lee demonstrated higher *epistemic authority*. After asking B1 why they did not select the other posters and listening to Norman and Ariel's critiques of two unselected posters, Ms. Lee added to Norman's critiques, which was followed by Norman repeating Ms. Lee's critiques. During B1's "critical discussion" as abovementioned, Varun's successful refutation of Norman's critique was met by Ariel's condescending remark asking if Varun thought he was "very smart". This suggests Ariel did not recognize Varun's authority to critique, and epistemic authority was not considered shared among B1 members. For *disciplinary accountability*, Ms. Lee mostly held students' critiques accountable for justifying their ideas and non-scientific criteria. On the other hand, students did hold peers' critiques accountable to scientific criteria, such as during B1's "critical discussion". A possible reason for this observation is that at the start of the poster critique activity, Ms. Lee, introduced a set of non-scientific criteria as a *resource* to help Class B students critique the posters. Criteria introduced by Ms. Lee include: (1) whether the poster is engaging/interesting to the audience and (2) how well the information is communicated. An additional criterion, (3) the poster design mentioned by Ariel was also endorsed by Ms. Lee. Lack of elaboration on what "poster design" meant made the criterion ambiguous. Based on Ariel's reference to "poster design" during B1's critique activity, it could mean design goodness or appeal. Thus, the critique criteria introduced by Ms. Lee as a poster critique resource emphasized the non-scientific "communication goodness" criterion and the poster's emotional or aesthetic appeal to the audience.

Overall, greater extents to which *problematizing*, *epistemic authority*, and *disciplinary accountability* were incorporated in A1's critique activity seem relevant for higher disciplinarity observed in A1 than Class B groups during scientific poster critique activity. *Resources* for poster critique was useful for Class A as SSCs are aligned with scientific criteria but problematic for Class B as non-scientific criteria were introduced by the teacher.

Conclusions and Implications

Findings suggest taking a critical stance toward scientific claims is not natural to students. While teachers held students accountable to justifying ideas, they do not necessarily emphasize epistemic criteria, as in the case for Class B. However, evidence from A1 where students were guided to use scientific soundness criteria suggests such critique resources improved critique practices in the science classroom. Findings from the scientific poster critique activity and previous Class A intervention lessons reported elsewhere (Ong, 2018) suggest the student-centered critique instruction which incorporated all four PDE-CC guiding principles—problematizing, resources, shared epistemic authority, and disciplinary accountability—supported A1's achievement of high group PDE-CC during the poster critique activity. Thus, A1 students demonstrated taking a critical stance as they engaged in critical discussions using scientific criteria. Conversely, B1's less disciplinary discourse is related to inadequate incorporation of PDE-CC guiding principles during their poster critique activity and prior teacher-centered critique instruction Class B students experienced.

The poster critique activity demonstrates an example of argumentation activity focused on the practice of critique rather than tools for construction i.e., critiquing scientific poster instead of how to construct a scientific poster. A1 students were capable of engaging in critical discussions around their critique using scientific criteria valued by scientific communities in a productive way, which corresponds to processes and goals of scientific argumentation. Therefore, findings suggest if the instructional goal is to develop students' critique practices and critical stance, emphasis should be placed on argumentation as a critique practice. Teachers should provide epistemic tools valued by scientific communities for critique (e.g., the SSCs), provide an authentic context for students to practice critiquing (e.g., the poster critique activity), and model critiques for students to emulate (Ford, 2008) without taking over the critic role (compare when Mr. Gan versus Ms. Lee modeled critique).

Research highlighted in this chapter contributes to the growing literature that recognizes the importance of critique practices (Henderson et al., 2015, 2018) and problematizing epistemic decisions around transforming measurements to data, to evidence, and to scientific explanations for natural phenomena (Duschl & Bybee, 2014; McNeill & Berland, 2017) as the way forward for school science argumentation research. As findings reported in this chapter suggest, looking at scientific argumentation through the lens of epistemic practice involving epistemic tool use in relevant context is a promising approach for developing students' productive disciplinary engagement in critique practices.

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Richard Duschl his academic career is defined by collaborations and scholarly interactions with others in science education, learning sciences and science studies. There are 3 themes to his research: (1) How the history and philosophy of science can be applied to science education; (2) How the design of extended curriculum and teaching sequences can promote 'assessment for learning' instructional models, and (3) How argumentation and discourse frameworks help promote instruction-assisted development and science learning. An emerging theme of these scholarly efforts has been the development of teaching science as three-part harmony attending to conceptual, epistemic and social (critique and communication) learning goals.

Julia Plummer spent over a decade teaching children and adults in planetariums and other informal settings and has extensive experience teaching college-level introductory astronomy and science methods for preservice elementary teachers. Her research interests focus on how children and adults engage in scientific practices in the astronomy domain. This includes investigating formal (e.g., classrooms) and informal environments (e.g., planetariums and museums). Julia has also investigated the importance of spatial reasoning in the domain. Her research led to the development of astronomy learning progressions focused on explaining celestial motion phenomena and connecting observations of the current Solar System to its formation model.

Chapter 7

Effects of Concept Mapping Technique on Nigerian Junior Secondary School Students' Cognitive Development and Achievement in Basic Science and Technology (Integrated Science)

Bernadette Ebele Ozoji

Abstract This study investigated the effects of concept mapping technique on Nigerian junior secondary three students' cognitive development and achievement in Basic Science and technology. Randomized pre-test/post-test control group design was employed. Purposive sampling technique was used in selecting three out of 24 junior secondary schools that had comparable facilities in Jos, Plateau State, Nigeria. The participants for the study consisted of 622 junior secondary three students drawn from 889 students with proportionate stratified sampling technique. The participants consisted of an experimental group (n = 311) and a control group (n = 311). The experimental group was taught the concepts of atomic structure, acids, bases and salts; energy conversion and transfer, and heredity with concept mapping technique while the control group was taught the same concepts with the conventional lecture teaching method. Data for this study were collected using a Science Reasoning Tasks II and Basic Science and Technology Concept Achievement Test with reliability indices of 0.72 and 0.80, respectively. The findings of this study showed that concept mapping technique had significant effects on students' cognitive development ($t = 30.23 \geq t = 1.96$) and achievement ($t = 27.84 \geq t = 1.96$) in Basic science and technology. The implication of the study among others is that science and technology teachers should use activity-based instructional strategies, such as; concept mapping technique to enhance the cognitive abilities of students for improved achievement in science and technology. The findings further showed that there were no gender differences between the science reasoning tasks mean scores and basic science and technology achievement mean scores of students taught with the concept mapping technique. It was finally concluded that the concept mapping technique is effective in enhancing students' (both males and females) cognitive development and achievement in basic science and technology.

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Introduction

Science and technology are crucial for national development and emancipation of people of any country. It is the basis for effective living in this modern age and as such, it is essential that an educated person should possess some basic understanding of his/her daily life to function effectively as a citizen. It is in cognizance of this fact that Nigeria places a lot of emphasis on science and technology right from the basic education level.

The Nigerian government, in a bid to lay a solid foundation for science and technology, introduced Basic Science and Technology as a compulsory course at the basic level of education. One of the aims of science and technology education is the understanding of science and technology concepts and principles. This is spelt out in the National Policy on Education (Federal Ministry of Education, 2014) that at the secondary school level, science teaching aims to equip students to live effectively in this modern age of science and technology. In pursuance of this objective, the policy prescribes basic science and technology at the basic level of education and at least one science subject as a core course at the senior secondary school level.

The Federal Government of Nigeria is determined to further promote science and technology education through the establishment of the National Mathematical Centre in Abuja, opening of technical colleges and more universities of technology, building a separate Ministry of Science and Technology in 1985 and launching the first National Policy on Science and Technology Education Policy in 1986. The government also mandated that admissions into tertiary institutions should be in the ratio 60: 40 in favour of science and technology courses. Furthermore, the government has invested heavily in providing laboratory facilities in secondary schools through the STEP B project and provision of micro science kits for the teaching and learning of science subjects.

These efforts by the Federal Government have been laudable and show the determination of the government to see that science and technology instruction is repositioned. However, these efforts do not seem to have yielded the much desired results as evidences from literature support the claim of low achievement outcomes by students in science and technology courses at all levels of education in Nigeria over the years (Jegede, 1996; Onwuakpa & Nweke, 2000; West African Examinations Council, 2010–2016).

The implication of poor achievement by students in science and technology is due to a shortage of personnel in science and technology-related jobs (Amaechi, Obed, Orlu, & Thomas, 2017). This underachievement in science and technology is detrimental for the nation because it could jeopardize its move towards economic, social, political, scientific and technological advancement. Educators and researchers have suggested several factors hindering meaningful learning and high achievement outcomes in science and technology by students. Some of the factors are teachers' inefficiency (Olayiwola, 1999; Oloruntegbe, 2005), use of ineffective and traditional methods of teaching (Ozoji, 2010; Chollom, 2017) and students' personal characteristics (Uguma & Akpama, 2005, Ivowi, 2011; Okoli, 2012) among others.

Cognitive development has been identified as one of the key factors affecting meaningful learning and achievements of students in science and science-related courses (1qbal & Shayer, 2000). Cognitive development has to do with the growth of knowledge and thinking abilities within a child as a result of the child's interaction with the environment. According to Mayer (1987) cognitive development occurs when existing ways of thinking in an individual are modified as a result of interaction with the environment to take care of new experiences. Cognitive development can also be seen as levels of thinking or reasoning abilities of individuals (Ozoji, 2010).

Piaget (1961) sees cognitive development as occurring in stages, namely sensorimotor, pre-operational, concrete and formal-operational stages. The stages, however, differ from one another in their features. At the concrete operational stage (7–11 years) for instance, children think in concrete terms and cannot engage in abstraction, while at the formal operational stage (12 years and above), they can engage in formal thinking, as well as abstraction.

Students at the secondary school level are generally believed to be capable of employing formal operational thinking by virtue of their ages falling within the Piaget's classification of the formal operational stage. However, research findings have shown that most students in this category operate below the formal operational stages of cognitive development (Gyuse, 1990; Cephni, Ozsevgec, & Cerrah, 2004; Ozoji, 2010) both in Nigeria and elsewhere. This may be why students find it difficult to meaningfully learn the concepts and principles outlined in the science and technology curricula, which are abstract in nature, and as such, require the use of formal operations.

Studies by Akinmade (1992), Ncharam (2000), Adejoh (2006) and Chollom (2017) confirm that Nigerian students have difficulty in mastering the science and technology concepts and principles outlined in the national core curriculum for junior secondary schools, such as heredity, balancing of chemical equations, work and energy transfer. This means that students who are mainly concrete operational thinkers are faced with learning situations that require formal operational thinking that they are yet capable of employing. As Martins-Hansen (2002) puts it, the students are not cognitively ready for the types of lessons teachers present to them, and as a result of this, they are not likely to do well in science and technology courses.

Science educators and curriculum planners are therefore faced with the problem of how to enhance students' cognitive development to enable them to learn science and technology courses meaningfully and perform well in the courses. Science and technology as a discipline consist of many abstract concepts that require special approaches, such as concept mapping technique, problem-solving strategy to enhance the reasoning/thinking skills of the learners. There is a compelling need, therefore, to teach students how to think because students' difficulties in learning science have been shown to be on the increase since according to Reif and Larkin (1996) and Chollom (2017) scientific ways of thinking were not adequately taught in schools. Furthermore, Lawson (1985) advocated that schools should not just teach a collection of facts in a discipline but must help students acquire thinking skills because according to him, deficiency in thinking skills is real. In the same vein, Omoifo (2005) emphasized that science education should equip students with sufficient depth and breadth of scientific knowledge and facilitate students' thinking ability.

In an earlier study, Adey and Shayer (1994) recommended that the techniques of teaching specific concepts should be changed and strategies that are capable of challenging students' powers of reasoning should be adopted. They further argued that it is possible to intervene in students' cognitive development with effective science teaching strategies, and in that way, cognitive development could be significantly enhanced.

It is within these contexts that this study investigated the efficacy of concept mapping technique in enhancing junior secondary three students' cognitive development and achievement in basic science in Nigeria. The concept mapping technique is an information-processing teaching and learning technique which involves construction, sequencing and relation of ideas or concepts from the most abstract or most difficult to the most concrete or simplest idea or concept. This strategy is child-centred and activity-based. It is known to involve learners in higher order thinking, science processes and problem-solving skills. Concept mapping technique employs graphical tools known as concept maps to organize and represent knowledge. The maps consist of concepts enclosed in circles or boxes and relationships, between concepts indicated by a connecting line joining two words known as propositions.

Angelo and Cross (1993) indicated that the use of concept maps develop students' abilities to draw inferences from observations, synthesize and integrate information. The use of concept maps also enables students to make meaning out of information, make judgments and develop informed opinions (Njoku & Bewinwarin, 2013). The construction of concept maps helps learners recognize new relationships among concepts as well as refine their understanding of existing ones.

However, the concept mapping technique has been reported by Edozie (2006) to have a major demerit of freedom in selecting linking words by students which according to him may lead to ambiguity. However, he suggested that linking words should be selectively used for more effective instruction in using the concept mapping technique. The concept mapping technique was used in this study because its advantages far outweigh the disadvantages.

Objectives of the Study

This study investigated the effects of concept mapping techniques on Nigerian junior secondary three school students' cognitive development and achievement in basic science and technology. Specifically, this study investigated the cognitive developmental stages/levels and achievement of the junior secondary three (JSS3) students before and after their exposure to concept mapping technique, the effects of concept mapping technique on the cognitive development and achievement of students (male and female) exposed to it in basic science and technology.

Research Questions

This study was guided by the following research questions

1. What are the stages/levels of cognitive development of JSS3 students before and after their exposure to concept mapping techniques?
2. What are the achievement levels of JSS3 students before and after their exposure to concept mapping techniques?

Hypotheses

The following hypotheses were tested for significance at 0.05 level:

1. There is no significant mean difference between the post-test Science Reasoning Tasks II (SRTs II) scores of the experimental and control groups.
2. There is no significant mean difference between the post-test Basic Science Concept Achievement Test (BSCAT) scores of the experimental and control groups.
3. There is no significant mean difference between the post-test Science Reasoning Tasks II (SRTs II) scores of male and female students taught using concept mapping technique.
4. There is no significant mean difference between the post-test Basic Science Concept Achievement Test (BSCAT) scores of male and female students taught using concept mapping technique.

Theoretical Underpinnings

This study hinged on the theories of Ausubel (1963), Piaget (1961) and Gagné (1968). Ausubel's theory focuses on meaningful verbal learning and the use of advance organizers in teaching. The theory emphasizes the use of prior knowledge in teaching and learning. One assumption is that meaningful learning occurs when new information is related to an existing relevant knowledge known as subsumers in the cognitive structure of the learner. According to Ausubel, when relevant subsumers are not available in the cognitive structure of the learner, the new information is learnt by rote. Ausubel, therefore suggests the use of advance organizers for providing anchorage in the cognitive structure of the learner where subsumers are not available.

The instructional strategy of concept mapping used in the study was anchored on Ausubel's (1963) theory, in that, the concept maps were designed to find out what the learners knew about the science concepts selected for the study. Concept maps were also used as advance organizers where there was no prior knowledge by students to act as a cognitive bridge in their cognitive structure for the incoming new information. The process of constructing concept maps exposed the learners to scientific thinking and process-skills of classifying, organizing, sequencing, identifying vertical and horizontal relationships among science and technology concepts. These features of concept mapping are all in line with Ausubel's theory of meaningful learning.

Piaget (1961) in his theory of cognitive development outlined a sequence in the development of the child's scientific and logical thought. The sequence shows how children at various levels of thought or cognitive development cope with scientific and logical thought. The position held by Piaget is that cognitive growth occurs in stages which have precise age limits attached to them, namely sensorimotor stage (0–2 years), pre-operational stage (2–7 years), concrete operational stage (7–11 years), and formal operational stage (11–16 years).

According to Piaget's theory, in any teaching/learning situation, any information that is at variance with the learners' given schema or knowledge structure is not assimilated, in that, it will not result in cognitive growth. Cognitive growth occurs when incoming information is slightly more complex than the existing knowledge in the learner. I acknowledge that the Piagetian stage theory has received considerable criticisms in the fields of cognitive science and psychology. For instance, it has been argued that the theory does not help researchers in determining the adequacy of the methodology or enables researchers to easily or precisely replicate the study. Despite the limitations of the Piagetian stage theory, it was considered appropriate for this study, specifically to science and technology instruction, as the curricula of these courses matched the child's level of cognitive development for meaningful learning to take place. In the current study, children were taught Basic Science and Technology concepts deemed to be developmentally appropriate at the respective grade levels. The theory suggests that science and technology teachers should identify the stage/level of cognitive development children are operating in on individual basis. By so doing, teachers would be able to identify the reasoning patterns/thinking levels of the children and what instructional techniques to be used in order to enhance their intellectual ability for improved performance in science and science-related courses. In this study, the concept mapping technique employed was identified as the developmentally appropriate technique for teaching children Basic Science and Technology concepts.

Gagné (1965) proposed a learning hierarchy that comprises eight types of learning. They are signal learning or classical conditioning, stimulus-response learning, chain skill learning, verbal association, multiple discrimination, concept learning, principle learning and problem-solving. He postulated that learning is best achieved when we move from mastery of the smallest conceptual units to the more general and more inclusive. Gagné (1965) suggested that concept acquisition takes place in an orderly, sequential, integrative and hierarchical manner. One of the implications of Gagné's hierarchy of learning is that the teaching and learning of basic science and technology concepts should proceed from simpler concepts to more difficult concepts. This means that, in planning basic science and technology schemes and lessons, the teacher should be flexible in deciding what concept(s) to teach before the other(s) for meaningful learning to take place. In line with that, the selected concepts for this present study were arranged and taught in their order of increasing difficulty as follows: heredity, atomic structure, acids, bases and salts, energy conversion and transfer. Efforts were also made by the teachers before teaching any concept to ascertain the prior knowledge students had, and, then used them as prerequisites for new learning.

Another implication of Gagné's hierarchy of learning is on the orderly, sequential, integrative and hierarchical organization of learning experiences in basic science and technology. The concept mapping strategy used in this study embraced these important features. This hierarchy of learning also implies that basic science and technology teachers should engage students in problem-solving activities. This is in line with the objectives of the basic science and technology course which is activity-based and inquiry-oriented.

Significance of Study

This study is significant in the sense that, it could improve students' cognitive abilities and understanding of science and science-related courses, most of which are known to be abstract in nature (Ncharam, 2000), and as such, require the use of formal operations. Moreover, findings from studies show that most secondary school students do not use formal operational thought (Gyuse, 1996; Ozoji, 2010; Chollom, 2017). The enhancement of cognitive development through the use of concept mapping technique is possible because, during concept mapping, students are engaged in critical, reflective thinking, construction of ideas, organizing, sequencing and drawing of vertical and horizontal relationships among concepts. These processes are capable of improving their problem-solving skills and strategies, as they engage in mental activity and scientific reasoning.

Science and technology teachers would benefit from the outcome of the study because it would provide them with information necessary to understand specific developmental stages and reasoning patterns of the students they teach and how to design instruction to benefit them. Teachers could on their own identify the cognitive developmental stages/levels of their students by means of science reasoning tasks and employ effective instructional techniques in science and technology classrooms. The findings of the study would provide curriculum developers with information which could be used for the revision of the existing basic science and technology curricula for junior secondary school students in Nigeria and other countries. The study would reveal areas of students' needs and individual differences which might require policy and planning adjustments in the cognitive and affective domains which have to do with students' cognitive development.

This study is in line with the objective of the Nigerian National Policy on Education (Federal Republic of Nigeria, 2014) which prescribes that school curriculum should cater for individual differences of learners. Taking into account the different cognitive developmental stages of students during instruction is a step in the right direction towards the realization of the objective.

Research Design

This study adopted the pre-test/post-test control group design. The aim of the design was to compare the gain in scores of the experimental and control groups.

Participants

The population for the study consisted of 26,303 junior secondary three students distributed among 272 public junior secondary schools in Plateau State, Nigeria. Out of this number, 5767 students were selected from 24 schools that had comparable facilities in three senatorial districts of Plateau State. The actual participants for this study comprised 622 junior secondary three students (365 boys and 257 girls) selected from 889 students in three out of the identified 24 public schools (n = 5767 students). The schools were selected using the purposive sampling technique while the participants were selected and assigned to an experimental group (n = 311) and a control group (n = 311) with an appropriate sampling fraction, using a proportionate stratified sampling technique. The participants were stratified according to cognitive developmental stages and achievement levels using Science Reasoning Tasks 11 and Basic Science and Technology Concepts Achievement Test, respectively, as described in the section on instruments for data collection.

Instruments for Data Collection

Science Reasoning Tasks II (SRTs II) designed by Piaget and Inhelder (1974) was employed to measure the cognitive development of JSS3 students while a teacher-made test, namely Basic Science and Technology Concepts Achievement Test was used to measure students' achievement in basic science and Technology.

Science Reasoning Tasks 1, 11, 111 are groups of tests which investigate the relationships between Piaget's level of cognitive development at which children can function and the understanding of science they can achieve. The tasks comprise several sub-tasks which vary according to the stage of cognitive development they assess. According to Shayer as cited by Bomide (1986) the tasks make it possible for students to be classified on a 6-point scale ranging from preoperational to late formal operational thinking level/stage. The levels/stages are classified as follows:

1	Preoperational level
2	A Early concrete operational level
2	A/2B Mid concrete operational level
2B	Late concrete operational level
2B/3A	Transition level

3A Early formal operational level
3B Late formal operational level

Science Reasoning Task 11 (SRTs 11) used in this study was based on the work of Piaget and Inhelder (1974). The tasks bordered on the concepts of volume and heaviness and covered the period from late preoperational level to early formal operational level. According to Piaget and Inhelder, the STRs are used to assess the cognitive development of students aged 10–14 years.

SRTs 11 involved many Piagetian tasks that included how the amount of substance, its weight and volume as measured by displacement were seen to vary as shape and position varied. They consisted of 14-items which were hierarchically constructed. The first two items bordered on water pouring tasks while the others bordered on density and water displacement concepts. The tasks were administered in 50 min in each of the three schools used for the study. They were used to categorize students into different cognitive developmental/thinking levels.

Validation of the Instruments

The content validity of each of the instruments was determined by two professors in test construction and science and technology education, respectively. The reliability indices of the SRTs II and BSATCAT were determined as 0.72 and 0.80, respectively, with the Cronbach alpha method.

Procedure for Data Collection

The experimental and control groups were exposed to a pre-test in SRTs II and BS ATCAT to establish their equivalence before they were exposed to the concept mapping teaching/learning technique and the conventional teaching methods, respectively. The experimental group was taught the concepts of atomic structure, acids, bases and salts, energy and heredity for eight weeks, with concept mapping technique.

The control group was taught the same concepts for the same period of time with the conventional lecture method. At the end of the teaching period, both groups were subjected to a post-test in SRTs II and BSATCAT. During the administration of the STRs 11, the students were engaged in water pouring tasks and comparing by observation the given volume of water poured into measuring cylinders of different sizes. They answered questions, such as, ‘Do these cylinders all have the same amount of water?’ Yes…. OR, No…. They were also engaged in comparing sizes of popped and un-popped corn; measuring the amount of water displaced when a block of metal or a piece of plasticine rolled into different shapes was immersed in water in a container. The students' responses were categorized according to the thinking levels involved in answering the test items, such as

Question Item	Response	Thinking level
1. Do these cylinders all have the same amount of water ?	Yes	
	No	(2A)
2. Do these popped corns have		
(a) less amount of corn?		
(b) more amount of corn?	Tick the right option (√)	(2A)
(c) same amount of corn?	(a) or (b) or (c)	

In scoring each student's responses to the SRTs 11 items, the following Scoring Rules were used:

At least TWO 3A items right	(3A)
At least THREE 2B/3A items right	(2B/3A)
Only TWO 2B/3A OR 3A items right, provided FOUR or more 2Bs items are right	(2B/3A)
FIVE or more 2B or higher items right	(2B)
Any FOUR 2B or higher items right	(2A/2B)
At least TWO 2A items right, and THREE 2B or higher items right	(2A/2B)
Any TWO 2A items right	(2A)
Any 2A items and THREE 2B or higher items	(2A)
Up to THREE 2B items and no 2A items or ONE 2A and TWO or less 2B items	(1)

(Piaget & Inhelder, 1974).

(Piaget & Inhelder, 1974).

The students' responses to the STRs items were used to categorize them into different cognitive developmental levels/levels of thinking. For instance, when a student answered at least TWO 3A items right, he was categorized under 3A. This means that he was operating at the early formal operational level of thinking. Or, when a student answered any THREE 2B/3A items right, he was categorized as operating at the transition level or stage of cognitive development/thinking. Again, when a student answered only TWO 2B/3A OR 3A items right, provided FOUR or more 2Bs items are right, he was categorized as also operating at the transition level of thinking or cognitive development, etc.

Furthermore, students' responses to the SRTs 11 items were also marked dichotomously, by allotting one (1) mark to each correct response and zero (0) to each incorrect response. The scores were converted to 100 percent for the purpose of comparing the SRTs 11 scores and ISCAT scores of the students.

The Basic Science and Technology Achievement Test comprised 50 structured and standardized multiple choice test items on the concepts of heredity, energy, atomic structure, acids, bases and salts with options A to E for each test item. The items were scored dichotomously with one (1) mark allotted to each correct response and zero (0) allotted to each incorrect response. The scores obtained by the students were converted to 100 percent and used to categorize them under high achievement level (60.00% and above), average achievement level (50.00–59.00%) and low achievement (0.00–49.00%) level.

Method of Data Analysis

The research questions were answered by means of frequencies and percentages while the hypotheses were tested for significance with t-test statistic at 0.05 level.

Findings

The findings of the study are presented in line with the research questions and hypotheses. Table 7.1 addressed the first research question, 'What are the stages/levels of cognitive development of JSS3 students before their exposure to concept mapping technique?'

The data in Table 7.1 show that before the students were exposed to concept mapping technique 24.44% of them were operating at the preoperational stage of cognitive development, 74.92% were at the concrete operational stage, while 0.32% were at the transitional and early formal operational stages of cognitive development, respectively. After exposure of the experimental group to concept mapping technique, no student was found to be operating at the preoperational stage of cognitive development. However, 26.41% of the students were found at the concrete operational stage, 23.79% and 59.81 were found at the transitional and early formal operational stages of cognitive development, respectively.

Table 7.2 provides the analysis of results for research question 2 that addresses the levels of achievement of JSS3 students before and after their exposure to concept mapping technique.

Table 7.2 shows that before students were exposed to the concept mapping technique, they were all at the low achievement level (0–49%). However, after exposure to concept mapping technique, 76.05% of the students attained a high achievement

Table 7.1 Percentage distribution of students' in experimental group before and after exposure to concept mapping technique

Cognitive Dev. stage	No. of students	Percentage of students
Before treatment		
Preoperational	76	24.44
Early concrete operational	154	49.52
Mid concrete operational	70	22.51
Late concrete operational	09	2.89
Transitional	01	0.32
Early formal operational	01	0.32
Late formal operational	00	0.00
After treatment		
Preoperational	00	0.00
Early concrete operational	10	3.22
Mid concrete operational	18	15.79
Late concrete operational	23	7.40
Transitional	74	23.79
Early formal operational	186	59.81
Late formal operational	00	0.00

Table 7.2 Percentage distribution of students according to levels of achievement

Achievement levels	Number of students	Percentage of total number of students
Before exposure to different teaching methods		
High achievement level (60% and above)	0	0.00
Average achievement level (50–59%)	0	0.00
Low achievement level (0–49%)	311	100.00
Total	**311**	**100.00**
After exposure to different teaching methods		
High achievement level (60% and above)	235	76.05
Average achievement level (50–59%)	51	16.50
Low achievement level (0–49%)	23	7.45
Missing system	2	0.00
Total	**311**	**100.00**

Table 7.3 Mean Post SRTs scores of experimental and control groups

Test	No	$\overline{X}$	SD	t-cal.	t-crit
Post-test					
Experimental	311	60.09	12.36	30.23	1.96
Control	311	31.37			

level (60% and above), 16.50% of them attained an average level of achievement (50–59%). Therefore, the percentage of students at a low level of achievement was reduced from 100% to 7.45%. Two students did not write the post-test. From the results in Table 7.2, 92.55% of the students moved from low level to average and high achievement levels in the post-test as a result of their exposure to concept mapping technique.

Hypothesis 1 There is no significant mean difference between the post-test SRT scores of Experimental and Control Groups

Table 7.3 shows that the calculated value of t (30.23) is greater than the critical value of t (1.96). The null hypothesis was rejected showing that there was a significant mean difference between the post SRT scores of students taught with concept mapping techniques and those of students taught with the conventional lecture method.

The findings further showed that students in the experimental group taught with concept mapping had more significant improvement in cognitive development than those of the control group not taught with concept mapping technique.

The findings of the study, therefore, showed that the instructional technique of concept mapping had a significant effect on students' cognitive development.

Hypothesis 2 There is no significant mean difference between the Post-test BSATCAT Scores of the Experimental and Control Groups.

Table 7.4 shows that the calculated value of t (27.84) is greater than the critical value of t (1.96). The null hypothesis was, therefore, rejected, showing that there was a significant mean difference between the post-test BSATCAT scores of students taught with concept mapping technique and those of them taught with the conventional method. The findings show that the students taught with concept mapping technique out-performed those that were taught with the conventional method in the science and technology achievement test.

Table 7.4 Summary of t-test analysis of post-test Mean BSATCAT scores of experimental and control groups

Group	N	$\overline{X}$	SD	t-cal	t-crit
Experimental	311	64.29	10.98		
				27.84	1.96
Control	311	41.25	9.83		

Table 7.5 Summary of test analysis of post-test mean scores of science reasoning task of boys and girls taught with concept mapping technique

Group	N	$\overline{X}$	S	t-cal	t-crit
Boys taught with concept mapping	182	60.50	12.53		
				0.69	1.96
Girls taught with concept mapping	129	59.52	12.14		

Notes $P < 0.05$, df = 309

Table 7.6 Summary of t-test analysis of achievement test mean scores of boys and girls taught with concept mapping strategy

Group	N	$\overline{X}$	S	t-cal	t-crit
Boys taught with concept mapping	182	64.70	10.75		
				0.79	1.96
Girls taught with conventional mapping	129	63.71	10.84		

Notes $P < 0.05$, df = 309

Hypothesis 3 There is no significant difference between the Post-test Mean Scores of Science Reasoning Task of Boys and Girls Taught with Concept Mapping Technique

Table 7.5 shows that the calculated value of t (0.69) is less than the critical value of t (1.96). The null hypothesis was, therefore, accepted. This means that there was no significant mean difference between the post-test SRTs scores of boys and girls taught with concept mapping technique.

Hypothesis 4 There is no significant mean difference between the post-test Basic Science and Technology Concept Achievement Test (BSATCAT) scores of male and female students taught using concept mapping technique.

Table 7.6 shows that the calculated value of t (0.79) is less than the table value of t (1.96), meaning that the difference was not significant. Therefore, the null hypothesis was accepted, showing that there was no significant mean difference between the BSATCAT scores of male and female students taught with concept mapping technique.

Discussion of Findings and Implications

The findings of the study showed that the instructional technique of concept mapping had significant effects on students' cognitive development and achievement in science. Students in the experimental group had higher cognitive developmental levels than their counterparts in the control group based on their performance in the science reasoning tasks. The implication is that science and technology teachers should modify their teaching methods by incorporating concept mapping activities into them.

This will in no small measure help to enhance students' achievement in science and technology courses and reduce the rate of poor achievement in these courses. The findings further imply that concept mapping techniques have the capacity to enhance the thinking abilities of students exposed to them. Teachers should, therefore, use concept mapping technique to teach students the skill of thinking and actively engage them in mental construction activities for generation and sequencing of ideas, classifying, differentiating, hypothesizing, predicting and drawing inferences, as well as drawing relationships between concepts. This is important because studies have shown that most secondary school students do not employ formal operations and, that is why they do not perform well in science and technology courses which require the use of formal operations (Gyuse, 1996; Cephni, Ozsevgec, & Cerrah, 2004). Another implication of the findings of this study is that cognitive development does not only depend on biological factors; it can be promoted with the use of stimulating and effective instructional techniques by teachers, such as, the concept mapping technique for enhanced achievement of students in science and technology.

The findings also showed no gender differences between the science reasoning tasks scores and basic science and technology achievement scores of students taught with the concept mapping technique. The implication of the study among others is that science and technology teachers should use activity-based instructional strategies, such as concept mapping technique to enhance the cognitive abilities of students for improved achievement in science and technology. Furthermore, the findings of the studies show that female students can enjoy science lessons and do well in them to the same extent as their male counterparts. This implies that science and technology classrooms should be made gender friendly with innovative strategies of teaching and learning to stimulate cognitive growth in students, kindle and sustain their interest in the study of science and technology subjects for enhanced achievement outcomes.

The problem of poor achievement of Nigerian students (male and females) in science and technology is not a new problem. Therefore, science and technology educators need to search and research for teaching methods that can help students (male and females) more effectively learn the basic principles of science. In the search, concept mapping strategy came up as one potential solution, and this research found that concept mapping strategy is one effective teaching method that can improve students' scientific thinking and solve the problem of gender inequity in science achievement.

Conclusion

It was concluded that concept mapping techniques enhanced Nigerian students' cognitive development and achievement in basic science and technology. The technique also brought about gender equity in cognitive development and basic science and technology achievement of male and female students.

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Chapter 8
Embedding Multiple Modes of Representations in Open-Ended Tests on Learning Transition Elements

Nilavathi Balasundram and Mageswary Karpudewan

Abstract Past studies suggested writing incorporated with multiple modes of representations (MMR) were able to reduce students' misconceptions and teaching using technological tools can promote the use of MMR in presenting the answers in open-ended tests. As such, in this study, a writing-to-learn (WTL) activities integrated with graphic organizers using the "*Popplet*" application was used to teach transition elements. Following the teaching, the degree of MMR embeddedness in the open-ended tests was measured. For this purpose, mixed method design was used to identify the ability of 81 pre-university students in embedding MMR.

Past studies suggested writing incorporated with multiple modes of representations (MMR) were able to reduce students' misconceptions and teaching using technological tools can promote the use of MMR in presenting the answers in open-ended tests. As such, in this study, a writing-to-learn (WTL) activities integrated with graphic organizers using the "*Popplet*" application was used to teach transition elements. Following the teaching, the degree of MMR embeddedness in the open-ended tests was measured. For this purpose, mixed method design was used to identify the ability of 81 pre-university students in embedding MMR. Quantitative analysis, repeated measure one-way MANOVA was used to compare the means obtained from the three levels of open-ended tests: pre-test, post-test I, and post-test II. Additionally, qualitative analysis was conducted using students' open-ended test responses. MANOVA shows significant differences for all the three categories of MMR embeddedness: text assessment, general, and individual alternative modes. Qualitative analysis, specifically content analysis, showed the various ways students embedded MMR in the open-ended tests.

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Introduction

Multiple Modes Representations (MMR) such as diagrams, graphs, chemical equations, mathematical equations, and notations predominately found in science textbooks. The MMR functions to display the scientific concepts in a more accurate and clear manner is which most of the time text alone unable to present the concepts as intended (Gunel, Kingir, & Aydemir, 2016). For instance, the ionization energy of transition elements is better reflected with the chemical equation accompanying the text rather than simply using text to illustrate the energy. Given the integral role of MMR in teaching and learning science, having the MMR inserted within the text would not be able to synchronize the meaning conveyed both by the text and the MMR (McDermott & Hand, 2010). The meaning of the scientific concepts is echoed when the MMR is embedded within the text (Hand, Gunel, & Ulu, 2009; McDermott, 2009; McDermott & Hand, 2016). For students, using MMR effectively deliver two-fold benefits. Firstly, MMR prompts students to construct an understanding in a more sensible way (McDermott & Hand, 2010). Secondly, having MMR within the text, the understanding of the concept could be relayed in a more meaningful manner (McDermott & Hand, 2010). As such students should be taught to employ MMR in writings.

Writing-to-learn (WTL) activities such as summary report writing (Demirbag & Gunel, 2014; McDermott & Hand, 2016), multimodal writing (Tolpannen, Rantanity, & Aksela, 2016), argumentative writing (Chen, Hand, & McDowell, 2013), and explanation writing (Gunel, Hand, & McDermott, 2009) are some instances evident in the literature that encouraged embedding of MMR in the open-ended tests. Besides the conventional WTL activities, McDermott and Hand (2016) recommended for the WTL activities to be digital-oriented using more contemporary technology devices and programs. This is because mobile-based graphic organizers allowed arrangement of ideas in a proper sequence and this subsequently resulted in the students writing better English essays (Regan et al., 2018). Tablets and smartphones constitute contemporary technological tools that allow the generation of digital graphic organizers. In this chapter, learning about transition elements was researched from a different lens using MMR facilitated by a technological tool. Students were required to use the “*Popplet*” application tool available online for creating graphic organizers that promote MMR embeddedness.

MMR Embeddedness in Open-Ended Tests

Different terms such as multimodal representations (McDermott & Hand, 2010, Villanueva, 2016; Nam & Cho, 2016) and multiple modes of representations (McDermott & Hand, 2013; Gunel et al., 2016) were used to illustrate various modes. Generally, “*multimodal*” and “*multiple modes*” are used to represent similar ideas using various modes. The term “*modal”* is used to refer to various modes of instruction employed by the teachers in the classrooms. These include gestures, verbal, visuals, music, charts, graphics, role-plays, and powerpoint presentations (Close, Close, McKagan, & Scherr, 2010; Waldrip, Prain, & Carolan, 2010). On the other hand, the term "*modes*" denote the symbols, graphs, tables, chemical equations, mathematical equations, and notations used (McDermott, 2009; McDermott & Hand, 2010; Tolpannen et al., 2016; McDermott & Hand, 2016; Nam & Cho, 2016). Since this study focusses on embedding MMR such as symbols, graphs, tables, chemical equations, mathematical equations, and notations, the term Multiple Modes of Representations (MMR) is used throughout the chapter to represent the use of modes in learning concepts inherent to transition elements.

In a preliminary investigation on students using MMR, McDermott and Hand (2008) revealed that students simply added additional modes after the text. The modes and the text appeared in isolation and do not comprehend one another. In the following studies, the embeddedness of MMR within the text is stressed (Gunel et al., 2006; Hand et al., 2009; McDermott, 2009; McDermott & Hand, 2010, 2013, 2016). The MMR embeddedness was evaluated using three measures: text assessment, general, and individual alternative modes analysis (McDermott & Hand, 2010). Text assessment evaluates the appropriateness of the written product in terms of the accuracy of the concept definitions. In this study, the concept of transition elements was investigated. Text assessment includes evaluation of appropriate language and identifying key terms such as "*forms one or more stable ion*" and "*which have incompletely filled d-orbitals*". General alternative modes analysis measures how the alternative modes (other than text) are embedded to explain the concepts. In defining transition elements, two common alternative modes used were orbital diagram and notation. General alternative modes measure the clarity of the alternative modes (e.g., orbital diagram and notation) used in terms of having the modes labeled accordingly. For instance, labeling the $1s$, $2s$, $2p$ orbitals and labeling the notation. The individual alternative mode analysis is the analysis of how each alternative mode reflects the strategies and characteristics of MMR embeddedness. These include referring the modes in the text; next to appropriate text; scientifically accurate; linked to the definition of transition elements; and placed in a logical order with respect to the text defining transition elements.

Writing-to-Learn (WTL) Activities Integrated with Graphic Organizers in Transition Elements

Transition element is one of the topics included in inorganic chemistry in the Malaysian pre-university chemistry syllabus (Malaysian Examination Council, MEC, 2012). In learning transition elements, students are required to acquire knowledge on the uses of first-row transition elements and their compounds, physical and chemical properties of first-row transition elements, nomenclature, and bonding of complexes (MEC, 2012).

Currently, the conventional teaching method dominates the teaching and learning of transition elements in Malaysia (MEC, 2012). The lessons are mainly teacher dominated and guided by textbooks and notes. Predominately, teachers deliver the concepts by explaining the concepts in the classroom. After providing explanations, questions from textbook, activity book or past year examination questions were discussed. Students passively receive the information, take notes when the teacher explains and usually reiterate the memorized information in the exam (MEC, 2012). Additionally, students conduct one experiment for transition elements supporting the theory lessons (MEC, 2012).

Commonly, the reactions were represented using chemical equations. The notation was used to represent the electronic arrangement for transition element; graphs illustrate the changes in physical properties across the period such as atomic radius, ionic radius, density, melting point, and electrical conductivity; and diagram (e.g., orbital diagram) illustrates the complex ion and *d-d* transition in forming colored transition metal ions (MEC, 2012). As MMR are fundamental for teaching and learning transition elements, essentially important for students to have the knowledge of embedding MMR in transition elements.

Calls for the need to teach students how to embed MMR during learning, as well as to express their understanding in texts are imperative (Tolpannen et al, 2016). Gunel et al (2006) explored the effectiveness of WTL activities, comparing powerpoint presentations and summary report format for student learning quantum theory. The researchers found the use of powerpoint presentations helped students to successfully embed MMR compared to students who used a summary report format. McDermott and Hand's study proposed that WTL activities with technological tools would encourage students to embed MMR. Since the ability to organize information using various modes in a proper sequence should facilitate learning about transition elements, technological tools that permit using MMR in organizing the information should encourage such learning.

Among the available applications, the "*Popplet*" app produces a well-ordered and neat graphic organizer compared to the one done on a whiteboard or paper (Appstore, 2013). The application provides templates to create a graphic organizer easily without any hassle of drawings. The templates facilitate creating attractive organizers with colors using different types and sizes of font, and allows inserting pictures and diagrams from other sources such as websites or notes. For instance, text boxes were generated to explain the melting points, definition of the melting point, factors affecting melting points in transition elements, the trend of melting point in the first-row of transition elements, and explanations for any anomaly. Students were allowed to use a different type, size, and colors of the font for the definition of melting point, factors affecting the melting point, and the explanation for the anomaly. In addition, students allowed to insert graph to show the trend of the melting point of a transition element.

Several researchers have used the "*Popplet*" app and found it useful for organizing information. Sessions, Kang, and Womack (2016) found that students who used the "*Popplet*" app resulted in more cohesive and organized written products for English essays than those who used pencil and paper. Zammit (2016) has used the

"*Popplet*" app in learning literacy. Besides that, the *"Popplet*" was also used in prewriting strategies in the English classroom (Lapp & Eriza, 2018; Heintzelman, 2016). However, the *"Popplet*" app has not been used in the science classroom. Lin, Strickland, Ray, and Denner, (2004) conducted a study to generate computer-based concept maps as a prewriting strategy for English essays. They found that students who used computer-based concept maps generated more ideas and scored higher in the overall quality of the concept maps. Similarly, Regan et al. (2018) found that students who used mobile-based graphic organizers were able to improve their writing with logical arguments and cohesive summaries during the English lessons. Similarly, in the science classroom, a graphic organizer helps teachers and students to explicitly present the scientific concept (Kress & Selander, 2012). Nakiboglu (2018) conducted a research on various graphic organizers such as flow diagram, spider map, compare and contrast chart, persuasion map, and fishbone diagram among 9th to 12th grade chemistry courses. The researcher found graphic organizers helped the students to connect and form relationships between concepts in chemistry (Nakiboglu, 2018). Hence, this study used WTL activities integrated with graphic organizers using *the "Popplet*" app to encourage the MMR embeddedness in open-ended tests.

Based on the reviewed literature, the aim of this study is to evaluate the effectiveness of WTL activities integrated with graphic organizers using the "*Popplet*" app to embed MMR. Based on the aim of the study, the following research question is formulated: "what is the effectiveness of WTL activities integrated with the graphic organizers using the "*Popplet*" application in encouraging pre-university students to embed MMR in terms of text assessment, general, and individual alternative modes?"

Method

Participants

The sample of this study consisted of 81 (45 males and 36 females) pre-university (18–19 years old) science stream students from four intact classes in a school. The students have completed their SPM (*Sijil Pelajaran Malaysia*) examinations obtaining grade C and above in at least five subjects. After completing the pre-university level students will be enrolling in science related courses mainly at the local public university. As such, chemistry is a compulsory subject for this group of students. For these students, it is important to secure a good grade in chemistry to ensure placement in the university courses.

The four classes were taught by two chemistry teachers. The teachers were provided with lesson plans on WTL activities integrated with graphic organizers using the "*Popplet*" app prepared by the researchers. The teachers executed the lessons closely following the lesson plans.

*Lessons on WTL Activities Integrated with Graphic Organizers Using the "*Popplet*" Application*

This study was carried out for eight weeks. During the eight weeks, the four subtopics constituting the main topic of transition elements were taught. The subtopics are physical properties of the first-row of transition elements, chemical properties of the first-row of transition elements, nomenclature and bonding of complexes, and uses of the first-row of transition elements and their compounds. In each week a total of five hours were used to expose the students to the treatment. Each lesson was conducted in four stages: introduction, activity, class discussion, and summary. In the first week, the lesson started with the pre-test. This was followed by teaching the first sub-topic physical properties of transition elements (Definition of transition elements).

An example of the sequence of activities in each lesson is as follows: For the first lesson, in the introduction stage, the teacher wrote two statements on the board: "*All transition elements are d-block elements" and "All transition elements are* ***not*** *d-block elements"*. Students gave various responses. Students who gave the correct answer were required to follow the lesson closely to make sure they had understood the concept correctly.

During the activity stage, students were given examples of transition elements such as vanadium, scandium, manganese, nickel, and copper (any first-row transition element) for students to write the respective electronic configurations. Then, students were also required to write down electronic configuration for one of the ions for vanadium, scandium, manganese, nickel, and copper. Students compared the electronic configuration of transition elements with their ion in their d-orbitals. Students were guided by the teacher to give the definition of transition elements using the electronic configurations that they have written. Following that, students generated a graphic organizer using the "*Popplet*" app for the definition of transition element based on all the information they have gathered. In the graphic organizer, students were asked to include MMR such as notations and orbital diagrams to depict their understanding.

During the class discussion stage, students presented their findings to the rest of the class. The teacher reviewed the presentations and feedback was given for further improvement. Based on the findings of the discussion, the graphic organizer was further improved and emailed to the teacher.

During the summary stage, students used the graphic organizer to write the definition of transition elements by embedding MMR. The same questions from the introduction stage regarding the statements about transition elements were asked to ensure the questions are correctly answered. Similar activities were conducted for the other subtopics in the transition element for eight weeks. An example of a lesson plan is shown in Appendix 8.1.

Open-Ended Tests

Open-ended tests were conducted in three stages, pre-test, post-test I, and post-test II to observe the effectiveness of the WTL activities integrated with graphic organizer using the "*Popplet*" app in encouraging the MMR embeddedness. A pre-test was conducted before the lessons to measure students' previous knowledge of transition elements. The students were repeatedly measured using post-test I conducted at week 4 and post-test II conducted at week 8. Post-test I and post-test II conducted to observe the students' ability to embed MMR. This is because according to Ellis (1999) the effectiveness of the treatment is better reflected from prolonged exposure and repeated measurement of the effect. The questions from the open-ended tests were adapted from STPM past year papers set by *Majlis Peperiksaan Malaysia* (Malaysian Examination Council). Questions in the open-ended tests were given to one chemistry lecturer and two experienced pre-university chemistry teachers to check the content validity. The chemistry lecturer and two pre-university chemistry teachers commented that the questions were suitable for the students. The questions in all the tests were similarly distributed according to the levels of the cognitive process dimension in the Revised Bloom Taxonomy (Anderson and Krathwohl (2001).

From the pilot study, it was discovered that students needed 40 minutes to answer the questions in each test. Five students were randomly interviewed to check whether they understood the questions. According to the five students, the questions were clear, straight to the point, and easy to understand.

Examples of the questions from pre-test, post-test I, and post-test II with expected MMR embedded for each question are given in Table 8.1.

Table 8.1 Examples of open-ended questions from pre-test, post-test I and post-test II

Open-ended tests	Questions	Expected MMR embedded in writing
Pre-test	Titanium, Ti has proton number of 22. Describe and write the electronic configuration of Ti atom using Aufbau principle, Hund's rule, and Pauli Exclusion Principle	Chemical symbols, notation, diagram
Post-test I	Vanadium is a transition element. It forms a colored complex ion. (a) Why vanadium is a transition element? (b) Why vanadium exhibit more than one oxidation state?	Chemical symbols, notation, diagram
Post-test II	Explain the formation of complex ion between copper (II) ions and ethane-1, 2-diamine (ethylenediamine)	Chemical symbol, notation, diagram, chemical equations

Quantitative Data Analysis

Assessment of the open-ended tests was guided by the Multimodal Writing Task Embedding Inventory (MWTEI) as provided in Appendix 8.2. MWTEI was adapted from a study by McDermott and Hand (2009). To ensure the inter-rater reliability of the scale used in this study, 10% (8 responses) of students' writing samples were randomly selected and independently scored by the authors, pre-university chemistry teacher, and another chemistry education researcher. An inter-rater score of 84% based on a simple agreement of codes was obtained from comparing the rating provided by the authors, pre-university chemistry teacher, and another chemistry education researcher for the eight responses. In addition, one chemistry lecturer and two experienced chemistry teachers checked the appropriateness of using MWTEI for this study. Based on their comments and recommendations, some criteria were removed. For instance, the criteria on originality of MMR were removed from individual alternative mode analysis. This is because the MMR that students used in answering the tests are readily available in the literature. The MMR was not generated by the students.

Students' responses to the open-ended tests were analyzed using MWTEI consisting of the three measures: text assessment, general, and individual alternative modes. The scores for the three measures were analyzed using MANOVA. The grand total score, computed by adding all the scores from the three measures, was analyzed using ANOVA. The text assessment examined the use of text in explaining the transition elements' concept. The general and individual alternative modes examined how other alternative modes representations (other than text) were used to explain the transition elements' concepts. Each of these three categories has subcategories with components that were given a score between 0 and 2. Students were given score 2 if they have presented the subcategory component clearly, students were given score 1 if the subcategory component were presented partially and score 0 were given if the subcategory components were not presented (Appendix 8.3). The categories and subcategories constituting the MWTEI and their corresponding scores are shown in Table 8.2.

One-way repeated measure multivariate analysis of variance (MANOVA) was performed to show the main effect of the WTL activities integrated with graphic organizer using the "*Popplet*" app on the text assessment, general, and individual alternative modes usage (dependent variables) measured on the pre-test, post-test I, and post-test II. In addition, one-way repeated measure univariate analysis of variance (ANOVA) was performed to show the effect of four weeks' test time on the MMR embeddedness in the open-ended tests.

Table 8.2 Distribution of the Categories in Multimodal Writing Task Embedding Inventory (MWTEI)

Categories	Subcategories	Subcategories components	Descriptions	Score
Text assessment	Assignment expectations	Covered required topics	Students present the main concept that has been asked in the question	2
		Accuracy of science concepts	Students need to describe the science concept accurately in the writing	2
		Completeness of meaning	Students have covered all aspects in their writing	2
	Audience considerations	Appropriate language/vocabulary	Students present the main concept that has been asked in the question	2
		Identified key terms (Underlined, highlighted)	Students need to describe the science concept accurately in the writing	2
General alternative mode analysis		Appropriateness for the audience	Audience are able to understand the modes presented	2
		Key terms included in the modes	Able to provide a clear representation of the modes and help the audience to understand the modes	2
		Accurate and correct representations	MMR is scientifically correct	2
		Modes linked to main concepts	MMR are linked to the main concept	2

(continued)

Table 8.2 (continued)

Categories	Subcategories	Subcategories components	Descriptions	Score
		Appropriate distribution of modes	MMR are placed in a logical order with respect to text	2
Individual alternative mode analysis	Embeddedness strategies	Caption	Students use captions to link to the content of the modes	1
		Next to the appropriate text	Students have the same content with text close to them	1
		Referred to text	Students referenced their modes in the text such as "As the figure above showed…"	1
		Explained in text	Students provide more details by explaining the modes	1
	Characteristics	Accuracy	MMR are scientifically accurate	2
		Necessary for explanation	MMR and captions are linked well so that audience understand what is being described	2
		Conceptual connection to the text	MMR are relevant to the concept explained in the text	2

Qualitative Data Analysis

Qualitative data analysis was conducted to highlight qualitative differences in students' responses so as to support the result of the quantitative analysis. Content analysis was used to analyze the degree of MMR embeddedness in open-ended tests using MWTEI. Appendix 8.3 shows an example of how students' responses were analyzed. Content analysis was conducted in four stages following Bengtsson's (2016) framework: decontextualization, recontextualization, categorization, and compilation. Each stage was performed three times to maintain the quality and trustworthiness of the data.

The codes for MMR embeddedness were predetermined. The categories in MWTEI were used as predetermined codes. During the decontextualization process, the data were screened for the predetermined codes. The responses were read for three times and the predetermined codes that appeared were highlighted. This was followed by the recontextualization stage to check the highlighted predetermined codes. Subsequently, the predetermined codes that emerged in the students' responses were categorized into categories that constitute text assessment, general, and individual alternative modes as shown in Table 8.2. Finally, the findings were reported.

Result

Quantitative Result

The overall mean values increased from pre-test ($M = 2.07$; $SD = 2.90$), to post-test I ($M = 16.25$; $SD = 7.35$), and to post-test II ($M = 23.84$; $SD = 5.41$). The MANOVA result suggests that the effect of test time is significant, Wilk's Lambda = 0.031, $F(2, 79) = 1241.618$, $\eta^2 = 0.969$, the partial eta square value of 0.969 indicates that 96.90% of the total variance in post-test scores was due to the treatment; the effect of embedding MMR in open-ended tests categories are significant comparing the pre-test, post-test I, and post-test II scores, Wilk's Lambda = 0.134, $F(2, 79) = 254.398$, $\eta^2 = 0.866$, the partial eta square value of 0.866 indicates that 86.60% of the total variance for embedding MMR was due to the treatment; the interaction between embedding MMR in open-ended test categories and test time is significant, Wilk's Lambda = 0.111, $F(4, 77) = 154.416$, $\eta^2 = 0.889$, the partial eta square value of 0.889 indicates that 88.90% of the total variance for embedding MMR in post-test scores was due to the treatment.

The result of univariate ANOVA from the grand total score indicates the main effect of test time is statistically significantly different, $F(2, 160) = 1430.657$, $p = 0.000$, $\eta^2 = 0.947$, the partial eta square value of 0.947 indicates that 94.70% of the total variance in post-test scores was due to the treatment; the main effect of embedding MMR in open-ended tests categories are statistically significantly different, $F(2,160) = 303.836$, $p = 0.000$, $\eta^2 = 0.792$, the partial eta square value of 0.792 indicates that 79.20% of the total variance for embedding MMR was due to the treatment; the interaction effect of embedding MMR in open-ended test categories and test time violated the assumption of sphericity and the mean score is statistically significantly different with a Greenhouse-Geisser correction, $F(2.134, 170.702) = 230.608$, $p = 0.000$, $\eta^2 = 0.742$, the partial eta square value of 0.742 indicates that

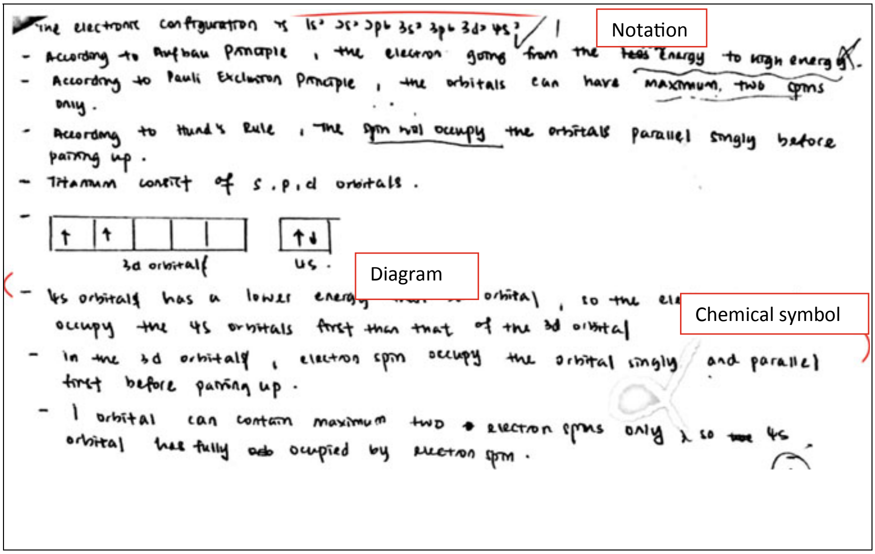
74.20% of the total variance for embedding MMR in post-test scores was due to the treatment. Both multivariate test and the univariate test shows consistency.

Qualitative Results

A student's responses for the open-ended test are shown in Figs. 8.1 and 8.2.

Figure 8.1 shows a student's response in the pre-test. Text assessment was analyzed in terms of assignment expectations and audience consideration. In assignment expectations, the student has provided an inaccurate understanding of the Aufbau principle and the student's response showed there was no completeness in meaning. For example, a student mentioned "*the electron going from low energy to high energy*". The correct statement should be *"the electrons occupy lowest energy orbitals first before the highest energy orbitals*". Thus, it could be seen that the student had not covered all the aspects because the student mentioned "*energy"* only but not "*energy orbitals"*. Besides that, the student showed an inaccurate science conceptual understanding of "*low energy"* when explaining about Aufbau principle. It is supposed to be *the "lowest energy orbitals"*. In audience consideration, the student used language that the audience can understand but key terms were not identified in the students' response. In conclusion, assignment expectations and audience consideration were poor in the response.

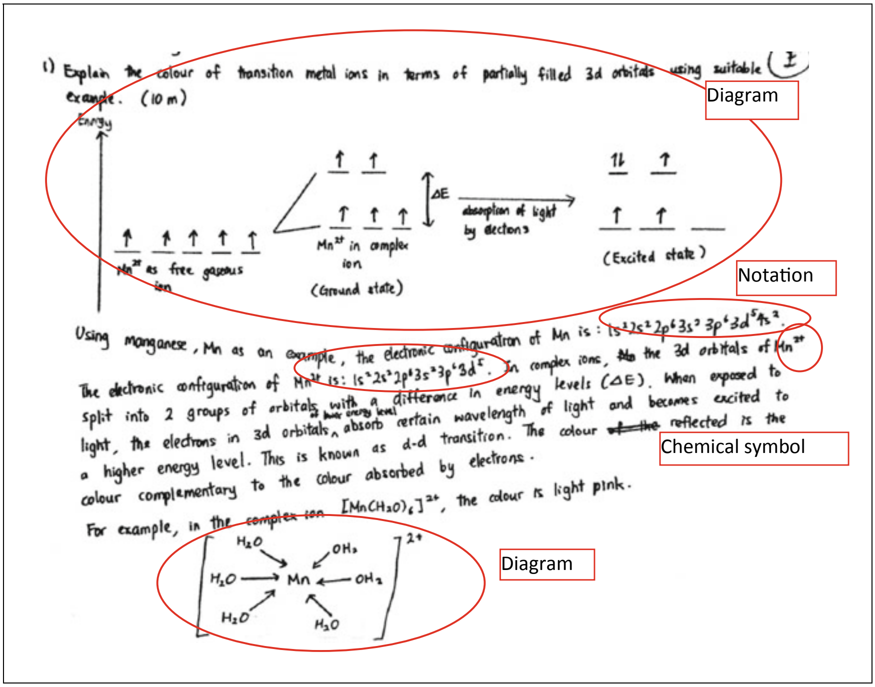
General alternative modes analyses indicate the appropriateness of using alternative modes (e.g., notation, chemical symbol, and diagram) rather than text to explain



The electronic configuration is $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^2\ 4s^2$

- According to Aufbau Principle, the electron going from the ~~less~~ Energy to high energy.
- According to Pauli Exclusion Principle, the orbitals can have maximum, two spins only.
- According to Hund's Rule, the spin will occupy the orbitals parallel singly before pairing up.
- Titanium consist of s, p, d orbitals.
- 4s orbitals has a lower energy than 3d orbital, so the electron occupy the 4s orbitals first than that of the 3d orbital
- In the 3d orbitals, electron spin occupy the orbital singly and parallel first before pairing up.
- 1 orbital can contain maximum two electron spins only, so ~~the~~ 4s orbital has fully ~~ad~~ occupied by electron spin.

Fig. 8.1 A student's response from the pre-test



1) Explain the colour of transition metal ions in terms of partially filled 3d orbitals using suitable example. (10 m)

Using manganese, Mn as an example, the electronic configuration of Mn is: $1s^2 2s^2 2p^6 3s^2 3p^6 3d^5 4s^2$.
The electronic configuration of Mn^{2+} is: $1s^2 2s^2 2p^6 3s^2 3p^6 3d^5$. In complex ions, ~~Mn~~ the 3d orbitals of Mn^{2+}
split into 2 groups of orbitals with a difference in energy levels (ΔE). When exposed to
light, the electrons in 3d orbitals of lower energy level absorb certain wavelength of light and becomes excited to
a higher energy level. This is known as d-d transition. The colour ~~of the~~ reflected is the
colour complementary to the colour absorbed by electrons.
For example, in the ~~complex ion~~ $[Mn(H_2O)_6]^{2+}$, the colour is light pink.

Fig. 8.2 A student's response from post-test II

the concept. Figure 8.1 reveals that the notation was appropriately used but the diagram was incomplete because it shows the filling of electrons in 3*d* and 4 *s* orbitals only. The key terms given by the student were not clear because the student did not mention whether the notation represents the ions, atom or element. The representation of the diagram was not accurate because the electronic configuration of titanium was not complete. Besides that, no links were used to connect the explanation (the text) and the MMR. There was no appropriate distribution of modes because the alternative modes were simply placed in between the text.

Individual alternative modes analysis were used to analyze the notations, chemical symbol, and diagram. Embeddedness strategies and characteristics categories were used to analyze the alternative modes separately. The diagram was used to describe the individual modes analysis in terms of embeddedness strategies and characteristics of the mode. Similar analysis was conducted for the other modes individually. In embeddedness strategies for diagram, the student did not use any captions to link with diagram, had some content close to the text, did not refer diagram in text, and there were not much details in explaining the diagram. In characteristics for diagram, it was not accurate because the diagram was incomplete, there was no link between caption and diagram because a caption was not given for the diagram and the incomplete diagram was not relevant to explain the filling of the electrons in the orbitals. Overall, the embeddedness of notation, chemical symbols, and diagram in the pre-test was very poor.

Figure 8.2 shows the same students' response from post-test II. The student was able to cover the concept required, that is, the formation of color in manganese ion. The student used manganese ion as an example to describe the color. The student showed the ground state of manganese ion and excited state of manganese ion. The explanation for the formation of colors involves accurate concepts such as "*3d-orbitals split into two groups orbitals with a difference in energy levels*" shows the accuracy of science concepts. Completeness of the meaning was reflected when the student described the electronic configuration of manganese ion that was partially filled, the splitting of *d*-orbitals after the ion was exposed to light, *d-d* transition when the electron absorbed energy and promoted to a higher energy level and the complementary color was reflected. Overall, the assignment expectation was fulfilled. For the audience consideration, the student used appropriate language. However, none of the identified key terms can be observed. Thus, the audience consideration was only partially fulfilled.

Three types of alternative modes were used: notation to represent the electronic configuration of manganese, Mn and manganese ion, Mn^{2+}; chemical symbol to represent orbitals such as *d*-orbitals, energy levels, ΔE and the species Mn, Mn^{2+} and $[Mn(H_2O]^{2+}$; a diagram to represent the *d-d* transition taken place from the ground state to the excited state. All these alternative modes were evaluated in terms of general alternative modes analysis. All the alternative modes used were appropriate for the audience because it helped the audience to understand the formation of color in manganese. Key terms were included in the alternative modes because the student mentioned the notations are for which species (ions or atom) and element. Furthermore, the student labeled the ground and excited state of the electrons in the diagram. Thus, the representations were accurate. All the alternative modes were linked to the formation of the light pink color of manganese ion. The student included the notations for manganese and manganese ion in between text. Besides that, the students included the diagram before the explanation. Hence, all the alternative modes were appropriately distributed.

Individual alternative modes analyzed two notations, three chemical symbols (representing d-orbitals, manganese species, and change in energy) and a diagram. The diagram was used to describe the individual modes analysis in terms of the embeddedness strategies and the characteristics of the mode. Similar analysis was conducted for the other modes individually. In embeddedness strategies for diagram, student did not linked diagram with content because there were no statement from the explanation refers to the diagram that shows there is no caption. The diagram which was placed before the explanation shows that the mode (diagram) was accurately placed next to the appropriate text. The student did not mention any statement referring to diagram such as "*Diagram above shows the d-d transition of the electron*" which showed modes were not referred to the text. However, there were further explanations about *d-d* transition in the text which showed the diagram that was explained in the text. In terms of characteristics of modes, the diagram used had a y-axis and was labeled for each step involved in the formation of color which reflected the accuracy of the diagram. The diagram was necessary to illustrate the *d-d* transition. The diagram was also relevant to explain the formation of color that showed that it had a conceptual connection to the text. Similar analysis was conducted for the other modes as well.

Discussion

The outcome of the study suggests that students' embedding of alternative modes improved in post-test II compared to post-test I and pre-test. The outcome of content analysis also suggests that students have multiple ways of embedding MMR which can be seen obviously in post-test II. For instance, one student embedded diagram and notation, another student embedded chemical equation and diagram in describing the formation of the colors.

For the text assessment, the findings of this study revealed that students did not identify any key terms in their open-ended tests due to the low emphasis on key terms during the lessons with WTL activities integrated with graphic organizers using the "*Popplet*" app. Key terms were the important points identified by the students by underlining or highlighting it. For example, the definition of transition elements is "*A transition* elements *is the one that forms one or more stable ions which have incompletely filled d-orbitals*" and the key terms extracted from the definition of transition elements are "*forms one or more stable ions*" and "*incompletely filled d-orbitals*". This finding parallels findings from a study performed by Tolppanen et al. (2016). Tolppanen et al. (2016) used a multimodal lesson to investigate the degree of MMR embeddedness. The researchers found that the multimodal lesson did not impact the text assessment as the students did not use any texts to respond and only used alternative modes. Tolppanen et al. (2016) claimed that this could be due to the emphasis on alternative modes in the multimodal lesson which led the students to believe the use of alternative modes was given utmost importance rather than the integration of the text. Similarly, in this study, graphic organizer produced using the "*Popplet*" app encouraged students to use alternative modes such as graphs, diagram, notations rather than emphasizing the text and the key terms.

For the general alternative modes, students used various alternative modes to represent the same concept such as diagram or notations to represent the electronic configuration of titanium in post-test II compared to the pre-test. Students used at least one alternative mode to represent a concept in the post-test II compared to the pre-test whereby the students did not use any alternative modes. This demonstrates an improvement in embedding MMR from pre-test to post-test I and to post-test II. Students were able to express their understanding clearly by using various alternative modes to represent a concept. This is similar to McDermott's (2010) study where WTL activities in science classes successfully encouraged the students to embed MMR. Students were able to integrate their written text with alternative modes at the end-of-unit assessment compared to the control group. McDermott (2010) claimed students benefited dealing with a concept using various modes as they are able to express their understanding clearly.

For the individual alternative modes, students had poor embedding strategies and characteristics during the pre-test because students were not exposed to embedding MMR. Gunel et al. (2016) asserted that students were familiarized with MMR after lessons on electrochemistry by embedding MMR delivered. Variation of alternative modes can be observed from one student's response to another student's response. Consideration of individual alternative modes is important as some representations are more appropriate for a particular chemistry concept than others. For example, the diagram to show the *d-d* transition is important to represent the formation of colors in transition metals ions as compared to the diagram of the complex ion and chemical equation. Similarly, Yesildag and Gunel (2009) found pictorial mode is important and suitable to study light, photo-electricity, and Compton effect. On the other hand, both researcher also found textual mode is suitable to study the Broglie unit.

Conclusion

The findings of this study showed that WTL activities integrated with graphic organizers using the "*Popplet*" app were able to promote embedding MMR. Students were able to embed more modes in post-test II compared to post-test I. In post-test I, students used only text or one alternative mode only in the open-ended test. On the other hand, in post-test II, students were able to use more modes (at least 2 modes) in open-ended tests. A higher score for MMR embeddedness comprising text assessment, general, and individual alternative modes in post-test II also suggests students were able to express their understanding efficiently in an open-ended test. This, in turn, suggests students improved their learning in transition elements through the "*Popplet*" app. The findings suggest learning of transition elements using graphic organizers with the "*Popplet*" app encouraged the MMR embeddedness. Thus, the use of technological tools such as the "*Popplet*" app to promote MMR embeddedness seems a promising new lens for research on improving students' understanding of transition elements.

In order to further establish the findings on embedding MMR, it is recommended to conduct another study that targets other components of embedding MMR with other concepts in chemistry, as well as in other science subjects. Besides that, due to the availability of various applications that are able to generate graphic organizers, it is recommended to attempt this study with other applications to generate the graphic organizers. In order to further establish the findings on the effectiveness of WTL activities integrated with graphic organizers using the "*Popplet*" app, it is recommended to have a controlled group in the study. Control group treatment allows a comprehensive comparison to be made and it will strengthen the findings obtained in the study. Besides that, a control group is useful to serve as a benchmark to measure the results of the other groups.

This study focusses on transition elements which is a topic covered in the pre-university syllabus. Hence, the findings may not be generalized to other science courses such as physics and biology or to other chemistry topics. For example, chemistry concepts such as reaction kinetics require students to determine the rate constant and order of the reactions mainly involves calculation that includes different MMR from transition elements (MEC, 2012).

In this study, embedding MMR were introduced as one of the approaches to teach transition elements. Embedding MMR in this study is projected in the open-ended tests. On the contrary, MMR could be embedded in the teaching process with the use of different modes such as verbal, visual, and mathematical mode (Waldrip, Prain, & Carolan, 2006).

Appendix 8.1: Lesson Plan

Week	Period/Lesson	Outline of lesson	Cognitive processes	Notes
1	3 and 4	*Transition elements* *13.1: Physical properties of first-row of transition elements* Objective: (1) Define a transition element in terms of incomplete d-orbitals in at least one of its ions *Phase 1: Introduction* (10 min) (1) Teacher writes statements on the whiteboard and asks the students which one of the statements is correct. The statements are: – *All transition elements are d-block elements* – *All transition elements are* ***not*** *d-block elements* (2) Students response to the question based on what they have learnt previously (3) Students are introduced to transition elements and where they are located in periodic table (4) Students are given few examples of transition elements surrounding them such as copper (can be found in electrical wiring), iron (can be found in school gate), zinc (can be found at school rooftop), chromium in stainless steel and titanium in alloy	(1) Explain in their own words about transition elements based on their previous knowledge (2) Able to give more examples of transition elements	Students recall Hund’s rule, Aufbau principle, and Pauli exclusion principle

(continued)

(continued)

Week	Period/Lesson	Outline of lesson	Cognitive processes	Notes
1	3 and 4	*Phase 2: Activity* (20 min) (1) Students are given examples of transition elements (first-row transition elements) and required to write their electronic configuration (2) Students compare the electronic configuration of transition elements with s-block elements such as Na and Ca (especially the valence electronic configuration) (3) Students were guided by teacher to explain the definition of transition elements based on the electronic configuration (4) Students finds out why scandium and zinc are not a transition element and discuss with teacher (5) Students are required to use "*Popplet*" app to generate graphic organizer based on the lay out given by the teacher	(1) Students were required to write electronic configurations for transition elements (2) Students do comparison of electronic configurations of transition element with Group 1 elements especially the valence electronic configurations (3) Students able to reason why scandium and zinc are not transition elements (4) Students in group generate graphic organizer using "*Popplet*" app	
		Phase 3: Class discussion (40 min) (1) Three selected students presents their definition of transition elements in front of the class (2) Teacher gives 10 min time for students to present their graphic organizers and comment given by teacher and other students (3) Students discuss that scandium and zinc are not transition elements based on their electrons in *d*-orbital (4) Discuss that copper is a transition element (5) Students discuss the definition of transition elements and form the correct definition (6) Students need to send the improved graphic organizer to teacher	(1) Students are required to present in front of the class (2) Students discuss if there are further improvements need to be done on the graphic organizer and send the complete graphic organizer to teacher (3) Students discuss that scandium and zinc are not transition elements and copper is a transition element	

(continued)

(continued)

Week	Period/Lesson	Outline of lesson	Cognitive processes	Notes
		Phase 4: Summary (10 min) (1) Students were asked to write in their logbook on what students have learnt today (2) Teacher asked students again about the statements given at the beginning of the class and students answer teacher (3) Provide problems related to the definition of transition element to do at home as homework *Multiple modes of representation involved:* (1) Diagram-arrangement of the electron in d-orbital (2) Text-definition of transition element and explanation (3) Notation-electronic configuration	(1) Students were required to write their logbook about the lesson today (2) Students answer question for the statement which were given at the beginning of the lesson (3) Students complete the problems given at home and check the answer with teacher later	

Appendix 8.2: Multiple Modes Writing Task Embeddedness Inventory (MWTEI)

Student Name:____
Writing Topics:____

Part One: Text Assessment

0 = No Evidence 1 = Some Evidence 2 = Present Throughout

No.	Criteria		Scores
1.	Assignment expectations	Covered required topics	
		Accuracy of science concepts	
		Completeness of meaning	
2.	Audience considerations	Appropriate language	
		Identified key terms (Underline, Highlighted, Italics)	
Total			/10

Part Two: General Alternative Modes Analysis

Mode type	Appropriate	Non-appropriate	Related Topic/ Subtopic

0 = No/None 1 = Attempted/Limited 2 = Complete/Entire

Criteria	Scores
Modes appropriate for audience	
Key terms included in modes	
Representations accurate	
Modes linked to main concepts	
Appropriate distribution of modes	
Total	/10

Part Three: Individual Alternative Mode Analysis

(Repeat for each appropriate individual alternative mode)
1. Mode Type: Concept addressed:
(a) Embeddedness strategies (b) Characteristics
(0 = Not employed 1 = Utilized)

Caption			Accurate	
Next to appropriate text			Necessary	
Referred to in text			Conceptual connection to text	
Explained in text			Mode is self-explanatory	
Original				

2. Mode Type: Concept addressed:
(a) Embeddedness strategies (b) Characteristics
(0 = Not employed 1 = Utilized)

Caption			Accurate	
Next to appropriate text			Necessary	
Referred to in text			Conceptual connection to text	
Explained in text			Mode is self-explanatory	

(continued)

(continued)

Caption			Accurate	
Original				

3. Mode Type: Concept addressed:
(a) Embeddedness strategies (b) Characteristics
(0 = Not employed 1 = Utilized)

Caption			Accurate	
Next to appropriate text			Necessary	
Referred to in text			Conceptual connection to text	
Explained in text			Mode is self-explanatory	
Original				

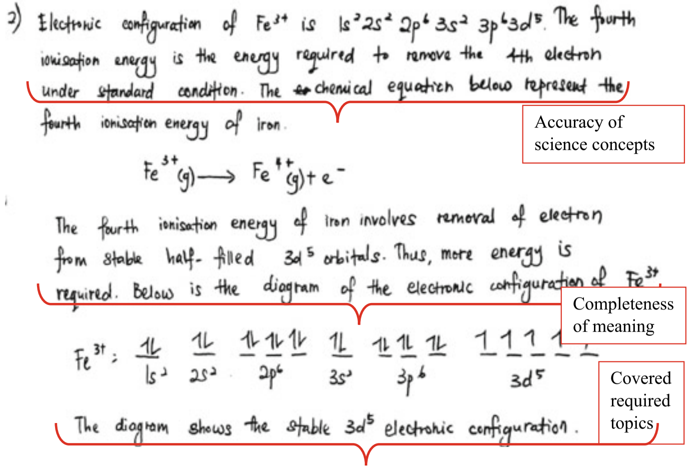
4. Mode Type: Concept addressed:
(a) Embeddedness strategies (b) Characteristics
(0 = Not employed 1 = Utilized)

Caption			Accurate	
Next to appropriate text			Necessary	
Referred to in text			Conceptual connection to text	
Explained in text			Mode is self-explanatory	
Original				

5. Mode Type: Concept addressed:
(a) Embeddedness strategies (b) Characteristics
(0 = Not employed 1 = Utilized)

Caption			Accurate	
Next to appropriate text			Necessary	
Referred to in text			Conceptual connection to text	
Explained in text			Mode is self-explanatory	
Original				

Appendix 8.3: Open-Ended Tests Sample Analysis For Text Assessment (Embedding Alternative Modes)

Analysis	Scores	Example of Student's Response
(a) Assignment expectations		Post-test I: 2) Suggest a reason in terms of electronic configuration why fourth ionization energy of iron is higher than expected
Student gives the electronic configuration of Fe^{3+} ion. Then student explained fourth ionization energy. This followed by, explanation of consequences if the fourth electron has been removed.This shows student has covered required topics	2	 2) Electronic configuration of Fe^{3+} is $1s^2 2s^2 2p^6 3s^2 3p^6 3d^5$. The fourth ionisation energy is the energy required to remove the 4th electron under standard condition. The chemical equation below represent the fourth ionisation energy of iron. $Fe^{3+}(g) \longrightarrow Fe^{4+}(g) + e^-$ The fourth ionisation energy of iron involves removal of electron from stable half-filled $3d^5$ orbitals. Thus, more energy is required. Below is the diagram of the electronic configuration of Fe^{3+}. Fe^{3+} : $\underset{1s^2}{\underline{\uparrow\downarrow}}$ $\underset{2s^2}{\underline{\uparrow\downarrow}}$ $\underset{2p^6}{\underline{\uparrow\downarrow}\,\underline{\uparrow\downarrow}\,\underline{\uparrow\downarrow}}$ $\underset{3s^2}{\underline{\uparrow\downarrow}}$ $\underset{3p^6}{\underline{\uparrow\downarrow}\,\underline{\uparrow\downarrow}\,\underline{\uparrow\downarrow}}$ $\underset{3d^5}{\underline{\uparrow}\,\underline{\uparrow}\,\underline{\uparrow}\,\underline{\uparrow}\,\underline{\uparrow}}$ The diagram shows the stable $3d^5$ electronic configuration.
Student give complete definition of fourth ionization energy of Fe^{3+}. This shows accurate science concept	2	
Student explain the consequences of removing electron from stable half-filled $3d^5$ orbitals with the support of diagram of electronic configuration. This shows completeness of meaning	2	
(b) Audience consideration (overall)		
Student use appropriate language that audience can understand	2	
Student did not show any identified key terms	2	
Total score	10	

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Chapter 9
Trustworthiness Challenge in Children's Environmental Problem Solving in the Digital Era

Mijung Kim and Suzanna So Har Wong

Abstract With an increasing challenge of socioscientific issues in the current society, students' critical thinking and decision-making skills in complex problem contexts become pivotal aspects of scientific literacy for the twenty-first century citizenship. To ensure students are prepared for the changing and challenging world, problem-based learning (PBL) has been practiced to develop the capacity of students' critical thinking, evidence-based decision-making and creative problem solving in problem contexts. Critical literacy skills have become essential in socioscientific and environmental problem solving contexts, as well as children's literacy practices at home and in school. Yet there have not been many studies on children's critical literacy skills and practices, especially critical evaluation on web-based information in science education. This study looks into a) what critical literacy practices children are engaged with when understanding local environmental issues and b) what are some ways teachers can teach these critical literacy skills in science classrooms. Twenty-four children in a Grade 5–6 combined class in an elementary school in Western Canada participated in this study. Children's problem solving activities were video/audio taped and classroom artefacts (children's writings, drawings, designs, etc.) were collected for data analysis. Thematic coding (open, axial, and selective coding) was employed to understand classroom interactions and critical literacy aspects throughout problem solving processes. The findings show (a) children practiced various review strategies such as cross-checking, member checking, and evaluating authorities of information to validate information in web space and (b) teachers strategized scaffolding for students' problem solving activities such as questioning, motivating, and inviting experts' knowledge. This study suggests that critical literacy and environmental problem solving skills can be co-constructed with teachers and students together in a problem solving inquiry project.

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Introduction

Problem-Based Learning

With an increasing challenge of socioscientific and environmental issues in the current society such as climate change, energy conservation, deforestation, etc., critical thinking and problem solving skills have been the key elements of the twenty-first century competencies and citizenship (OECD, 2013). In science education, problem-based inquiry has been encouraged to develop students' scientific reasoning and problem solving skills (Gillies, Nichols, Burgh, & Haynes, 2014; Pease & Kuhn, 2011). Researchers explain that problem tasks lead students into identifying problem contexts, researching, analyzing and evaluating data and evidence, and justifying their claims, thus, develop reasoning and decision-making skills (e.g., Hmelo-Silver, 2004). During the process of problem solving, students further enhance domain-specific conceptual knowledge (Pease & Kuhn, 2011) and social cognitive knowledge, i.e., knowledge of others' ideas and actions when they are engaged in collaboration (Fawcett & Garton, 2005; Hmelo-Silver & Barrows, 2008; Kim & Tan, 2013). In problem-based inquiry activities, students are engaged in various types of problems such as well-structured and ill-structured problems. Well-structured problems have a well-defined initial state and goal with knowable, comprehensible solutions whereas ill-structured problems are open-ended, emergent, situated, and multidisciplinary in character without strict boundaries (Jonassen, 2000; Jonassen, Strobel, & Lee, 2006; Laxman, 2010). Questions like 'why seasonal changes occur' or 'why it's winter in Canada when it's summer in Australia' can be examples of well-structured problems and questions like 'why people are concerned about farmed salmons' or 'if and how we develop community gardens in the local community' can be examples of ill-structured problems. In well-structured problem tasks, students' answers can be known and found in canonical scientific knowledge whereas answers in ill-structured problems are often new, open, and unpredictable. The open-ended nature of ill-structured problems involves students' creativity and flexibility during problem solving, alternative ways and solutions to the problems, and interconnectivity among disciplines, which challenges students more in decision-making and problem solving. Yet, because of the openness and connections to everyday lifeworlds, ill-structured problems can stimulate students to lead their problem solving process with interest and motivation and go beyond the boundaries of typical school science (Chin & Chia, 2006; Hmelo-Silver, 2004; Kirschner, Paas, & Kirschner, 2009). Ill-structured problems are encouraged to be practiced in science classrooms to develop students' cognitive knowledge, critical thinking, and decision-making skills (Hmelo-Silver, 2004; Kirschner et al., 2009). However, there are also certain challenges in students' learning through ill-structured problems. Because of the flexibility and openness of the problem solving process, students often struggle to formulate and identify problems and encounter difficulties in deciding what focus and direction they should take and in extracting and analyzing relevant information from irrelevant information toward the problem posed (Chin & Chia, 2006). During problem solving, the lack of information searching skills can be another significant challenge for students. When specific information is required for decision-making, students often do not know how to find the information and where to look into (Laxman, 2010).

The openness of problem-based inquiry also challenges teachers' pedagogical decision-making and teaching practice in the intended curriculum and standardized tests (Savery, 2006). As creative, flexible, and alternative ways of problem solving are valued and encouraged during problem solving, it is challenging for teachers to navigate and control the process and outcomes of problem solving to meet the intended curriculum as there exists an ongoing tension between supporting students' interests and creativity and achieving the curriculum goals in science classrooms (Scott, Mortimer, & Aguiar, 2006). Despite these challenges, teachers are encouraged to practice problem-based inquiry as it enhances various high-level cognitive skills of problem solving such as communicating, information searching, analyzing and evaluating, and justifying during problem solving process. To overcome the challenges for efficient problem solving in classrooms, researchers further suggest various scaffolding strategies such as question prompt, problem framing, peer interactions, and collaboration, etc. (e.g., Xun & Land, 2004).

Evidence Seeking & Critical Literacy Practices During Problem Solving

Problem-based inquiry develops students' evidence-based reasoning skills such as analyzing and evaluating data and information in order to justify their claims as best solutions (Belland, Glazewski, & Richardson, 2011; Zou & Mickleborough, 2015). To reach plausible solutions, students provide and evaluate different types and levels of evidence (Brown, Furtak, Timms, Nagashima, & Wilson, 2010) and connect their evidence to claim making, which is crucial for scientific thinking and problem solving (Kuhn, 1989; Kuhn & Pearsall, 2000; Piekny & Maehler, 2013). Students' evidence in science problem solving comes from various dimensions. For well-structured problem solving tasks such as 'how and why seasonal changes occur', students' claims could be based on scientific knowledge and classroom experiments to test the relationship between temperature change, heat source, and revolution with the tilt of the axis. When students are engaged in experiment-based problem solving, their evidence is from data collection during experiments and connected to conclusion and justification. When students are involved in ill-structured everyday problem solving tasks such as 'why people are concerned about farmed salmons', students' evidence seeking is going beyond science curriculum knowledge, textbooks, and classrooms. For this task, students need to understand what farmed salmons are, how and why they are different from wild salmons, how they are related to society and the environment, etc., which cannot be answered from textbooks or curriculum materials only. They will need to research for resources outside of classrooms for their problem solving. Thus, in ill-structured problem tasks, students' answers are often complex, interdisciplinary, and even uncertain with various alternatives. As many everyday local STSE (Science, Technology, Society, and the Environment) problems are new and current, there are not ready-made teaching resources to help students' problem solving in classrooms. Students often seek information through online resources, topic-related books, or talking to adults such as experts, teachers or parents to understand the current issues of their society and environment. The broad range of their information and data sources, especially online resources challenges teachers to design problem solving tasks and students to select and evaluate valid evidence for problem solving.

Contemporary children are growing up in media-rich homes that are surrounded by digital technologies and they engage in digital practices as a part of the play, problem solving, and learning in schools. As Rideout's (2017) study reveals, children from a very young age use digital devices for entertainment, to communicate with others, and to search for information in their daily lives. Children are experienced users of digital technology (Marsh, 2017) and this has impacted their approaches to solve problems. Historically, critical literacy skills, especially in the dimension of digital literacy practice are more prevalent in adult and high school education (e.g., Freire, 2010; Janks, 2010) than in primary schooling. Yet, it is becoming increasingly clear that teachers of elementary grades need to teach critical literacy practices and skills because contemporary children are using digital devices to search for information online in—and out-of-school (Marsh et al., 2017; Rideout, 2017). As students are familiar with learning and communicating in online space, information seeking in online space such as world wide web resources has become a common strategy of problem solving. With the rapid changes in communicative literacy practices in the current digital age, particularly in the 'post-truth' era, teaching students to be critical consumers of online information becomes crucial. While engaging in problem solving inquiry, especially with complex, everyday-related problems, students need to learn a 'repertoire of practices' (Luke & Freebody, 1999) including critical literacy practice to be able to critique, analyze, and interrogate how texts (e.g., multimedia and multimodal texts) work. Critical literacy practices in problem-based inquiry might include:

- Asking questions about the intention of the authors
- Examining multiple and/or conflicting texts
- Investigating the source of information
- Comparing and cross-checking the accuracy of information

In everyday-related problem solving process, students often search for science information on the internet for their interested topics or problems. Telling the difference between *fake news*, i.e., news from unreliable sources and evidence-based information online from reliable sources can be tricky for even the competent literate adults and the savviest media critics. Current sophisticated new software (e.g., Photoshop or a computer programme that can manipulate a video of a person on-screen) has made it harder to detect this kind of news and information fakery and manipulated video and audio productions on scientific facts. As technology has changed the nature of problem solving practice in real-world situations, it is critical to reflect this change in the teaching of problem solving in school science by introducing critical literacy lens to help understand problems and problem solving process.

The importance of critical literacy practices raises pedagogical concerns for elementary teachers such as how to help students become capable of evidence seeking and evaluating the authenticity of information during their problem solving. Based on these challenges, the study looks into the tendencies of students' problem framing and information seeking during problem solving in science classrooms. Based on our research findings from this study, we attempt to understand the possibilities and challenges of critical literacy practices in problem-based inquiry and develop teaching strategies and pedagogical recommendations for students' critical evaluation of information.

Study Design

Participants and Curriculum Design

This study was conducted in a Grade 5–6 combined science classroom in a public elementary school in Western Canada. Twenty-four students (12 Grade 5 and nine Grade 6 students) and a classroom teacher worked on problem solving process in the unit of Trees & Forests for 12 weeks. In the beginning weeks of the unit, the classroom teacher and students reviewed science concepts of forests and trees such as types of trees, animal habitats and ecosystems in forests, values of trees and forests, sustainability, etc., based on the curriculum. They also explored news articles related to trees and forests in local communities. The teacher encouraged students to come up with research topics related to the unit of *Trees and Forests* and investigate their own problems later on. In the beginning of students' problem solving, the teacher and students also discussed what fake news was and how they could find reliable information for problem solving. The teacher shared information on how to identify reliable and valid resources such as questioning who is the knowledge provider, which sources are more reliable than others, cross-checking information across websites, etc. When she introduced the importance of trustworthiness, she used the terms, reliability, validity, and trustworthiness interchangeably without making any distinctions. In addition, the teacher showed examples of reliable sources to the students such as research done by scientists and news articles from national broadcasting companies. During the study, they had two field trips (one for tree planting at a local park and one for visiting forests at a local nature sanctuary), and the teacher invited two guest speakers from local forests and forest products associations and a researcher from a university to share their knowledge of trees and forests in the classroom.

Students developed their own research questions and sought information to understand and answer their own research questions. Based on students' research topics and interests, the teacher put students in small groups of 3–4 to work together. Students were also encouraged to email experts in universities and local forest groups to ask their questions and some experts replied to them with encouragement and answers. In the last week, students presented their final outcomes to each other and students in other classes in the format of science fairs.

Local Contexts

In 2016–2017, there were many wildfires and fires which caused severe damage in forests and local communities. In Fall 2016, the class accommodated several students from other regions who lost their homes and schools because of fires in their community. Throughout 2017, there were several wildfires on the Rocky Mountain area, which caused acres of tree burning, destruction of animal habitats, smoke, and asthma warning in the city. Thus, students were aware of the impact of fires in the forest and local communities. Another current concern in the local forest is the threat of Mountain pine beetles to local forests. In Summer and Fall of 2017, there were many news articles by national and provincial broadcasting companies on the serious threat of Mountain pine beetles attacking the province's boreal forests and spreading eastward across Canada (Todd, 2017, CBC news). The teacher and students brought the news articles to class and shared the stories of wildfires and mountain pine beetles in provincial boreal forests and national parks that students had visited.

Data Collection and Analysis

A qualitative case study was employed in this study. Two cameras videotaped the teacher and students' interactions and classroom activities during problem solving. Students' classroom artefacts such as research notes, email communications, presentation files, pictures of diorama of wildfires and forests, and storybooks were also collected. At the end of the study, students were asked to write their reflections on the challenges of problem solving process and strategies of information evaluation. The researchers reviewed students' reflection notes on their experiences of critical literacy practices and invited five students to 20 min semi-structured individual interviews to clarify their ideas on reflection notes and also share their stories of problem solving three weeks later. These students were chosen as they had different research topics (two from Mountain Pine Beetles, one from wildfire, one from sustainability, and one from tree diseases) and demonstrated active participation and interactions during class activities. Thematic coding strategies were employed for data analysis. First, for open coding, all video data, artefacts, reflection notes, and interviews were reviewed separately by the researchers. The researchers came up with themes by cross-checking the different data sources. For axial coding, the researchers met to share the themes from their initial coding and discussed the similarities and differences of themes. When there were differences in coding, the researchers looked through the data relevant to the themes that differed and discussed how to re-examine and negotiate the differences. Through a recursive process, the researchers together analyzed and negotiated to reach agreement on the common themes. For selective coding, the researchers selected a few episodes which distinctively exhibit the themes that we agreed upon. During this coding, we looked into students' verbal and written explanations, interactions during classroom activities, artefacts (modelling and presenting), and interviews to develop the depth of our understandings of the themes.

Study Findings

Locally Contextualized and Scientifically Oriented Problems

In students' problem framing process, it was evident and not surprising that students' research topics and questions were inspired and motivated by local contexts such as Mountain pine beetle problems, wildfires, and animal protection and sustainability in the local forests. Eight students chose to study Mountain pine beetles (MPBs) problems in the forests, five students chose forest fires, three students chose wood products, three students chose animal protection, and two students chose tree diseases. As their research problems emerged from their interests in social and local issues, their problems were framed with the ill-structured and complex approach and then became specific and oriented to science knowledge. For instance, students in the MPBs group raised a question, *why the MPBs is a big problem today and how people can stop it*. Then, they developed specific questions to research scientific knowledge around MPBs in order to move forward their problem solving. For example, students came up with scientific questions such as where MPBs live and breed, how long they live, what they eat, who eats MPBs, etc. Another example is shown in the students' group working on the topic of the substantiality of local forests. To understand the question, *if local tree harvesting plans are sustainable*, students wanted to know specific details of the types of local trees, tree cutting and wood products, and decision-making regarding the long-term harvesting plans by the local forest industry, for instance, *how many years does it take for the forest to grow back in Alberta, how many trees are cut every year, and how old are trees when they are cut*. Students' research questions started as broad, socio-environmental, and ill-structured problems in local contexts and later developed into well-structured, scientific questions in order to answer their research question. Students' problems were locally contextualized and scientifically approached to understand and solve their problems.

Seeking Sources of Knowledge and Evidence

As students' research topics were new, emerging, and specific to the current local problems, their problem solving required resources beyond the curriculum and classroom materials. Even though there were information and resources available in the class (e.g., forest ecosystems, tree identification charts, leaf patterns, human usages of forests, etc.), they were not enough to answer specific questions such as what the life cycle of Mountain pine beetles is, what the causes and consequences of forest fires are, how engineered wood products are made, etc. Thus, students expanded their search to web resources, contacted expert groups, and went to their local libraries with their parents outside of the school. Based on classroom observation, students' research notes, presentations, and reflection writings, it was evident that all students used information from websites to answer their questions. In their research notes, all students included web resources and four students included information from experts' emails. In their final projects, about 70% of students used web resource information with citations in their poster boards and PowerPoint presentations while the rest made models of Mountain pine beetles' lifecycles and diorama of forest fires and roleplayed in broadcasting a news segment on environmental issues in the national parks. Despite the diversity of their presentation formats, students all included information from web resources. The web sources that students used were websites of Government agriculture and forests, NGOs of local forests and products, the local and national broadcasting companies, e.g., CBC (Canadian Broadcasting Corporation) news, National Geographic kids, Discovery education, YouTube, and Wikipedia. There was also information from experts such as researchers and scientists from universities, government forest association, and wood engineering companies. Some students used books on certain topics such as mountain pine beetles, forests, and wildfires, but they explained it was difficult to find books to answer their specific questions whereas it was convenient to find information online. Internet resources seemed instantly available and accessible to students, thus, they were conveniently used by most students for problem solving.

Implementing Strategies for Evaluating Evidence

As students encountered various web resources during their research, it was critical for students and the teacher to understand and examine the trustworthiness of information sources to justify their claims. Based on students' research notes, written reflection, and interviews, it was found that students practiced the following criteria to validate the information for their problem solving.

Cross-Checking Across Websites and Research Notes with Peers

In the beginning of students' problem solving, the teacher discussed critical literacy practice strategies in class. Among those strategies, the most frequently used strategy was cross-checking of multiple websites. With specific questions such as where MPBs live and how they travel, students encountered different websites through search engines. To evaluate if the information was reliable and trustworthy in those websites, students said they checked if the same information was presented across the websites. Students explained once they found similar or the same ideas across different sources, they took it as reliable and valid information. A student, Nate explained during the interview as follows:

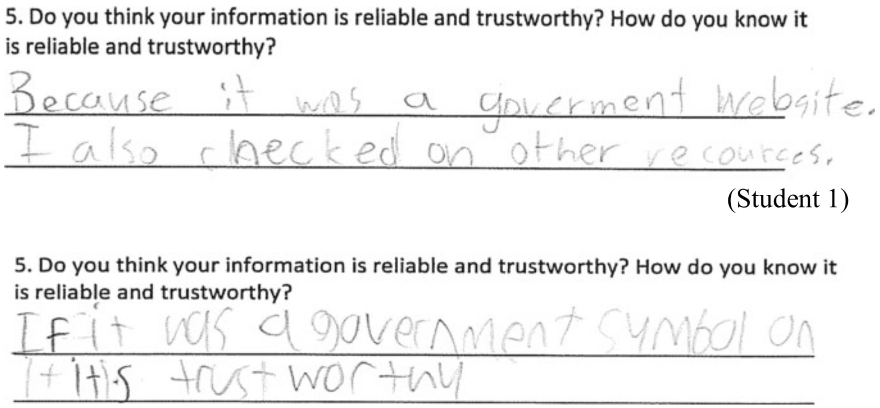
Dialogue #1

Interviewer	So [you said] you were checking websites, books, Wik-ipedia… What were you checking on?
Nate	I was checking on if what it says was true.
Interviewer	How do you know it's true?
Nate	Well, if the most sources say that, mostly the same thing, then it's probably true or else it's probably a big scam

Students also compared their individual research notes with team members to confirm their collected information. As they got information from different sources to answer the same research questions, they said it was useful to compare their research notes. Through the cross-checking and comparing process, students evaluated and validated the information as evidence to answer their questions and later included it in their final reports and presentations.

Evaluating the Trustworthiness of Websites

In the beginning of the unit, the teacher searched and shared local newspaper articles to engage students into the topic and students also started to bring more articles to update each other on the topic. The teacher further shared information from the websites of the government and research centres and discussed if and why those resources could be more valid and reliable than others. Through the collective review and discussion in class, she raised the importance of evaluating the trustworthiness of information in websites. Evidently, students began to practice critical review strategies in their own information seeking. It was observed students looked for the government logos or URLs ending with.ca or.gc.ca to identity those websites during their research. They indicated that certain web resources were more reliable and trustworthy than others such as the government websites, e.g., Agriculture and Forests of Canada or National broadcasting company. Seen in the example of students' reflection notes



5. Do you think your information is reliable and trustworthy? How do you know it is reliable and trustworthy?

Because it was a goverment website. I also checked on other recources.

(Student 1)

5. Do you think your information is reliable and trustworthy? How do you know it is reliable and trustworthy?

If it was a government symbol on it it's trustworthy

(Student 2)

Fig. 1 A snapshot from students' reflection note

(Fig. 1), almost all students acknowledged the Government of Canada website was reliable and trustworthy in their written reflection and during interviews.

During the interview, students mentioned that the information on the Government website looked reliable because they put the footage of the authors who actually wrote each part of the website information on the website. Students also cross-checked the information on the Government website with other resources (Fig. 1, student 1). They explained information at any websites created by universities and educational NGOs (e.g., workwild.ca) would be valid as it was provided by researchers and scientists in the field. Students said websites with 'org' also seemed trustworthy and reliable. To verify the validity of those websites, some said they looked for logos or copyright symbols at the bottom of the websites (Fig. 1, student 2). Students did not use much information from Wikipedia as they said Wikipedia was not reliable as everyone could change the text. Interestingly, one group of students trusted some information from videos they viewed on YouTube channels. Students argued that videos with high numbers of viewers would be reliable as one student said, '*Four thousand people watch this video, it couldn't be fake!*'

Information from Direct Contact with Experts

The teacher's efforts to invite guest speakers to the classroom and contact experts via emails helped students to get valid information for their problem solving. Students had two guest speakers from forests and wood engineering research institutions and also contacted a couple of researchers in universities via emails. Students asked their specific research questions such as 'Why do you guys make a 200 year plan for harvesting? What part of Alberta do you cut trees? How many trees do you harvest each year? Would burned trees be still good wood to make wood products?', and experts provided students with information relevant and specific to students' problems. Students relied on information they received from the experts via emails and guest speakers to answer their research questions. Students explained that the expert knowledge was true and reliable, thus crucial for their problem solving.

Dialogue #2

Interviewer	How did you know what he said was reliable?
David	Because he was the senior forest entomologist at the university.
Interviewer	So do you think that makes difference?
David	Yah, the title! I mean, you can't just get through the university, just saying I know about this and you lie and then it's actually no

In the interview dialogue #2 above, David trusted the expert's title qualified his information to be true as he added later that to get the title at the university required years of research, which means his knowledge was valid and reliable. Experts also sent students some websites to go to via emails together with their answers to students' questions. Students explained these websites were trustworthy because they were recommended by experts.

Teacher as a Trustworthy Information Provider

It is not surprising that students strongly agreed that the information from the teacher was valid and trustworthy, yet, it was worthwhile paying attention to how students justified their trust on the teacher's information as valid information. During the interview, students explicitly said that some information was valid because it was from the teacher. One student said, '*If she is not correct, she would say. The other day, she said, 'oh I was wrong yesterday' and tells what's right. In other class, she said, 'I don't know well about this, I will check' and next day, 'oh I was wrong, it's actually this*'. The way the teacher checked, verified, and shared information with students was perceived as a trustworthy action. The teacher acknowledged her mistake that she provided the wrong information to students and later corrected it with another information. Based on some students' comments regarding the inaccurate information and further correction provided by their teacher, it suggested that the teacher's act was perceived as genuine and sincere inquiry process to get trustworthy and valid information. The teacher was trustworthy not because she was always right with correct knowledge but she humbly acknowledged her mistakes and ignorance and corrected it in front of the students to improve the validity of information for problem solving. Based on their trust toward the teacher, the information and websites introduced and used by the teacher were recognized as trustworthy and valid information sources.

Conclusion & Discussion

In this study, it was apparent that students chose their own topics of interest in relation to the current local society and environment, which increased engagement and motivation. Students started with broad, locally contextualized research questions and later developed scientifically oriented questions to understand and solve their research questions, which was connected to science concepts in the curriculum. Students were highly motivated to search for information through various resources. A student during the class said that he stayed up till midnight searching for information because he was so interested in his topic. Other students were also eager to contact experts with curiosity and enthusiasm when they could not find answers from other sources such as websites, books, or other adults around them. Because students research questions were framed around the very current local issues which were not part of the curriculum and there was not much upheld knowledge, their problem solving stretched the boundaries of learning beyond the classroom, which challenged the teacher to provide relevant resources to keep students' motivation and engagement in researching. For this very reason, the dependence on web resources was evident in this study and it was vital for the teacher and students to understand and practice critical literacy skills to evaluate out-of-classroom resources.

To develop students' critical literacy skills in problem solving contexts, the teacher facilitated various teaching strategies on how to look for valid information. In the beginning of the unit, she shared the importance and various ways of critical literacy practices such as cross-checking and examining the sources of information and ongoingly asked students to justify the trustworthiness of their information. She also demonstrated the research process of information seeking, verifying and sharing information, and examining her own mistakes in front of the students. As students perceived the teacher as a trustworthy information provider, demonstrating the practice of critical literacy skills on her problem solving became an effective teaching strategy to encourage students to practice them on their own. For further scaffolding, the teacher sought support from experts to provide more information to students. She invited experts as guest speakers to classrooms and contacted researchers in research institutions to share their expert knowledge and help with students' questions via email, written texts or conversations on their specific topic. With the teacher's pedagogical scaffolding on critical literacy practices, students practiced critical review of resources and developed their strategies of researching information and evaluating evidence to complete their problem solving. Students began to practice cross-checking, member checking, checking the information source of the website and trusting resources from the teacher and experts.

This study shares possibilities of developing students' critical literacy practices during students' ill-structured problem solving process on new and current issues in science classrooms. As students are often interested in current local issues, which are new, emerging, and thus unknown to the teachers and students, web resources could be the most convenient sources for the most updated and current information on the issues in the local communities. As technology is everchanging the accessibility and availability of information; thus, the ways of people's problem solving in today's world, teaching problem solving in science classrooms need to reflect this change by incorporating critical literacy lens for the validity of information (Comber, 2003; Freebody & Luke, 1990; Green, 2012). Like people's problem solving in everyday lives, classroom problem solving especially on socioscientific and environmental issues depends on web resources as possible learning tools in today's classrooms (Iding, Landsman, & Nguyen, 2002).

Online resources helped students in this study to understand the details of problem contexts and find possible answers and solutions to their problem, which could not be provided by the curriculum materials in classrooms. Students, through critical literacy practices in online space, started to practice the strategies that the teacher shared in the beginning and further developed their own strategies, for instance, expanding cross-checking of websites to comparing their research notes and member checking among classmates or with the adults in the classroom. They also added more criteria on evaluating websites such as looking for copyright symbols, no commercial ads, numbers of viewers, etc., through group and class discussions. As some students mentioned the YouTube video viewed by thousands of people was a reliable resource because of the numbers of viewers, their criteria were not fully developed and sophisticated. However, we believe their critical literacy skills will be developed through teachers' ongoing scaffolding and classroom practice. We used some scaffolding strategies to teach students how to critically evaluate online information. We encouraged the student to think aloud and question the author's intentions and points of view on the topic and to guide them to check the validity of online sources by asking the following questions:

- Who is the author of the information? Is the author an expert in the field?
- What are the intentions of the author? What does the author want the audience/reader to think?
- Whose voices are represented? Whose voices are discounted?
- What would an alternative source say about the same topic?

These questions could be modified and expanded to scaffold students' critical literacy practices further based on the students' grade levels, research topics, and sources of information during problem solving.

Emphasizing the possibilities of developing critical literacy skills during problem solving, we also acknowledge there are concerns and challenges such as problem solving inquiry requires much dedication and attentiveness from teachers to plan and facilitate in classrooms as the access and availability of online information is often vast and overwhelming and sometimes teachers by themselves get challenged to detect invalid online information. This demands teachers' open-mindedness and willingness to become a problem solver by practicing critical literacy skills together with students. As students will live in a more digitally oriented society, how to scaffold students' critical literacy practices will become more crucial and challenging for teachers in classrooms. There needs to be further attention and research in-depth to understand the possibilities and challenges of teaching problem solving inquiry in science classrooms in the post-truth era.

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Chapter 10
Assessing Conceptual Understanding in Primary Science Through Students' Multimodal Representations in Science Notebooks

Caroline Ho and Fei Victor Lim

Abstract This chapter reports on a study which explored how teachers could identify gaps in their students' conceptual understanding, and facilitate students' use of both appropriate content vocabulary and visual representations to communicate scientific concepts through the use of science notebooks. The study pilots a framework that was developed for assessing, through students' artefacts, the extent to which students' conceptual understanding, specific content vocabulary, and the ability to show relationships between concepts were made explicit. Implications are discussed, with attention given to refinements of the framework.

Introduction

There is a growing recognition of the significance of teachers' multiple representation modes used to construct scientific knowledge in the classroom (Edwards, 2015; Klein & Kirkpatrick, 2010). This chapter discusses the teachers' attempt at evaluating students' conceptual understanding and language use in science through students' multimodal representations in their science notebooks. This chapter argues for the value of adopting the lens of multimodality in science education. It reports on the pilot of a framework to evaluate students' multimodal meaning-making in their science notebooks, in particular, to identify evidence of their conceptual understanding of science. In line with the overall focus of this volume, the aim of this chapter is to show how the introduction of the dimension of multimodality in science education can provide teachers and educational researchers with a new lens to examine students' conceptual understanding of science to enhance their science learning. It also discusses how teachers can assess, through the pilot of a framework in the study,

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students' conceptual understanding expressed in their appropriate use of language for science and multimodal representations in their science notebooks.

Multimodality in Science Teaching and Learning

Meaning in science is made through multiple modes such as language, images, diagrams and figures (Halliday & Martin, 1993; Lemke, 1998; Marquez, Izquierdo, & Espinet, 2006; Schleppegrell, 2004). Prain and Waldrip (2010) highlighted the importance of understanding students' development of scientific literacy through student-generated multimodal representations. Airey and Linder (2009) proposed theoretical inroads to be made in understanding which 'constellation of modes best opens up the possibility for experiencing each of the particular ways of knowing' (p. 42). Tang (2015) also argued that 'literacy instruction that scaffolds students' knowledge and practices toward scientific multimodal practices is relevant and necessary' (p. 318). This culminates in the call to reconceptualise science education by extending beyond the domain of print-oriented academic language to that of multimodal discourse as it promotes students' deep understanding of concepts (Edwards, 2015).

Multimodal literacy is about students learning to view multimodal texts critically and to communicate effectively through multimodal representations (Jewitt & Kress, 2003; van Leeuwen, 2017; Lim, 2018). Multimodal literacy draws on the understanding of how linguistic and non-linguistic choices integrate and interact in the organisation and development of information and ideas (Lim, O'Halloran, Tan, & E, 2015). As students engage in the process of knowledge co-construction through meaning-making across various semiotic modes (Kress & van Leeuwen, 2001), they are provided with opportunities to exercise their 'creative, adaptive capacity in using semiotic resources to construct meaningful knowledge through multimodal representations' (Ho, Nelson & Mueller-Wittig 2011, 1084).

The study described in this chapter contributes towards our understanding of the benefits of students' multimodal meaning-making through their entries in science notebooks. It presents an approach, prototyped in a school on the Whole School Approach to Effective Communication in English administered by the English Language Institute of Singapore (ELIS) (ELIS, 2011), of how students' conceptual understanding and language use can be assessed through their multimodal artefacts in a primary science context. Studies on students' use of multimodal representations in science learning include Yeo and Gilbert's (2017) research on secondary school Physics students' use of various multimodal representations in scientific explanations, as well as Tang, Ho and Putra's (2016) research on how teachers supported secondary school Physics and Chemistry students to interpret, translate and integrate multimodal representations s in written scientific descriptions and explanations based on observable phenomena. There is presently a dearth of related studies pertaining to monitoring students' conceptual understanding and language use through multimodality in learning science at the elementary level. This study attempts to fill the current gap, particularly in the research context of this region.

Students' Science Notebooks

Ruiz-Primo, Li, and Shavelson (2002) define a science notebook as 'a compilation of entries that provide a partial record of a student's instructional experiences over a certain period of time' (p. 2). By capturing information about the students' learning experiences with the scientific phenomena, science notebooks 'imitate the journals that actual scientists use as they explore the world' (Hargrove & Nesbit, 2003, 3). As such, notebooking encourages students' natural curiosity and enhances their motivation for learning by making meaningful connections to their everyday life.

In addition, students' use of science notebooks offers teachers an opportunity to 'assess students' understanding and provide the feedback students need for improving their performance' (Ruiz-Primo et al., 2002, 24). As students write and draw in the notebook, their thinking is made explicit and this provides the teacher with valuable insights on the students' understanding. In this study, we examine the implementation of a framework developed with explicit criteria to support teachers in monitoring students' use of language and visual representations to express their conceptual understanding in science.

Study on Primary Students' Use of Science Notebooks

The study is contextualised in a Singapore primary school in a public housing estate with a mix of students from working class and middle class socioeconomic background. Primary schools in Singapore offer a six-year curriculum in English, Mathematics, Mother Tongue and Science for students from age seven (Grade One) to twelve years old (Grade Six), leading to a national examination – the Primary School Leaving Examinations (PSLE).

The study was guided by two questions:

- What benefits, in terms of supporting and monitoring students' science learning, does the use of science notebooks offer to teachers and students?
- How can a framework support teachers in assessing students' conceptual understanding through their multimodal representations in science notebooks?

The study involved eighty Grade Five students from two classes (one high progress and one mixed progress) and seventy-five Grade Six students from two classes (one high progress and the other low progress). The lessons focused on the topic of *Cells*. The two teachers, under the guidance of their former head of department, jointly planned the lessons by integrating the use of science notebooks into their lessons to support students' learning in a systematic and organised way. The teachers used the 5E Inquiry-based Instructional Model (Bybee et al., 2006) to guide their planning. Students in the initial 'Engage' and 'Explore' stages learned about the different parts of cells. The next stage, 'Explain', was where the different functions of parts of the cell were unpacked with the integration of student-generated representations into lessons. The teachers, at this stage, sought to draw out students' understanding of the different parts of cells and their respective functions with templates and instructional resources. Students folded the cut-outs from the templates and wrote the labels of the relevant parts and description of the corresponding functions of the parts of animal and plant cells (Fig. 10.2).

Guided by the teachers, students discussed their ideas in groups of four to five students. Individually, they then made decisions on which aspect of the science phenomena to represent and how these can be realised through the use of writing and visual representations. Upon completion of their notebook entries, students, through gallery walk and presentations in class, responded to peer feedback and provided input on other students' work. To reinforce their learning, students progressed from the template cut-outs to individually drawing their notebook entries and crafting written descriptions of the various parts and functions that made up plant and animal cells. The students' entries in their notebooks are the primary data examined in this chapter.

Assessing Conceptual Understanding and Language Use in Science

A framework (Fig. 10.1) was developed to monitor and assess the students' levels of conceptual understanding, procedural knowledge and language use in their multimodal representations. The framework was focused on three domains: science concepts, content vocabulary and visual representations. The domain of science concepts examined the degree of accuracy in the conceptual understanding conveyed and the students' ability to show relationships between concepts. Content vocabulary was about students' use of the scientific register, that is, the appropriate scientific vocabulary to represent their understandings. With visual representations, the extent of accuracy and specificity in the labelling of details in the visuals was of interest. The students' level of proficiency in these areas were categorised as Beginner, Emerging and Competent.

The teachers applied the criteria in the prototype framework holistically for formative assessment of their students' learning. The framework was not intended for summative assessment in the form of a numerical scoring rubric to measure students' achievement. Rather, it served as a diagnostic tool for the purpose of guiding teachers in determining students' strengths and weaknesses in specific domains for appropriate follow-up with students.

Domain/Level	Competent	Emerging	Beginner
Science concepts	The written text demonstrated understanding of **MOST** of the science concepts accurately and attempted to show the relationship between concepts	The written text demonstrated understanding of **SOME** of the science concepts accurately and attempted to show some relationship between concepts.	The written text demonstrated **LITTLE / NO** understanding of science concepts, with no attempts at showing the relationship between concepts.
Content vocabulary	Appropriate scientific vocabulary was used **MOSTLY** accurately to convey understanding of the science concept.	Appropriate scientific vocabulary was used, with **SOME** minor lapses, to convey understanding of the science concept.	**LITTLE / NO** use of appropriate scientific vocabulary to convey understanding of the science concepts.
Visual representations	Visual representations are **MOSTLY** accurate and labelled with the relevant details.	Visual representations are **PARTIALLY** accurate and labelled with **SOME** details.	There are **FEW / NO** visual representations with no details labelled.

Fig. 10.1 Framework for assessing students' conceptual understanding and language use through multimodal representations (Adapted from Ruiz-Primo, Li, & Shavelson, 2002; Reed, 2012)

Discussion on Applying the Framework to Students' Artefacts

The template (Fig. 10.2) designed by the teachers served as scaffolds to guide students in generating their own representations of the plant and animal cells in their science notebooks. The teachers emphasised the need for accuracy in their students' expression of science concepts, content vocabulary, and visual representations.

Figure 10.3a and b showed a student artefact evaluated by teachers as Competent. The teachers observed that the student showed an accurate understanding of the composition of animal cells through visual representation (Fig. 10.3a). The student used the scientific vocabulary taught and made clear, through arrows serving as directional

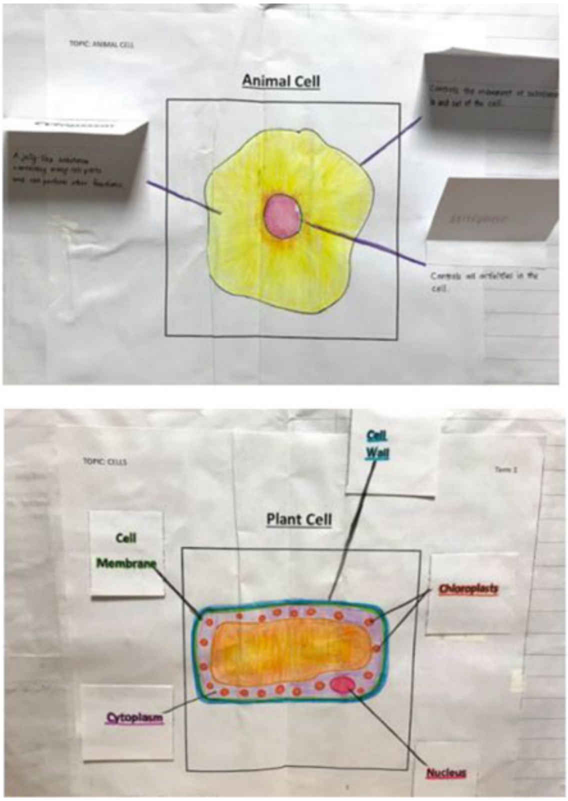


Fig. 10.2 Students' notebook entries using cut-outs to label parts of cell

signs, the various parts of the cells. The teachers also felt that the visual representation of the plant cell (Fig. 10.3b) was accurately drawn and neatly labelled. It was unsurprising to the researchers that the student's representations in Fig. 10.3 were classified as Competent as it had close resemblance with the representations in the teachers' template (Fig. 10.2). Based on the domains in the framework, the student's representation had demonstrated an accurate expression of science concepts, through appropriate scientific register, as well as accurate depictions of the visuals.

It was interesting to note that, in the student's representation of the animal cell, two more visual representations, not shown by the teachers in their example of an animal cell, were added. These additional representations that accompanied the cell membrane and nucleus could be conveniently ignored, and taken as distracted doodles in the science notebooks, as they may not be recognised as the privileged representations sought by the teachers. Nonetheless, it can be of interest to study these visual representations more closely. The visual representation at the top right in Fig. 10.4 appeared to be a rectangular opening, with three short oblique lines, flanked by two similar shapes. Its proximity to the description of the cell membrane suggested that it could be related to the linguistic text. The context of knowing that earlier in the lesson, the teacher had described the cell membrane using the metaphor

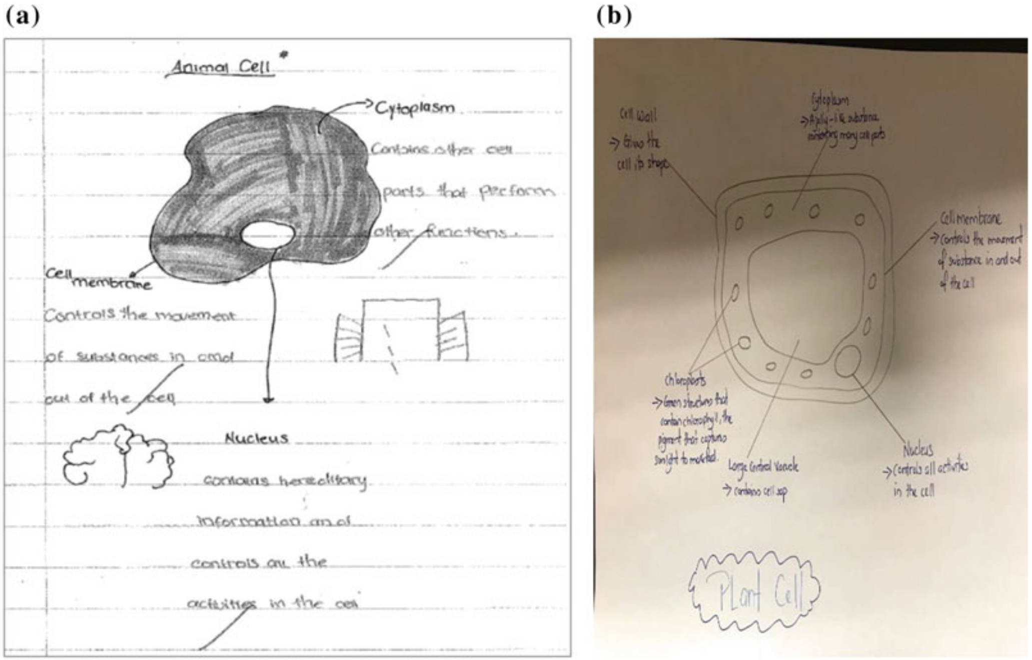


Fig. 10.3 a Student artefact A of animal cell. b Student artefact A of plant cell

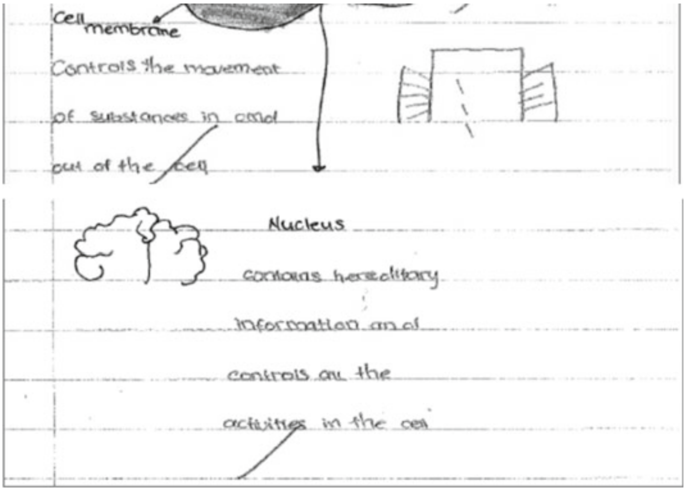
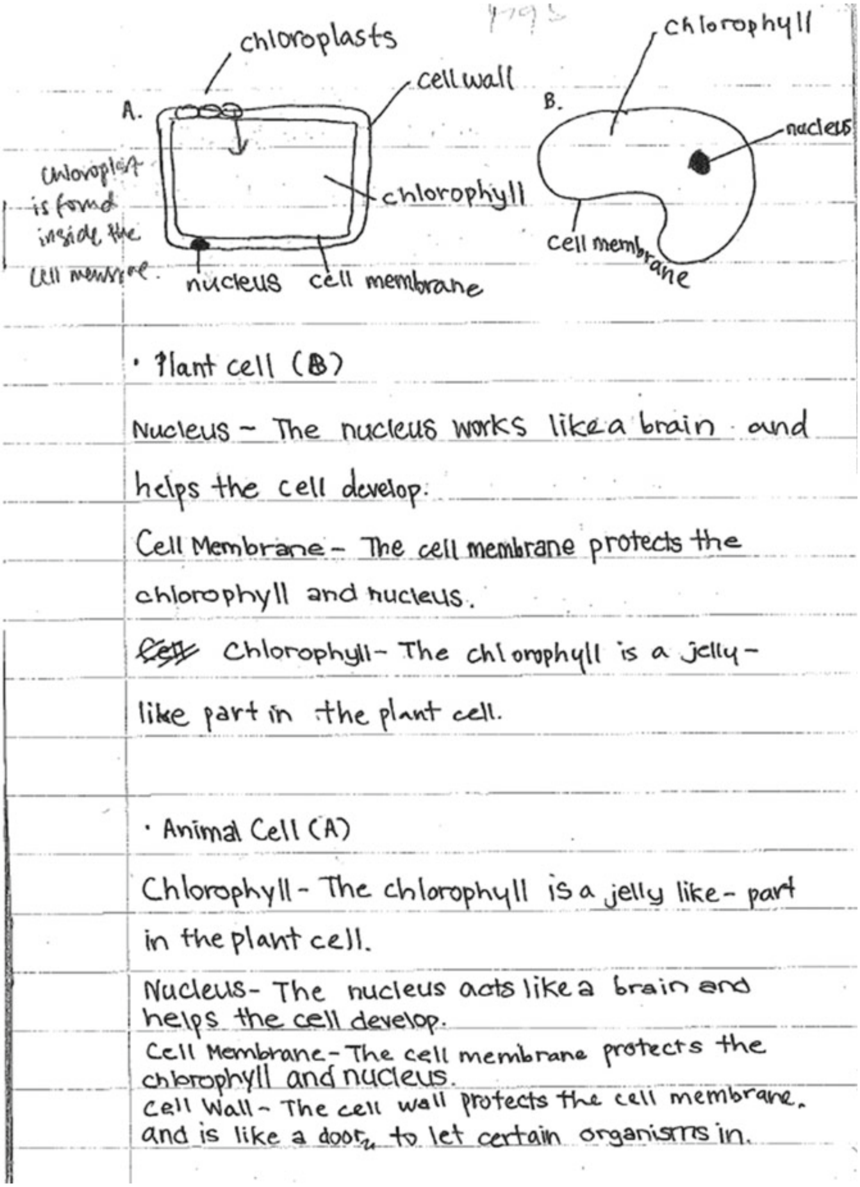


Fig. 10.4 Additional visual representations in student srtefact A

of a door that lets other organisms in, helped us to elucidate the meaning of the visual representation made by the student as that of a door, with the oblique lines signifying movement of substances. The bottom left visual representation in the same figure, while more abstract, is positioned next to the linguistic text on the Nucleus, which ‘contains hereditary information and controls all the activities in the cell’. In relations to the linguistic text, a possible interpretation of the waves in the visuals could be that it signified the ‘hereditary information’, as well as a visualisation of ‘control’.

In recognising the meanings of the signs made by students, we follow Kress’s (2010) argument that all signs are motivated and realise the interest of the sign-maker - in this case, a ten-year old child expressing his nascent understanding of scientific concepts. Rather than ignoring them as irrelevant squiggles, the two additional visual representations are recognised as motivated and meaningful in expressing the student’s rudimentary attempt to signify the ‘relationships between concepts’ as described in the framework. It is also of interest that while the student has produced a faithful reproduction of the visual representations from the teacher’s example, he has also engaged and negotiated with the knowledge presented by the teacher and exercised his creativity to produce original and creative representations. The latter is learning, in the social semiotic sense, as the student is engaged in an active process of transforming his inner world of knowledge through his representations. Kress (2010, 182) defines learning as ‘the result of the transformative engagement with an aspect of the world which is the focus of attention by an individual, on the basis of principles brought in by her or him to the engagement, leading to a transformation of the individual’s semiotic/conceptual resources’.

Figure 10.5 showed a student artefact classified as Emerging. The teachers explained that the visual representation of an animal cell was inaccurate as cell wall, chloroplasts and chlorophyll were irrelevant to animal cells. They also observed that



- Plant cell (B)

Nucleus - The nucleus works like a brain and helps the cell develop.

Cell Membrane - The cell membrane protects the chlorophyll and nucleus.

~~Cell~~ Chlorophyll - The chlorophyll is a jelly-like part in the plant cell.

- Animal Cell (A)

Chlorophyll - The chlorophyll is a jelly like-part in the plant cell.

Nucleus - The nucleus acts like a brain and helps the cell develop.

Cell Membrane - The cell membrane protects the chlorophyll and nucleus.

Cell Wall - The cell wall protects the cell membrane. and is like a door, to let certain organisms in.

Fig. 10.5 Student artefact B

the student did not use the scientific language but described the parts of the cells in figurative language, namely, ‘works like a brain’, ‘jelly-like part’, and ‘like a door to let organisms in’. As the vernacular register, rather than the scientific register, was used, content vocabulary was classified as Beginner level. The visual representation was also only partially accurate as there was an omission of chlorophyll and cell wall. Hence, the visual representation was classified as Emerging. Furthermore, the teachers felt that there were insufficient details in the way specific aspects of the science concept were described. For example, it was not merely that chloroplasts helped the cell to develop, but that chloroplasts which contained chlorophyll were used for the plant cell to make food. They also pointed out the inaccuracies in the visual representation and labelling of specific features in the plant cell. Chloroplasts do not occur between the cell wall and cell membrane; in addition, the chlorophyll should be positioned inside chloroplasts. In light of these inaccuracies, the teachers felt that the student’s artefact was at the Emerging level. The researchers observed that the student had not consistently used scientific vocabulary with the level of precision and accuracy demanded of the subject. Insufficient details were observed in the description of key aspects of the concept. With regard to topological meanings, inaccuracies in the visual representations of the animal cell with the cell wall, chloroplasts and chlorophyll clearly irrelevant to animal cells pointed to a less than competent grasp of the targeted key concepts.

Figure 10.6 illustrated a student artefact classified at the Beginner level. The teachers noted the accurate drawing and labelling of the cell wall in the plant cell although the cell membrane in the plant cell was not labelled. The student further did not describe the functions of the parts. As such, the teachers were unable to determine the extent of the student’s conceptual understanding, as well as the appropriate content vocabulary acquired.

Given the lack of details in the student’s representation, assessing students’ learning through the artefact posed difficulties. Notwithstanding, the researchers noted the fairly accurate visual representations of both the animal and plant cells, as well as the correct labelling of the parts. The student appeared to have demonstrated the understanding of the science concepts as expressed through the visual representations.

Teacher and Student Perspectives

The teachers and students’ perspectives were elicited from their reflections conducted post-lesson. The guiding questions focused on the benefits from the use of science notebooks and the framework piloted to assess students’ conceptual understanding and language use through multimodal representations.

The students reported that they had ‘a deeper understanding of the science concepts’, and that the notebooking activity had ‘made difficult concepts or words easy to understand’ and ‘helped them understand the topic better’. Students’ language use has also improved as they were able to use ‘more scientific words’, know ‘how to

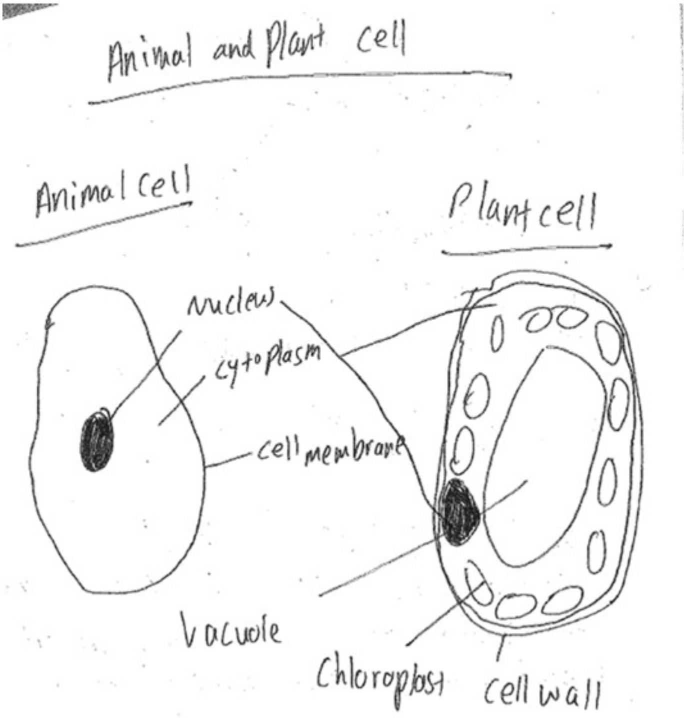


Fig. 10.6 Student artefact C

describe the function of parts' and 'answer in a more scientific way'. Visual representations supported students' learning as 'the visuals help[ed] [them] organise the information clearly' and developed in them the understanding that 'science concepts do not always have to be represented in sentences'.

The teachers' perspectives highlighted the value of the framework as it supported teachers to 'pinpoint, zero in [and] highlight specific areas of weaknesses of students individually and on a class level', and to differentiate students' learning needs so as to determine 'which aspects of the topic to re-teach, recap and emphasise'. The teachers expressed that the framework has made explicit the 'expectations and demands' and was a 'powerful diagnostic tool' for them. Teachers noted that 'all three domains – science concept, content vocabulary, and visual representations are equally important', although they felt that, in particular, 'content vocabulary was useful' as the examinations required the 'use of precise content vocabulary'. The teachers' use of the framework to evaluate students' multimodal representations indicated a high level of implicit trust and a reliance on the areas and descriptors explicated in the framework. As such, the researchers felt that there is value in further improving the framework based on the teachers' reflections and how they have used it in this study.

Discussion and Implications

This study is contextualised against the growing interest and work on multimodality and science education internationally. Students' use of science notebooks offers a way to encourage them to think, learn and communicate science like professional scientists (McDermott & Hand, 2013). However, it is also acknowledged that students may not all be versatile and effective in multimodal meaning-making, particularly, in their expression of scientific concepts (Danielsson & Selander, 2016). As such, teachers play a crucial role in facilitating students' learning with multiple representations through explicit instructions (Prain & Waldrip, 2006; Tang, Tan, & Yeo, 2011), as well as providing meaningful formative feedback on students' multimodal artefacts.

In the initial stages of the study, the teachers were concerned over the time constraints within the regular science curriculum to integrate the use of students' notebooks in their lessons. The integration of science notebooks into the classroom is facilitated through the provision of appropriate examples, where teachers modelled and guided students in their notebooking activities. The teachers also took care to ensure that the activity was not perceived as an additional activity, distinct and separate from the science curriculum. Over time, teachers also developed the ability to address the learning needs of students with different abilities. They exercised flexibility to enable high progress students to select their own materials for their artefacts and supported low progress students with modelling and guidance, as well as with examples from their peers.

As teachers developed multimodal literacy in their students through their use of science notebooks, a challenge they faced was to be able to evaluate students' multimodal representations and provide meaningful feedback (Towndrow, Nelson & Yusuf, 2013). In this study, a framework has been prototyped to evaluate students' conceptual understanding and language used in primary school science. This represents a significant first step in supporting the teachers in teaching multimodal literacy within the context of science. Based on how the teachers have used the framework to assess students' multimodal representations and their reflections, some improvements to the framework could be explored.

One refinement could be to recognise and evaluate the types of meanings made through the visual representations. For instance, students could consider how salience or prominence is realised through relative size and contrast. They could also reflect on their choices of the visual elements in the foreground and background, as well as the choices in the positioning and layout of their visual representations on the page. In other words, teachers and students could be guided in recognising the meaning-potential of images and pay more attention to the choices made in visual representations. The recommendation to develop a 'semiotic awareness' (Towndrow et al., 2013) in teachers and students is supported by similar arguments made by Unsworth (2014), Mills and Unsworth (2017), and Lim and Tan (2018), on the importance of developing multimodal literacy in students and to 'structure their noticing, offering a fresh view of choices that may have been taken for granted' (Macken-Horarik, Love, Sandiford & Unsworth, 2017, p. 255).

Another possible refinement to the framework is to enhance the present descriptors for language that focuses on the word level in the content vocabulary domain to also consider how meanings in phrases and clauses can be examined. This could support students in moving beyond the use of scientific terminology, to also be mindful of the linguistic expectations as they construct sentences and longer stretches of text. This will provide a foundation from which teachers and students can build on as students, at higher levels, eventually progress to the production of longer, written answers, which will require them to structure and organise extended texts in the appropriate scientific register.

Conclusion

This study indicates that students were able to show evidence of their conceptual understanding of science and to represent them multimodally in science notebooks. Allison and Goldston (2018) argue that it is critical for pedagogical practice in science to be enriched with meaningful multimodal practices so that students can develop skills and knowledge central to being scientifically literate. As such, we posit that teachers need to be supported in growing their competencies to facilitate multimodal meaning-making in science learning. One of the ways this has been explored in the study is through the provision of a framework that teachers' can use in assessing students' multimodal representations and to elicit evidence of their students' conceptual understanding in science.

This study pilots the initial design of the framework to evaluate students' multimodal representations in their science notebook as evidence of their conceptual understanding in science. As a pilot, this study is limited to a relatively small number of data sets and participants. Notwithstanding, this study indicates that teachers and students are interested in using student-generated multimodal representations and have indicated that there is value in exploring the use of science notebooks as a way to learn science and represent their conceptual understandings multimodally. The study also reports on both the teachers' reception towards and reliance on the framework used to assess students' multimodal representations. This study has demonstrated the value in applying such a framework for teachers to assess students' conceptual understanding in science through their multimodal meaning-making. The framework developed has systematised the teachers' observations of students' multimodal artefacts by drawing on explicit criteria for denoting specific levels of competency. It can, at the same time, be adapted and refined further to accommodate the features discussed earlier. It is important for teachers to be better supported through the development of a more robust framework as they continue to encourage more use of students-generated multimodal artefacts in science learning.

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Chapter 11
An Analysis of Power Play in the Subculture of Lower Track Science Classrooms

Tang Wee Teo

Abstract Subculture refers to a relatively diffused social network of shared identity, distinctive meanings around certain ideas, practices and objects. It emerges from a sense of marginalization from or resistance to perceived norms and conventions of a society. As compared to dominant and mainstream classroom cultures imposed and reinforced by schools or teachers, subcultures—constructed by students—may sometimes seem weird, childish, untamed or silly. Hence, subcultures are seldom taken seriously and deemed to disappear as students mature. In this chapter, I aim to: (1) introduce the concept of subculture, which is rarely discussed in the science education literature, to take a more nuanced approach towards the cultural studies of science education research; (2) demonstrate how an analysis of power relationships can contribute to the understanding of subculture in science classrooms. The theoretical framework used to examine subculture is symbolism interactionism. I analyzed a science lesson in a lower track classroom for the interplay of power between the teacher and students to illuminate the subculture of the science class. Specifically, teacher dominance, student dominance, and balance power play were identified. The subculture was shaped by the power play of the social agents and it was aggregative. The findings have implications for science teaching.

Introduction

Subculture is defined as: "A relatively diffuse social network having a shared identity, distinctive meanings around certain ideas, practices, and objects, and a sense of marginalization from or resistance to a perceived "conventional" society" (Haenfler, 2014, p. 16). To illustrate what subculture means, I refer to the *otaku* in Japan. *Otaku* is a term used to refer to a group of people with an obsessive interest in anime and manga. According to Kinsella (1998, p. 294),

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> Otaku was portrayed as a section of youth embodying the logical extremes of individualistic, particularistic and infantile social behavio[u]r. In their often macabre descriptions of otaku lifestyle and subculture, social scientists conveyed, perhaps, their deeper anxieties about the general characteristics of Japanese society in the 1990s.

As Fiske (1992) has described, subcultures can operate as "shadow cultural economies" (p. 30) for individuals who feel that they are not qualified due to the lack of education, do not possess the necessary cultural capital afforded by their families and social status. This void can be filled in an alternative social world in which they have access to an alternative cultural and social prestige. In the case of the *otaku*, they created an alternative social space in the world of amateur *manga* (Japanese comics).

While the socio-political, socio-historical and socio-cultural origins of *otaku* differ from that of the classroom subcultures, they are similar in terms of the individual or group response to intrinsic needs and extrinsic forces driving them to *perform* or *act out* (Goffman, 1959) in ways that are different from the dominant cultures. It is the "norm" for teachers to have expectations of students to be self-motivated, diligent, achieve academically and respectful. However, McFarland (2001) and many other scholars (see e.g., Boren, 2001; Chory-Assad & Paulsel, 2004; Higginbotham, 1996) have discussed how socio-political, socio-historical and socio-cultural structures can also lead to the emergence of the everyday forms of student defiance.

Subcultures of Schooling

As compared to dominant and mainstream classroom cultures imposed and reinforced by schools or teachers, classroom subcultures created by students may sometimes seem weird, childish, untamed or silly. Hence, subcultures are seldom taken seriously and deemed to disappear as students mature. Subcultures, however, have ushered in generations of adolescents into adulthood, providing affirming spaces for students who might otherwise feel marginalized among their peers (Haenfler, 2014). Subcultures also foster non-normative values that they often take with them as they grow. For example, students may text on the cell phone during a lesson because they think that it is okay to do it as long as they are not caught by the teacher, the enforcer of the school rules (i.e., normative structures). Sometimes, teachers may just forget how brutal school education can be on students who undergo identity crisis, struggle to learn the canonical disciplinary jargons and do not fit in.

The appreciation and understanding of subcultures in science classrooms, however, is poor and this could be in part, due to two reasons. First, schools and classrooms are traditional places where teachers command authority in deciding the rules, regulations and routines (Giroux, 1986). Subcultures (e.g., punk culture) are often stereotypically associated with deviant practices, behaviours and thinking. Subcultures can be misconceived as the opposing undercurrents that intentionally contest the norms for the sake of doing it. This view renders the understanding of subculture as unimportant or something to be eradicated rather than understood and used to inform curriculum decisions.

Second, the current science education literature is picking up on cultural studies, especially when there is a journal (*Cultural Studies of Science Education*) devoted to this genre of work. However, most of the studies discussed cultures as though they represent the mainstream cultures of the context. But what if the cultures are, in fact, subcultures, which emerge from mainstream cultures that can mediate the latter? How would this affect the interpretations of the data and change the implications of the study? A more nuanced approach to doing cultural studies in science education is needed to push the frontiers of this important field of work.

Purpose of This Paper

I take the position that rather than to deny or dismiss the existence of subcultures or contest them in power struggles with students, it is worthwhile for teachers to understand how it plays out in the science classroom to shape the outcomes of teaching and learning. Instead of "causing problems", subcultures often provide solutions to troubled children in the form of a meaningful community (Haenfler, 2014). This paper aims to: (1) introduce the concept of subculture, which is hardly discussed in the science education literature and the cultural studies of science education research; and (2) demonstrate how an analysis of power relationships can contribute to the understanding of subculture in science classrooms.

Theoretical Framework

The theoretical framework used to examine subculture is symbolism interactionism (Blumer, 1969). I use it to unpack the interactions among the social agents—teacher and students—to illuminate the power relationships. In particular, I focus on the discursive exchanges during the science lesson.

Symbolic interactionism is useful in framing the analysis of the power relationships as embodiments of subcultures because it helps to centre the meaning making process on the *existence*, *creation* and *living* of subcultures. I examine how social agents broker their power in constructing, interpreting, modifying and applying different meanings that they attribute to their science curricular experiences. These meanings are derived from the interaction process which could be dialogic or non-dialogic, within self or with others. To give a concrete example of this, imagine Person A asked Person B: "How is it going?" As part of the meaning making process Person A will first try to understand what Person B is asking, why is s/he asking what s/he has asked and what s/he wants to know. Person A will then decide what s/he wants to divulge depending on the relationship s/he has with Person B, how Person B will use the information and so on. Person A may offer a short reply and wait for

Person B's reply to decide if the latter is really interested to know more, is concerned about Person A's well-being or simply paying a curtsey. Hence, meaning making plays a significant role in shaping the content, approach and mood of dialogues.

Essentially, symbolic interactionism is premised on five key tenets that first, a human society or group life comprises of individuals engaging in actions in a repertoire of activities. This is also the case in classrooms where teachers and students engage in diverse social activities—formal and informal, educational and non-educational, productive and non-productive in nature.

Second, social interaction is a process that forms human conduct and not "a thing" that facilitates the release of such human behaviours. The two-way interactive process described earlier is what Goffman (1959, 1975) has described as "acting out" in order to maintain "face". When individuals act according to what is expected, then they are known to be acting "inline"; the contrary would be "out of line". In reality, what constitutes "inline" or "out of line" is not clear because what is the norm within a subculture may be perceived as out of the norm in the main culture. In any case, this second tenet still holds in examining social interactions in subcultures.

Third, the object or products of symbolic interactionism are things that can be referred to. In looking at the subcultures of the science classroom, the interactive exchanges—such as: *Who takes the lead in the topic of conversation? How often does turn-taking happen during the teacher-student interaction? How long did each person speak?*—can be the unit of analysis.

Fourth, symbolic interactionism takes the view that individuals possess the "self" (Mead, 1934) in acting out, rather than being acted upon or on. The self is in a state of consciousness in thinking and acting and not merely reacting or responding to an external stimulus. This is an important tenet in the forming of a subculture, as it does not simply occur, but emerge out of the conscious intent of the social agents to carve an identity and to create a personalized space.

Lastly, the social agents do not act alone but interlinked. Such actions are unlikely to be balanced in a classroom where a teacher is oftentimes regarded as the authority and students engage in power struggles to seek or avoid attention. Hence, the power play will be evident in the formation of maintenance of subcultures as social agents act out against other social agents outside the subculture and from within.

Context of the Study

In this paper, I apply the theory of symbolic interaction to examine the power play in the subculture of a lower track science classroom. The data of this study were drawn from a one-year case study of a Secondary 2 (equivalent to Grade 8, aged 14) lower track science classroom in a mainstream, public, and co-educational secondary school located in the eastern part of Singapore. In Singapore, children undergo six years of compulsory primary education (Grades 1–6, aged 7–12). Based on the results in the national examinations taken at the end of Grade 6, the majority of the students will be streamed into three different tracks—Express, Normal Academic and Normal

Technical. Collectively, I refer to the Normal Academic and Normal Technical tracks as the lower tracks based upon the cut-off scores for entry into the different tracks. More details about the tracking system and science education policies have been explained by Tan, Teo, and Poon (2016). The case study class being observed was a Normal Academic class. The teacher was a beginning teacher who had about three years of teaching experience at the time of the study. We selected the Normal Academic class because this class had a lot more social interactions, formal and informal, between the teachers and students. The student population in the Normal Academic classroom was representative of the other similar classrooms in Singapore. Overall, this case study class offered a good context for examining how power played out in the subcultures of the science classroom. All proper procedures for institutional human ethics clearance and participants' consent or assent were obtained prior to the conduct of this study. Pseudonyms are used in this paper to maintain the privacy of the participants.

Methodology

Data

During the data collection, 62 science lessons, each lasting between 35 and 70 min, in the academic year were video-recorded. The analysis was done using the emergent coding method and constant comparative approach (Glaser, 1965). This chapter is based on an in-depth microanalysis of one lesson video. This lesson was selected after performing a preliminary scan of all the lesson videos to identify the number of episodes that showed power play. During the scan, I am cognizant that subculture has strong links to the dominant culture because the former is derived and emerged from the latter. As such, when I was identifying evidences of power play in the classroom, I also juxtaposed it with the school culture which in this case, was the school culture of *care* and *academic excellence* advocated by the School Principal (interview, March 1, 2017). During the analysis, the evidences of teacher dominance, student dominance and balanced (i.e., roughly equal amount of teacher and student discourse in one episode) power relationships were teased out and mapped against the school culture of care and academic excellence. The data were organized in a two-dimensional matrix—power play versus dominant culture as shown in Table 11.1. The coded data in the matrix were validated by an independent researcher who acted as the consultant of this study.

Table 11.1 The two-dimensional matrix used to organize the data. The vertical categories were identified during the emergent coding process. The horizontal categories were explicated by the School Principal during the interview

	Care	Academic excellence
Teacher dominance		
Student dominance		
Balanced		

Results and Discussion

Selected examples of the excerpted data are shown in Table 11.2. No relevant data were identified from the video for two cells ("student dominance" and "academic excellence", and "balanced power relationships" and "care").

In essence, in the cell of "teacher dominance" and "care", the following evidences were found: (1) expectations on student accountability, (2) maintaining class order, (3) instructing on decorum, (4) providing information and (5) disapproves students making unnecessary distracting noise. Referring to the except in Table 11.2 to illustrate (1), the teacher was checking with the students on the homework that was assigned to students. When Sair admitted that he did not remember what was assigned, the teacher instructed him to stand up. In this case, the teacher made the call to ensure student accountability and show that he cared whether the students did their work. Sair understood that it came with a price in being honest about his negligence.

In the cell of "teacher dominance" and "academic excellence", the following evidences were found: (i) making sure students have materials to study and (ii) making sure students have access to writing materials. Referring to the excerpt in Table 11.2 to illustrate (ii), the teacher was checking with the students if the students had taken notes, especially when many new science terms were introduced. He gave students instructions on how they could best organize the notes to make it neater and facilitate learning.

In the cell of "student dominance" and "care", the following evidences were found: (a) student trying to "own" teacher and (b) teacher is unable to answer the students' questions. To "own" a teacher was a common practice in the lower track classrooms (Teo & Liu, 2018). From the teacher and students' interview (not reported in this paper) to "own" could mean creating a situation that does not allow a person to respond. In this case, a group of students were trying to "own" the teacher when he could not reach the string attached to the projector screen. In this episode, the students dominated the classroom discourse for several minutes of the lesson.

In the cell of "balanced power relationships" and "academic excellence", the following evidences were found: (I) getting students to recall what they needed to do for homework, (II) teacher prompted student turn-taking through student nomination, (III) teacher encouraging students' inputs, (IV) answering students' question, (V) student jokes and (VI) teacher disattend. Referring to the excerpt in Table 11.2 to illustrate (V) and (VII), this episode was different from the one earlier. The teacher chose to disattend, or consciously ignore, the students' comment as he knew that they were playing with words and waiting for his reactions. Despite the situation, he remembered that he had to explain the science content to the students and to regain back the control of the classroom discourse.

Table 11.2 Excerpted data to illustrate the types of power play that aligns to the dominant structures of the school culture

	Care	Academic excellence
Teacher dominance	*Expectations on student accountability* Teacher: Ok, right now do you still remember what was the homework that was given to us? Sair: [with class]: No…. Teacher: Uh, who said no? Sair: [raises hand] Teacher: Ok, Student 1 you stand up Sair: [Gestures to show displeasure, stands up] At least I honest can? Teacher: Good, I like your honesty	*Making sure students have materials to study* Teacher: So, if you look huh, this is your mouth. Your mouth contains what? The teeth. And then the teeth cut and grind the food into smaller pieces. I need you guys to copy this into your notebook. Okay? Each page I need you all to take note. Each one of this is one page. Every single organ is one page. Don't squeeze everything together. Just make one page for one organ Julia: [Slurry voice] One organ Siu Sia: Cher [Colloquial term for "teacher"] like that leh? Teacher: Ok, as long as it is neat, it is easy for you to see the sequence it is good Sair: Cher, can I draw big big? Teacher: Er, can
Student dominance	*Student trying to "own" teacher* Teacher: [Trying to press projector button, tiptoes, uses pen to help reach] Uma: Hahaha, short. [Laughs, then covers mouth] Julia: Cher, WhatsApp group you never reply Sair: Cher, cher, cher, Uma say you short Uma: I didn't Raafe: I say you tall Teacher: It's ok, you guys can become taller Julia: When you reach puberty Teacher: Ok, right now, who knows, what are the homework? [Raises hand]	No instances observed

(continued)

Table 11.2 (continued)

	Care	Academic excellence
Balanced	No instances observed	*Student jokes; Teacher disattend* Teacher: Yes. So you see huh, this is something that I need you all to take note of- Julia: What is that green thing? Teacher: This is, the green thing is like- Sair: Algae Teacher: ball of food that you are swallowing Sair: Ball Julia: Why green one? Teacher: After you guys have finish copying the thing, you put down your pen, then later I'll explain to you what is happening in your oesophagus

It is noteworthy that no relevant data were identified from the selected lesson video in the two cells do not imply that students did not take charge of their academic performance ("student dominance" and "academic excellence"), or that the teachers and students co-construct a subculture of care in the classroom ("balanced power relationships" and "care"). I can only explain that such episodes were not observed in the lesson video selected. It is possible that some power relationships are not explicitly performed in lessons.

Based on the data collected, I identified the following characteristics of the subculture of this lower track science classrooms.

Subculture Is Shaped by Power Play of Social Agents

According to the School Principal, she wanted the school culture to be one of "care" and "academic excellence". By this, she meant that the teachers and students show concern for people, the school and things that happened around them. She wanted students to achieve academically to the best of their abilities. As shown in the excerpts, the process during which these goals were achieved involved the power play between the students and teachers. In one episode, the teacher played the dominant role in dictating what should be done and what expectations he had of the students. In another episode, the students took charge of these learning experience and the teacher responded to the students' comments before diverting their attention to the homework. In the last episode, the teacher and students shared out the control of the lesson with the teacher using the strategy of disattending to the comments that had nothing to do with the science lesson. What can be inferred from here is that the subculture of this lower track science classroom is shaped by the exercise of control by the teacher and students, depending on when they chose to advance or retract in the next course of action. Such decisions will determine how the science lesson will progress thereafter. For example, the students may get too carried away if the teacher had continued to engage in the non-science discourse. If the teacher started scolding the students, he may lose the rapport with them and science learning would not progress either.

Subculture Is Aggregative and not Individualistic

Each excerpt in Table 11.2 showed that more than one person was involved in each episodic event illustrating the power play. This means that the subculture of this class was formed by an aggregation of practices, situations, stories, experiences and beliefs of two or more individuals in order to gain prominence in the classroom. In putting the selected episodes together, the subculture of the lower track science class described in this study was illuminated. Specifically, the science discourse was oftentimes juxtaposed with comments, basically from the same group of students, that had little to do with the science content. When several students combined their efforts and became successful in detracting the science classroom conversations, they made the second attempt in the bid to "own" the teacher. That is also how the subculture of "owning" (Teo & Liu, 2018) become a common practice in the lower track classrooms, and in this science classroom.

Conclusions and Implications for Practice

In this chapter, I have done a subcultural analysis of a science lesson in a lower track classroom to show how a more nuanced analysis of culture can yield alternative insights into the workings and experiences of a science learning context. Specifically, I examined the interplay of power among the teachers and students to show how the social agents define and shape the subculture of a science classroom. This version of the culture was *performed* through exchanges in the internalized meaning making process of the social agents in the classroom through a network of power relationships. Through such performed acts, connections to the school culture of care and academic excellence could be identified.

An important implication of this study is that pedagogical considerations of science teaching should be embedded within the subcultures of a classroom. In other words, teachers should plan lessons with the knowledge that subcultures exist, and their actions would be part of the creation or destruction of the subculture. For example, if the teacher (described in this study) had decided to retaliate or work against the subculture of the science class, he might find himself in a situation where the students turn against him, resist overtly or passively altogether. As such, the subculture of the class would have a more immediate impact on the success of the teaching and learning experience, as compared to the dominant school culture. In sum, science teaching should be negotiated within the subcultures of the science classroom and teachers' willingness to work within these layers of cultures of schooling would have an impact on the overall learning experience of students.

Another implication of this study is for science education researchers, especially scholars with special interests in cultural studies, to consider re-examining the term "culture". Indeed, "culture" is a complex construct (Kroeber & Kluckhohn, 1952). In this paper, I approach this problem by looking at a subverted form of culture that emerged from the interplay of power among the social agents. Of course, there are other ways to tease out subculture. Returning to the example of the *otaku*, one can examine the way people dress, the artefacts they carry, the make-up worn, the way of talking and so on. A more comprehensive analysis than the one presented in this paper would benefit teachers in understanding the subcultures of the classrooms that they teach. In my future analysis, I will be examining how subcultures form by analyzing social cliques in the classroom as a membership key to the subculture of a science classroom.

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Chapter 12
Facilitating the Use of Research in Practice: Teaching Students to Plan Experiments

Kim Chwee Daniel Tan

Abstract Research is a systematic inquiry into phenomena to understand the phenomena and/or to solve problems related to the phenomena. Though tentative and not always correct, research knowledge can provide different perspectives of practices in school and balance the use of practitioner knowledge in classroom teaching, which is also not always correct. Several studies have indicated that teachers may not be able to find research that is relevant and practical for their immediate needs, and even if the relevant research reports can be found, teachers may have difficulty in reading, understanding and acting on them; the studies suggest that intermediaries work with teachers to address these issues. This chapter proposes guidelines to help intermediaries identify relevant studies that can help teachers address their areas of concern, interpret these studies, present them, explain how the findings and suggestions from the studies can be implemented in their classrooms and work with them in the implementation. The guidelines were developed based on a case study in which an intermediary (the author) facilitated the use of educational research by three chemistry teachers in their practice by supporting the teachers in the development of research-informed instructional material and strategies to address their students' difficulties in planning chemistry experiments.

Introduction

Research is a systematic inquiry into phenomena giving rise to primary data which are based on observations or experiments, or secondary data which are derived from an inquiry into primary studies (Walter, Nutley, Percy-Smith, McNeish, & Frost, 2004). Though not always correct and subjected to revision, research knowledge can provide guidance for the practices in school and 'be a counterbalance to the emphasis on practitioner knowledge or conventional wisdom' (Levin, 2011, p. 16). Research knowledge needs to be mobilised to have an influence on practice, and this does not mean just telling practitioners about the research or interventions and expecting them

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to deliver the lessons, but working with them in their specific contexts (Levin, 2013; Ryder, 2015). Research can have a great impact on practice when teachers collaborate with researchers to determine the important problems of practice before working together to design interventions, implement them and evaluate their effectiveness, as well as look into the issues arising from the implementation and the conditions required for success (Penuel, Fishman, Cheng, & Sabelli, 2011). Teachers can make significant contributions to such collaborations with their contextual knowledge, instructional expertise and practical wisdom (Hill, 2001).

Using Research Knowledge

Tan and Gilbert (2014) reported that Singapore chemistry teachers' concern over their students understanding of the concepts taught and the implementation of the directives and initiatives of the school and the Ministry of Education were important impetuses for them to examine their existing practices, and possibly to use educational research to inform changes. However, teachers may not be able to find research that is of interest, relevant and practical for their immediate needs or areas of concern as researchers generally do not write for a teacher audience (Abbott, Walton, & Tapia, 1999; Cordingley, 2008; Edwards, Sebba, & Rickinson, 2007; Levin, 2011). In addition, what seems to be applicable to the researcher might not be evident to the teacher as studies have found that teachers have difficulty reading and understanding research reports in addition to locating and acquiring them (Cordingley, 2008; Levin, 2013; Nelson, Leffler, & Hansen, 2009; Ratcliffe et al., 2004; See, Gorard, & Siddiqui, 2016). Research knowledge may also be too general and theoretical for the teacher to decide whether it is plausible and feasible in his/her highly specific context situation (Cain, 2015; Kessels & Korthagen, 1996; Tan & Gilbert, 2014) and how to act on it in his/her classroom (Ratcliffe et al., 2004; Lewis, 2015; Herrington & Daubenmire, 2016).

Nelson et al. (2009) suggest that intermediaries who can 'aggregate, translate and apply research evidence directly to specific, highly local issues' (p. 52) may be helpful as schools generally do not have people with the capacity to do so (Levin, 2011). Intermediaries can be organisations or individuals who are known to, and trusted by, teachers, and are readily available for consultation (Nelson et al., 2009). They raise the teachers' 'awareness of research findings and approaches, helping them to identify developments that might be more worth attending to and supporting them in trying out new approaches' (Ratcliffe et al., 2006, pp. 149–150). In this chapter, guidelines which may help intermediaries to collaborate with teachers are described, addressing the important issues of the accessibility, plausibility and feasibility of research to teachers (Tan & Gilbert, 2014), facilitating the use of research in practice.

Methods and Procedures

The guidelines for intermediaries were developed from a case study in which high school chemistry teachers co-developed research-informed instructional material and strategies with the researcher to address their students' difficulties in planning experiments. The author was 'the primary instrument of data collection and analysis' (Merriam, 2009, p. 39), conducting semi-structured interviews with, and surveys of, teachers and students, holding formal and informal conversations with the teachers, and communicating through emails. Audio-recordings of lessons, as well as student and teacher artefacts provided additional data for the study.

Three teachers were involved at the start of the study. Nancy (all names are pseudonyms) was a senior teacher with 31 years of teaching experience, Ken taught in the school for 11 years and Ron had three years of teaching experience. Two other teachers joined the group later: Frances taught for five years while Tammy had two years of teaching experience. The teachers participated in the study because they wanted to address their students' difficulties in learning chemistry. They were teaching in School Z which provided a six-year integrated programme from Grades 7–12 (Ministry of Education, 2018) catering to academically-inclined students (13–18 years old). The students in integrated programmes are exempted from the national examinations at the end of Grade 10, and continue their Grade 11 and 12 education in the same school, with the majority of students sitting for the General Certificate of Education Advanced Level (A-level) examinations at the end of Grade 12.

Approval by the ethics committee of the researcher's institution to conduct the study was granted in May 2014 and permission from the Ministry of Education to conduct the study in School Z was obtained in June 2014. Informed consent was obtained from the teachers and students (and their parents) who participated in the study.

Guidelines for Intermediaries

This section describes the interactions of the researcher and the collaborating teachers, resulting in the proposal of the various guidelines for intermediaries to work with teachers to facilitate the use of research in the classroom.

Working with Teachers: Expect Changes, Be Flexible

In October 2013, the researcher contacted Ken, who was well known to the researcher, to ask if teachers in School Z would like to participate in a study in which they would work with the researcher to explore how educational research could be used to address student difficulties in chemistry. At the end of October 2013, the researcher met three teachers, Nancy, Ken and Ron in School Z and decided to explore the possibility of addressing student difficulties in organic chemistry, especially the synthesis and reactions of compounds with more than one functional group. At the end of January 2014, the teachers met the researcher with the intention of discussing how the project would proceed. During the meeting, the researcher asked them to clarify the issues involved. After pondering over and discussing the issues, the teachers unexpectedly decided that their students' difficulties in organic chemistry were not serious enough to warrant a study, and that student difficulties in planning experiments was a more pressing matter to pursue. This was because their students usually could not answer planning questions well and the teachers had difficulty teaching the topic. Thus, asking questions to understand the concerns of the teachers and giving them opportunities to clarify their thoughts are important to confirm the research topic and minimise change in the direction of the collaboration once it has started. If the teachers change their minds when the project is in progress, it may be better to go along with the teachers' decision as their interest will determine their motivation to participate in the study. In July 2014, the researcher was informed that Frances and Tammy would also be joining the team. It was fortunate that they did so as Ken and Ron had to withdraw from the project from late 2014 onwards due to heavy administrative demands as they were appointment holders in the school. Otherwise, Nancy would be the only teacher left in the project; without support from colleagues, the likelihood of the collaboration continuing/succeeding might be low as discussed in a later section.

Clarifying Matters: Identify the Issues Involved

The teachers, on their own initiative, surveyed eight Grade 12 students on their difficulties in planning experiments. The students were asked about the problems they faced in planning experiments and why these problems arose. The data showed that one of their main problems was that they were unaware of the expectations of the questions. The other major problem for them was generating the detailed procedures required. The two main reasons that they gave for their problems were their lack of preparation for planning questions and that they were weak in the content which the experiment was based on, especially organic chemistry. Other reasons given included the lack of experience with experiments that they had to plan and the lack of understanding of procedures. Frances and Tammy also observed students' presentations of their plans on a volumetric analysis experiment in Nancy's class and noted that the students were unaware that of the detailed procedures required. For example, the students did not justify the amounts of reagents used in the experiment and did not state that a volumetric flask was required to prepare a dilute solution for titration. They were also unfamiliar with the capacities of common apparatus and the need to consider the experimental error associated with an apparatus. In addition, they did not state the colour changes which would be observed during a titration when a particular indicator was used. In the second half of 2018, another survey of 75 Grade

11 students from four classes was conducted. The results generally agreed with the data from earlier survey and classroom observation that the students had difficulty identifying the objectives of the experiments or the requirements of the question, calculating and justifying the amount of reagents needed for the experiments and could not produce the detailed procedures required. One suggestion made by a student was that teachers could explain each procedure in detail, why the procedure had to be carried out in a certain manner and what would happen if alternative procedures were used; this would help students to understand the significance behind each step or procedure.

Suggesting Possible Research: Be Guided by the Issues

The teachers had to address the students' inability to provide, in a logical and systematic manner, detailed procedures that are specific to the context of the experiment, and students' insufficient knowledge and understanding of experiment procedures, reagents and apparatus. Teachers have little difficulty with planning experiments because of their much wider and in-depth experience with the subject and with chemistry experiments, but they have difficulty teaching students to plan experiments. One reason could be that a wide range of experiments can be given to students to plan, some of which may be novel, so there are no 'standard' answers available. Within the limited curriculum time allocated to this topic, lessons cannot cater for the planning of such a wide range of experiments. Another reason could be that much of the teachers' knowledge of planning experiments is tacit and they do not make their thinking processes sufficiently explicit for their students to emulate. This is not helped by the fact that when their students are in the laboratory conducting experiments, rather than emphasising on the 'thinking behind the doing', the teachers tend to focus on the students carrying out the procedures correctly and getting the correct answers as these are important for the students to do well in the practical assessment.

The researcher decided that research done on cognitive apprenticeship (Collins, Brown, & Holum, 1991), non-mathematical problem-solving (Cartrette & Bodner, 2010) and productive failure (Kapur & Bielaczyc, 2011) seemed to be able to offer help to teachers to facilitate their students' learning of how to plan experiments. Cognitive apprenticeship offers suggestions on how to make an expert's thinking visible for novices to have a sense of, and acquire, the critical concepts and skills involved in tasks. Non-mathematical problem-solving emphasises the understanding of the processes involved in the generation of solutions, which include the identification and resolution of errors that can arise. In productive failure, students are encouraged to solve complex problems collaboratively without any instructional support by teachers until a teacher-led consolidation phase where what the teacher presents should make more sense to the students in the light of their difficulties in solving the problems. The three approaches provide ideas on how to: (1) make explicit the teacher's thinking and application of chemistry concepts when they plan experiments so that students can learn and model, (2) scaffold student learning and thinking, (3) create a safe space for students to explore ideas and generate their own plans with attention to the critical conceptual features involved, (4) encourage students to articulate and make their thinking visible and (5) provide opportunities for students to be exposed to alternatives proposed by their peers and to explore the merits and limitations of the various ideas proposed. Other studies such as those on inquiry-based science (Crawford, 2000; Flick, 2000). and practical work (Hart, Mulhall, Berry, Loughran, & Gunstone, 2000; Nakhleh, Polles, & Malina, 2002) could also provide ideas to address the students' difficulties, so it has to be stated that the three studies selected by the researcher were based on his personal (idiosyncratic) belief that they had much to offer to address the students' difficulties in planning experiments.

Presenting Possible Research to Teachers: Focus on Key Ideas

In July 2014, the researcher made a presentation to five chemistry teachers in School Z. Nancy, Ron and Tammy were present, as well as two other teachers who were not participating in the study. He planned to present first on productive failure, followed by cognitive apprenticeship and non-mathematical problem-solving, focussing mainly on (1) what each research study was about and the theories involved in the study, (2) how each study was conducted, (3) what the findings were and (4) the implications of each study on the teaching and learning of experimental planning. He wanted to focus on the key ideas so he did not provide a detailed description of each study. Otherwise, the presentation could be too overwhelming for teachers; the details could be discussed during the planning and implementation of instructional material and strategies. Due to the lack of time, non-mathematical problem-solving was not presented to the teachers on that day.

Tammy mentioned that during the presentation, 'the researcher often highlights the main focus of the research study and this makes it easier to "digest" the journal article' and 'gain insight on significant research findings'. Although teachers could read papers on their own, she pointed out that she found 'journal articles quite wordy and sometimes difficult to comprehend' and she 'may not have access to some of them'. Nancy also stated that '(s)ome research papers are too daunting to read and also not easily accessible'. Thus, presentations to teachers make research accessible to them and have to focus on key ideas with minimal details to help teachers understand the essence of the research. Overwhelming the teachers with details may reduce the intelligibility of the presentation and the inclination of the teacher to participate in the study.

Deciding on the Research: Allow Teachers to Choose

At the end of the presentation, the researcher gave the presentation slides and the research papers to the teachers so that they could refer to them to get more details if required. Frances was not present at the presentation so the material provided her with the relevant information. When the researcher wanted to arrange another time to present on non-mathematical problem-solving, the teachers indicated that it was surplus to their needs as they had decided on productive failure and cognitive apprenticeship, so the presentation was not required. Tammy stated that both productive failure and cognitive apprenticeship were useful and complemented one another, and that learning through failure would help students ‘to understand the rationale of concepts learnt, or specific procedures in a planning experiment’ rather than memorising procedures without understanding them. She added that ‘if students learn through understanding, they are able to analyse the question using heuristics and would be able to apply what they have learnt to an unfamiliar context’. Nancy and Frances also stated that both productive failure and cognitive apprenticeship were useful and relevant to the teaching of experimental planning. Like Tammy, Nancy mentioned that productive failure ‘get(s) students to think in-depth, be reflective in their learning’. This was necessary because ‘deep understanding of content and procedure is critical in order for students to master this section’ as ‘(p)lanning experiments is complex by nature and requires students to be able to apply and transfer what they have been taught to novel situations’. Frances stated that ‘students find teachers amazing as they are able to solve questions easily and are able to apply to many novel situations’, so if the teacher’s thinking was made visible to students, they might pick up the relevant skills from the teacher. Also by making the students’ thinking visible to teachers, teachers would be able to identify students’ difficulties and address them. The feedback from the teachers indicated that they understood the key ideas from the research studies and how these could be used to help their students learn to plan experiments. The researcher believed that leaving out non-mathematical problem-solving was not a loss as productive failure and cognitive apprenticeship already could provide useful guidance to the development of instructional material and strategies to teach the planning of experiments.

Collaborating with Teachers: Make It Convenient for Them

Much of the communication between the researcher and the teachers was conducted through email as the teachers had limited time to meet the researcher regularly. When the teachers collaborated with the researcher to develop the instructional material and strategies, they would email the instructional material that they modified from their existing worksheets to include elements of productive failure and cognitive apprenticeship to the researcher for his comments. It was easier and less time consuming for teachers to modify existing material than to develop new material from scratch, and this lowered the barrier for the participation of teachers in the project. They would also have confidence in the revised material as it was based on their own familiar resources. The researcher would comment on the revised material, raise any matter of concern and emailed them back to the teachers. The teachers would then revise the worksheets, conduct and audio-record the lessons and send the audio-recordings to the researcher. The researcher would then analyse the audio-recordings to determine students' difficulties and lack of understanding of the procedures and use of reagents and apparatus. He would also highlight the episodes where the teachers used productive failure and/or cognitive apprenticeship pedagogy during the lesson, and their impact on students. The detailed analysis of the lesson would be emailed to the teacher who conducted the lesson for her comments, while general findings would be sent to all three teachers. It was up to the teacher who taught the lesson to share the detailed analysis with the other two teachers. Meetings would then be arranged to discuss the instructional material, the lessons conducted and how both could be improved.

Teachers Participating in the Project: Support from Peers

At the end of the project, the researcher asked the teachers if they preferred to participate in the research project alone or with a group of colleagues. All three teachers stated that they preferred to work with a group of colleagues. Nancy mentioned that 'we support each other professionally and emotionally as well' and that '(m)ore heads better than one'. Frances gave similar reasons for supporting and generating more ideas to 'to adapt these pedagogies to achieve a better outcome for the students'. Tammy valued the meetings and discussions that the teachers had as she gained valuable insight into their thought processes, as well as 'to gain a better understanding of some misconceptions students have'. For Tammy, it was also 'an eye-opener to be able to observe how Nancy facilitated the class and how she scaffold teaching points'. Thus, the teachers preferred to participate in projects together with other colleagues than participate alone because they could turn to colleagues for support, discuss matters with and learn from each other.

Conclusions

This chapter proposed guidelines to help intermediaries work with teachers to facilitate the use of educational research in their practice by making research more accessible, plausible and feasible to teachers (Tan & Gilbert, 2014); intermediaries can select and interpret relevant studies for teachers, explain how these studies can help improve teaching and learning, and discuss with the teachers if the findings and suggestions from the studies are feasible in their context. The collaboration between teachers and intermediaries has to be convenient to both parties, and teachers need to have ownership in the project, so their decisions and concerns are to be taken seriously. Bridging research to practice requires long-term collaboration between teachers and educational researchers/intermediaries in order to transform teaching (Herrington & Daubenmire, 2016), so the interactions between the parties need to be empowering and fruitful in order to sustain the collaboration.

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Chapter 13
Working Memory Capacity and Teaching and Learning of Stoichiometry

Fui Seng Chang and Mageswary Karpudewan

Abstract Cognitive neuroscience education is a new trend in educational psychology research. In the context of science education, research performed from the perspective of neuroscience is gaining incremental importance. The findings of studies on neuro-cognitivism have significant implications in designing classroom teaching and learning strategies. Notably, the studies on neuroscience education suggested investigating the role of working memory (WM) in teaching and learning of specific science concepts that deal with solving problem such as stoichiometry. This study investigated the level of working memory capacity (WMC) of 80 Form Four science stream students (16–17 years old). At the same time, the study also explored how working memory was considered in teaching and learning of stoichiometry from students' and teachers' perspectives. The findings revealed that the level of WMC among the students appeared generally low and from the students' and teachers' perspective, WMC was frequently ignored in the stoichiometry lessons. The findings of this study offer revisiting the research on WMC in science education from the perspective of teaching and learning of stoichiometry.

Keywords Neuroscience education · Secondary students · Stoichiometry · Working memory capacity

Introduction

Cognitive neuroscience education is a new trend in educational psychology research. Particularly in the context of science education, many available studies have investigated teaching and learning of science from the neurocognitive perspective (Anderson, 1992, 1997; Anderson & Kunin-Batson, 2009; Immordino-Yang & Damasio, 2007). Immordino-Yang and Damasio (2007) investigated the attention, memory, decision-making, and social functioning as neurobiological evidence that affects the

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learning in schools. According to Immordino-Yang and Damasio (2007) when students engaged in decision-making about the real-world, transformation of knowledge and skills learned in the classroom to the real-world context takes place. The brain controls the transformation process, and cognitive neuroscience research reveals that the idea (*knowledge*) or information is encoded onto the working memory (D'esposito & Postle, 2015). Working memory is a mental workspace that stores and processes information in translating the classroom knowledge to the real-world context. The information stored on working memory was later retrieved and translated into specific behaviors while executing the task (St Clair-Thompson, Overton, & Bugler, 2012). The ability to hold, retrieve, and manipulate information varies among individuals. This ability is referred to as working memory capacity (WMC) (Wilhelm, Hildebrant, & Oberauer, 2013). In other words, WMC determines the specific behaviors executed in completing the task.

WMC is one of the factors that influence the cognitive performance of students (Gathercole, Pickering, Knight, & Stegmann, 2004). Mainly WMC is highly correlated to students' performance in subject matter that focuses on problem-solving such as Mathematics and Sciences (St Clair-Thompson et al., 2012). This is because in science lessons students required to generate information, recognize, analyze and transfer information in solving the problems. According to St Clair-Thompson et al. (2012) due to the differences in WMC, the readiness to learn a topic, concept, skills, and ideas vary among the students in the same age group. During any teaching and learning session, students need to retrieve the stored information and manipulate the information in completing the given task. Students who lack the ability to hold and manipulate the information omit crucial information that guides their actions and encounter difficulties in completing the task. This group of students is identified to have low WMC (Gathercole et al., 2004; Yuan, Steedle, Shavelson, Alonzo, & Oppezzo, 2006).

Among various science concepts stoichiometry is one of the abstract and most difficult topics in chemistry for students to comprehend (Dahsah & Coll, 2007). This is because, in stoichiometry, students learn concepts that are invisible to human eyes such as mole, chemical formulae, and equations (Hafsah, Rosnani, Zurida, Kamuruzaman, & Yin, 2014). These fundamental chemistry concepts are essential for students to further their study in chemistry (Dahsah & Coll, 2007). In learning stoichiometry, students are required to understand the definition of mole and utilize higher-level thinking skills in solving stoichiometry task (Dahsah & Coll, 2008; Gulacar, Damkaci, & Bowman, 2013). For example, students need to acquire the knowledge mole as a unit of measurement that describes the number of atoms, molecules, and ions in any substances. Students learn to integrate their understanding of mole in writing the chemical formula using subscripts and understand that the chemical equation is a symbolic representation of the chemical reaction. Later this knowledge is applied in solving problems that require conversion of mole-mass-mole and balancing equations. As such ability of the students to retrieve and manipulate information delivered in the classroom teaching is paramount importance. In other words, WMC determines the ability of the students in solving stoichiometry problems.

Solaz-Portales and Sanjose-Lopez (2009) asserted that students successfully solve the problems when the mental demand (steps involved in solving the problem) is lesser than the WMC. Overloading of WMC happens when the demand to solve the problem is above the students' abilities to hold, retrieve, and manipulate information (Smith, Sáez, & Doabler, 2016). In such situations, students' information processing capacity declines. Subsequently problem-solving capacity of the students' decreases. This happens because, in the case of overloading WMC, the brain loses the efficacy to maintain critical information and inhibit irrelevant or misleading information (Solaz-Portales & Sanjose-Lopez, 2009).

Hafsah et al. (2014) reported Malaysian students having difficulties to understand stoichiometry concepts because the students lack problem-solving ability. The learners encounter difficulties in solving problems dealing with conversions of mole-to-mass, the role of limiting reactant, writing a chemical equation, and identifying the composition of stoichiometry. Solving problems on stoichiometry requires students to know chemical formulae of the substances, writing a balanced chemical reaction, knowing the mass and moles of the substances. Hence, solving stoichiometry problems involves processing a large amount of information (Gulacar et al., 2013). Probably, the students have inadequate ability to hold, retrieve, and manipulate large amount of information. In other words, the mental demand of the stoichiometry problems is higher than the WMC of the students. The overloading of WMC explain the difficulties faced by Malaysian students in solving stoichiometry problems.

Teaching methods that heavily relies on delivering facts frequently result in overloading of WMC. This is because a huge amount of information is given during the short duration of the lessons. Working memory with limited space unable to store the large amount of information, although the attentional priority and saliency of the subject affect WMC (Li, He, Wang, Hu, & Guo, 2017). This results in the loss of valuable information, and at the same time, the working memory loses processing power (Smith et al., 2016). When the processing power is depleted students tend to be confused (Solaz-Portales & Sanjose-Lopez, 2009).

On the contrary, the processing power of the working memory is enhanced if the information is acquired in a meaningful way (Li et al., 2017). When the students are provided with opportunities to analyze, evaluate critically, and synthesize, the information is organized in a coherent manner that is intelligible to the learners (Smith et al., 2016). As such, teaching strategy determines the storage of information in the working memory and the ability to hold, retrieve, and manipulate the information.

Association between working memory and learning is well established (Baddeley, 2017). Specifically, in science education, working memory is referred to as a constructive operator for problem-solving and predictor for academic achievement (St Clair-Thompson et al., 2012). Stoichiometry is one of the challenging topics in chemistry among secondary school students as stoichiometry profoundly involves a problem-solving task that requires high mental demand. This study used the lens of WMC to "research" students' learning of stoichiometry with the intention that the findings of the study informs the teachers in planning their lessons.

Aim

Review of the literature depicts that students' WMC has paramount importance in learning, particularly in solving problems that require the use of thinking skills. Studies also proposed that it is essential for the teachers to use strategies that encourage the building of WMC specifically in teaching scientific concepts such as stoichiometry. This is because stoichiometry inherently deals with solving problems. Hence, this study is aimed at investigating Form Four science stream students' WMC and exploring the consideration of working memory in the current teaching and learning of stoichiometry. The findings of this study would be informative in planning for teaching considering the students' WMC.

Methodology

Research Design

The mixed method research design was used in this study. The quantitative method was implemented to collect numerical data on the level of students' working memory using The Cambridge Neuropsychological Test Automated Battery (CANTAB). Qualitative interview data were collected individually from two teachers and six students to explore whether working memory forms an integral part of current teaching and learning of stoichiometry concepts in the classroom.

Sample

The targeted population of this study was the Form Four (16–17 years old) Science stream students in the state of Penang, Malaysia. A total of 80 students from three classes from one government funded secondary school participated in this study. Government funded secondary schools located in urban areas throughout the country share many commonalities. These include the availability of teaching and learning facilities, enrollment of students, training of the teachers, and the school environment. For this reason, a conveniently located school was identified to participate in the study. As the researcher does not have the authority to choose the participating classes, all three Form Four science stream classes in the school participated in the study. As such, intact group sampling was used in this study (Gay, Mills, & Airasian, 2009). For the interview, six students were purposefully selected. From each class, two students who were able to clearly describe the teaching that executed during the lessons and how the teaching impacted their learning were interviewed. The two chemistry teachers teaching chemistry for the three classes were interviewed.

Instruments

The Cambridge Neuropsychological Test Automated Battery (CANTAB) is a cognitive assessment tool used for measuring the role of specific brain functions across a range of disorders and syndromes (Atkinson, 2015). The CANTAB was administered immediately after completing the lessons on stoichiometry prior to the interview to ensure that WMC reflects on the stoichiometry lessons. Beattiea, Schutteb, and Cortesa (2018) measured the WMC immediately after completing mathematic tasks to avoid interference from other factors. Similarly, in this study, following Beattiea's et al. (2018) strategy CANTAB was administered after the lessons on stoichiometry to avoid interferences from other factors that possibly influence the WMC of the students.

CANTAB has been widely used and reported reliable to be used to measure the working memory capacity of an individual (Luciana, Conklin, Hooper, & Yarger, 2005). There are eight memory tests included in CANTAB, but only the Spatial Working Memory test (SWM) was used in this study. This is because SWM measures delayed responses to the tasks in retaining and manipulating information regarding the task (Beattiea et al., 2018). The ability to retain, retrieve, and manipulate information implies on the WMC of the individual (Constantinidis & Klingberg, 2016). Hence, SWM measures portray the WMC of the student. As the SWM test was administered immediately after the lessons on stoichiometry and students were informed to refer to the lessons on stoichiometry in responding to the test, the ability of the students to hold, retrieve, and manipulate the information or WMC displayed infers on the stoichiometry.

SWM measures students' ability in using strategies to hold and manipulate the displayed information. The lowest level of difficulty involves 4 boxes, and the highest level involves 8 boxes. In solving the problem, students will be shifting from the lowest to the highest level. For the purpose of this study, the lowest is 4 and the highest is 8 boxes. The errors made in solving the problem reflected from SWM values. SWM between error score depicts the errors made in solving the problem involving 4 boxes. SWM's total error score portrays the accumulation of the errors in solving 4, 6, and 8 boxes problems.

The test began with the screen showing several colored square boxes as in Fig. 13.1. The participants should find the colored box with blue "token" and drag them to fill up an empty column on the right-hand side of the screen (Fig. 13.1). The test starts with four colored boxes and progressively increased to eight colored boxes. The number of blue "token" that should be found is parallel to the number of the colored box. The students need to find the blue "token" and drag it to the corner. For instance, in the 4 boxes problem, after trial and error, when one blue "token" was found, the students dragged the identified blue "token" to the side. Now the screen will be showing three boxes. Blue "tokens" are available in one of the three boxes. When the blue "token" was successfully found it will be again dragged to the corner. As two blue "token" have been dragged to the side, the left two colored boxes will appear on the screen. The students repeated the same strategy (trial and error) as

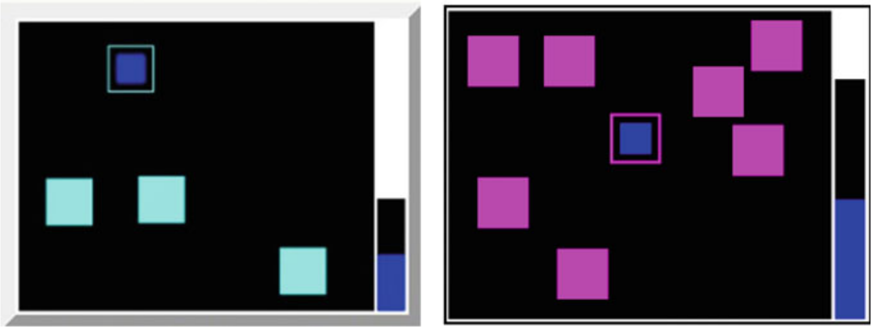

Fig. 13.1 The SWM test screen with 4 boxes and 8 boxes

earlier until all the four blue "tokens" were found. Then the problem will be shifted to the next level involving 6 boxes problems subsequently to 8 boxes. In the attempt to locate the blue "token", revisiting the same box indicates an error. It shows that the student unable to remember that they have visited the box. SWM between error score indicates a number of errors made or the number of time revisiting happen in solving the problem at the same level. SWM total error score indicates the sum of SWM between error scores obtained from 4, 6, and 8 boxes. SWM's total error score indicates the total number of times the boxes are revisited throughout solving the problem. The high scores and mean values for SWM between errors and SWM total errors represent poor memory (Beattiea et al., 2018; Schutte et al., 2017). Beattiea et al. (2018) mentioned that the presence of distractors and attention influence the SWM scores. The SWM between and total error scores will be lower if the students were trained to ignore distractors, and focused on the targeted location (Schutte, Keiser, & Beattie, 2017).

Interview Question

Semi-structured face-to-face interviews were conducted with teachers and students. Interview session with each person lasted for 20 min. First, a general question was posted. The teachers were asked to describe how they usually teach stoichiometry lessons and the students were asked to explain how the lessons on stoichiometry were usually taught. The teachers were further prompted with questions like what kind of activities they usually integrate into stoichiometry lessons, the depth of the syllabus and the time allocated to complete the lessons on stoichiometry. The students were prompted with questions like asking them to specify the activities used, whether the activities motivated them to learn and the depth of content covered. The questions mainly derived from suggestions to measure working memory from Kaufman (2010).

Pilot Study

A pilot study was conducted to validate the CANTAB and interview questions. For this purpose, a total of 30 students and 3 teachers from a neighboring school participated. A brief instruction was given to the students on how to perform the task using CANTAB. The students one by one were later asked to complete the task. The students said that the instruction provided by the researcher is explicit and they were able to perform the task in CANTAB. Initial testing of interview questions revealed that the questions appeared general. The three teachers were of the opinion in order to identify WMC; interview questions are required to provide detailed information. Based on the teachers' suggestions in the pilot study, the interview questions were revised.

Data Analysis

Spatial Working Memory (SWM)

SPSS (Statistical Packages for Social Science) version 22 was used to measure the frequency distributions, the standard measures of central tendency (mean), and the standard measures of dispersion (standard deviation) of the scores from CANTAB. SWM between errors and total errors for each participant was automatically calculated by CANTAB and transferred to SPSS to calculate the mean value for the SWM between errors and SWM total errors.

Interview Analysis

Guideline on thematic analysis as proposed by Braun and Clarke (2006) was used to analyze the interview responses obtained from the teachers and students. The definition for WMC provided by Gathercole and Alloway (2008) guided the thematic analysis conducted according to six steps as proposed by Braun and Clarke (2006). A total of three chemistry teachers were involved in all the six steps during the analysis. The first step of the analyses is transcribing and familiarizing the data. For this purpose, the data was re-read many times, and the response that implies on WMC was extracted from the transcripts. In the second step, the responses that render WMC were assigned to codes. In the third step, the codes were merged into subcategories and later into categories. The theme generated was reviewed to ensure the codes and categories match the themes in the fourth step. In the fifth step, the categories were given specific names, and finally, the thematic maps were produced in the sixth step. From the analysis performed in the six steps, the theme "overloading of WMC" emerged. Figure 13.2 illustrates the thematic map produced from the analysis of interview responses.

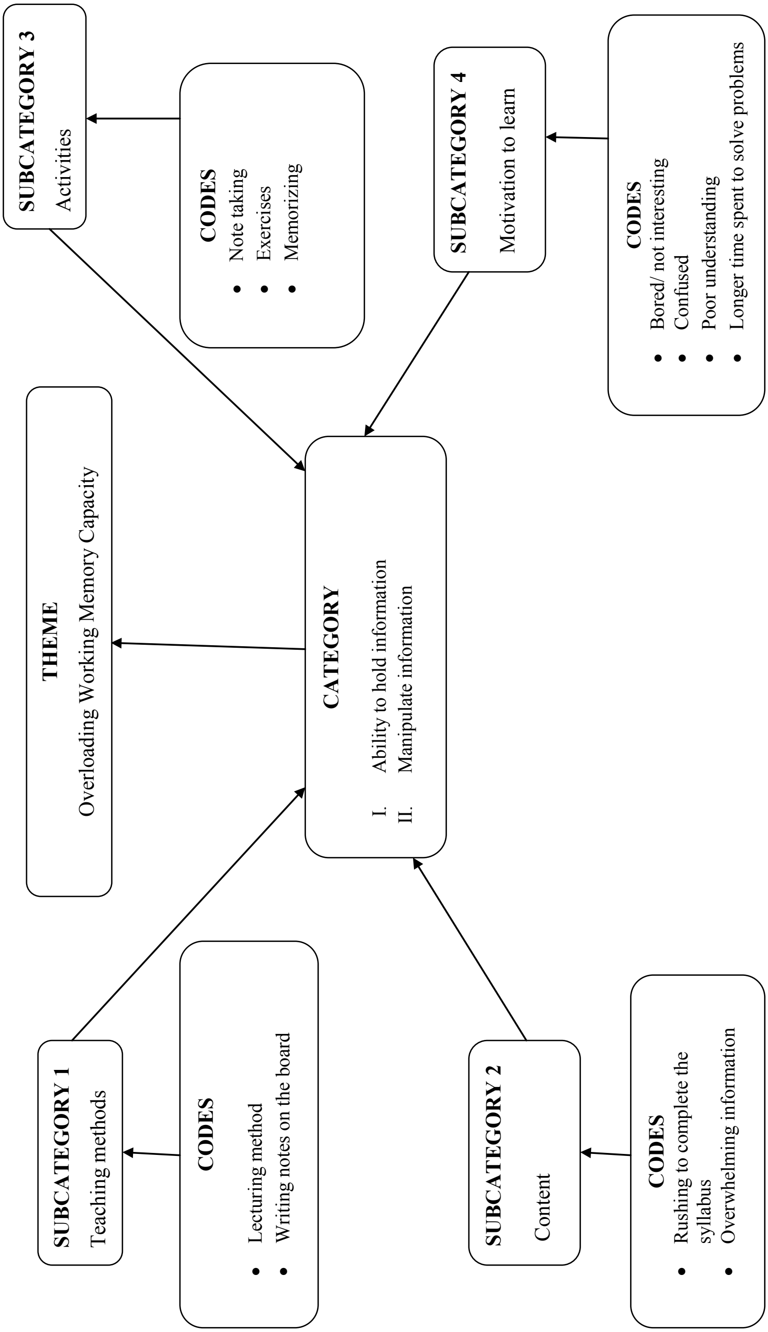

Fig. 13.2 Thematic map obtained from the analysis of interview responses

The transcript with interview responses was provided to the teachers. The teachers worked individually in assigning the codes into subcategories and categories. The teachers later met and compared their analysis. Decisions at each stage were made after the teachers reached an agreement over their discussion. For instance, as shown in Fig. 13.2, the codes such as "lecturing method" and "writing notes on the board" emerged from the transcript were grouped into teaching methods, i.e., subcategory-1. The codes "rushing to complete the syllabus" and "overwhelming content" identified from the transcript constitute subcategory-2. For subcategory-3, the code that implies the activities performed in the classroom includes "note taking", "exercises", and "memorization". In subcategory-4, motivation to learn is exemplified by the codes "bored", "confused", "poor understanding", and "longer time spent on problem-solving". The four subcategories cumulatively explain the categories (ability to hold and manipulate the information) which constitute the theme "overloading of WMC".

Results

Data presentation begins by presenting 80 participants' working memory capacity as "SWM between errors (4 boxes)" and "SWM total errors (8 boxes)". The high scores of "SWM between errors (4 boxes)" and "SWM total errors (8 boxes)" represent poorer use of the strategy to solve the task (Atkinson, 2015).

Table 13.1 presents the findings of the descriptive analysis of SWM between errors and SWM total errors. For SWM between errors involving 4 boxes, the lowest score obtained was 0, and the highest score is 10. A low mean score (M = 1.04; SD = 1.965) was obtained for SWM between errors. A lower mean score indicates the students made fewer errors and used effective strategies to solve the task. For SWM total errors involving 8 boxes, the lowest score obtained was 0, and the highest score is 75. The mean score for SWM total errors (M = 26.93; SD 16.03) indicates that most students have committed many errors and used poor solving problem strategies.

Figure 13.3 shows that data is not uniformly distributed and positively skewed. The data reveals that more than 40 students scored 0 errors in solving the task involving four boxes. This means that many of them have used an effective strategy in completing the task. According to Atkinson (2015), if the distribution is positively skewed, as in the case of Fig. 13.3, this implies an effective use of strategy in solving problems. Lower errors score also indicates that participants' working memory capacity

Table 13.1 Descriptive statistics of "SWM between errors" and "SWM total errors"

	SWM between errors (4 boxes)	SWM total errors (8 boxes)
Low score	0	0
High score	10	75
Mean	1.04	26.93
Std. deviation	1.97	16.03

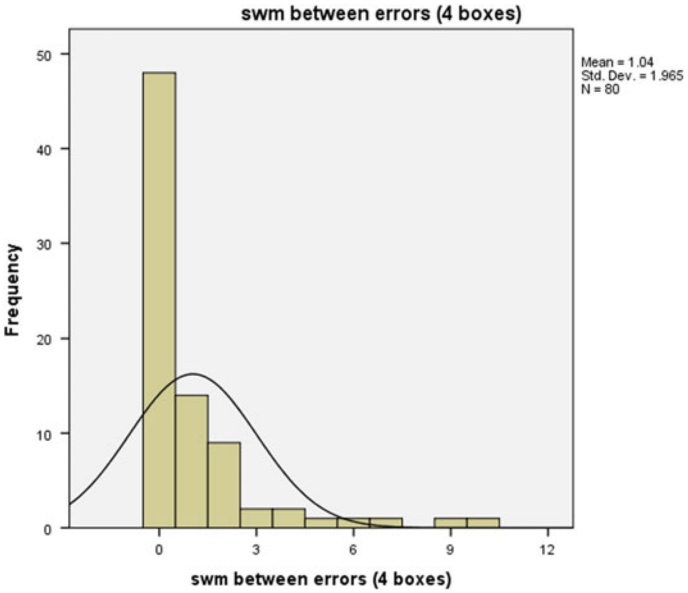

Fig. 13.3 Bar chart of SWM between errors (4 boxes)

is generally high (Atkinson, 2015). As such the students possess the ability to retain and manipulate more information.

When the number of boxes was increased to eight (Fig. 13.4), it was observed that many students committed more errors. From Fig. 13.4, it is noticed that the data presented in the bar chart is normally distributed. The data in Fig. 13.4 reveals that the majority of students committed 20–40 total errors with 12 students committing most errors (the tallest bar). This indicates that the students frequently attempted the "trial and error" approach to find the blue box and the students' working memory capacity was considered as average (Beattiea et al., 2018; Schutte et al., 2017).

Interview Findings

From the analysis of both students' and teachers' responses, the theme "low and overloading of working memory capacity" emerged. T1 and T2 refers to teacher 1 and teacher 2 respectively. T1 claimed that she frequently explains the concepts in detail first and then she provides examples reflecting the application of the definition. For instance, she provides the definition for a mole, followed by explaining the definition with some examples. T1 further said that students would be taking note of the important points. She will also write down the crucial points on the whiteboard to ensure students do not miss any information and pay more attention to the points that she has highlighted. Similar to T1, T2 also said that the lecturing method

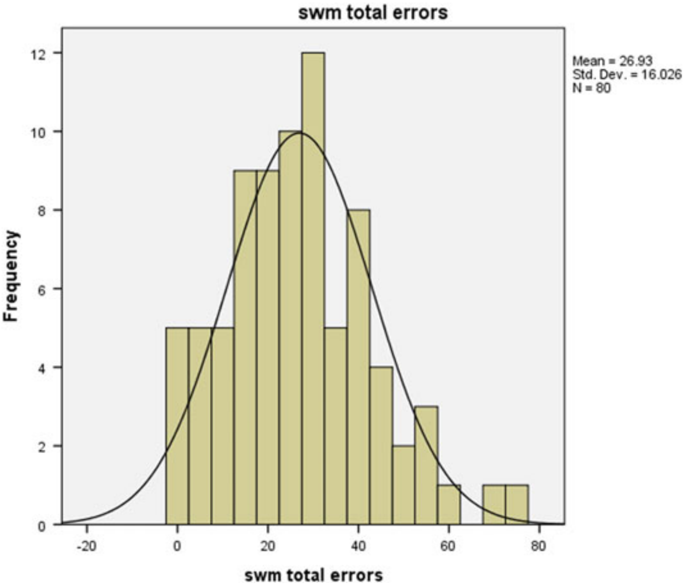

Fig. 13.4 Bar chart of SWM total errors (for 8 boxes)

dominates her class. T2 asserted she would begin the lesson explaining what a mole is. She explains mole in terms of ions, atoms, and molecules. Then she provides some examples and exercises. The teacher-centered approach used by T1 and T2 does not permit students to hold information in working memory. This explains the overloading of WMC occurs during the teaching.

T1 justified her claim for using lecturing method saying designing and implementing classroom activities takes more time. This will further delay completing the syllabus as she needs to cover mole concepts, relating mole and mass and linking mole with ions, molecules, and atoms. T2 reflected similarly and said time does not permit for having activities as she will be in a rush to complete the syllabus in time to prepare the students for the examination. Responses of T1 and T2 depict that time constraint is the reason for having teacher dominated teaching strategies and the need to cover the wider range of content results in opting for short ways of teaching the lessons. Addressing the overwhelming amount of content in a stipulated time apparently does not provide space for the students to manipulate the information. This is another factor that contributes to the lower and overloading of WMC.

The analysis of responses also revealed that note taking, and simple exercises are some of the activities given by T1 and T2 in the class. These kinds of activities are simple and less demanding. Hence, engaging in these activities does not require retrieving and manipulating the stored information. Simultaneously, T1 and T2 said that the students passively engaged in learning and students take a longer time to solve the given problem. Passive engagement portrays that students' motivation to learn the content is minimal.

From the students' viewpoint, all the six students were of the opinion sitting passively and taking notes is boring and these are the activities they normally performed during stoichiometry lessons. S3 particularly said that he is less motivated to learn because the lessons are boring and S4 and S5 added they are bored as well because the lessons are not interesting. S2 and S6 further added saying the teacher teaches very fast and most of the time we are confused. From the students' responses it could be postulated that they appeared less motivated to learn the content, the activities are less interesting, the strategy used failed to engage them in learning, and vast content coverage in a shorter duration contributes to the poor ability to hold and manipulate information (Holmes, Gathercole, & Dunning, 2010). Subsequently, this leads to lower or overloading of WMC.

Discussion

This study documents WMC of Form Four science students and how working memory is reflected in current teaching and learning of stoichiometry from students' and teachers' perspective. The lessons on stoichiometry were focused in this study mainly because stoichiometry is an abstract concept. Stoichiometry involves learning about moles, conversion of moles of ions, atom, and molecules to mass. Particularly, solving stoichiometry problems would not be successful if the concepts were understood in a compartmentalized manner. The students should have the analytical, critical, and creative skills in solving the problems (Gulacar et al., 2013). For the students to apply these skills, the teaching and learning activities in the stoichiometry lessons should consider students' WMC. The information should be presented in a logical sequence, for the knowledge to be easily extracted to use in solving problems that require different thinking skills (Raghubar et al., 2010).

The quantitative finding of this study shows that students tend to commit more errors in solving complex tasks. This is reflected from the higher SWM total errors involving eight boxes than the lower errors identified in the task with 4 boxes. The findings indicate that when the difficulty level of the task increases the students unable to retrieve and manipulate the stored information effectively. This circumstance relates to lower WMC (Gathercole & Alloway, 2008). The WMC of the students appears lower when the complexity and the difficulty of the task increases. The notion that more errors are committed in complex task corroborates with Solaz-Portales and Sanjose-lopez (2009) assertion that students were unsuccessful in solving complex questions (involving more steps) because the mental demand of the task is higher than the WMC.

The interview responses revealed the shreds of evidence that the lessons contribute to the overloading of WMC. The dominating teacher-centered strategy to deliver overwhelming content in a shorter duration affects the information processing capacity when the working memory is overloaded (Opdenacker et al., 1990). The unstructured way of note taking results in failing to retain information and possibly losing valuable information in working memory (Klingberg, 2009). As reviewed in the literature, large amount of content leads to demanding information processing. When this happens, students are unable to capture and retain the entire information. Consequently, students fail to hold and manipulate information during the learning process. This situation is parallel with Ashcraft and Kirk's (2001) assertion that exceeded information lays heavy demand on the capacity of working memory and disrupts working memory sufficiently to recall the existing knowledge.

Conclusion

Previous studies have evaluated students' WMC (Redick, Broadway, Meier, Kuriakose, Unsworth, Kane, & Engle, 2012) and highlighted the importance of WMC in teaching abstract subjects like mathematics (Raghubar, Barnes, & Hecht, 2010) and problem-solving ability of the students (Alloway & Alloway, 2010; Constantinidis & Klingberg, 2016). In this study, an attempt was made to revisit the role of WMC in teaching and learning of stoichiometry. This is because stoichiometry involves learning a highly abstract concept. In teaching the concept, a mere teacher-centered approach will result in students facing greater difficulty as reported in some studies (Osman & Sukor, 2013; Wright, 2011). The findings of this study inform that the teachers to some extent ignored the WMC of the students in learning stoichiometry concepts. The strategy used by the teacher should permit easy processing of information to order for the students to solve the problem. Easy processing depicts that students are able to use many skills at a time (Raghubar et al., 2010). For this to happen, teachers should avoid overloading of WMC which subsequently results in the students having lower ability to process the information in working memory (Alloway & Alloway, 2010; Gatherole & Alloway, 2008).

The SWM scores reported through this study reveals that students have committed many errors in completing the task. As the SWM scores depict the ability of the students to hold, retain, and manipulate information, the low score exhibits low WMC of the students. The lower WMC explains the reasons for the difficulty students encounter in solving the stoichiometry problems (Dunning, Holmes, & Gathercole, 2013). The teachers' intention to complete the syllabus and prepare the students for examination refrained them from using strategies that allow students to hold, retain, and manipulate the information. The teachers' action subsequently results in the students having lower WMC.

The study exhibits several limitations. Since the students and teachers participated in the study were from one school, the findings lack generalization. For the findings to generalize to a wider range of population the study is recommended to be repeated with students and teachers from more schools. Additionally, Onwuegbuzie and Teddlie (2003), suggested including more schools and students to have better control of the external variables and improve the internal validity to yield the same result. Challenges were also encountered in quantitative data collection due to the limited availability of CANTAB. For this reason, the researchers had to collect data after the formal schooling hours to ensure the data collection was performed promptly after the lessons on stoichiometry to avoid other interferences.

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Part III
Re-searching Science Teachers and Teacher Education

Chapter 14
Pre-service Science Teachers' Reflections on the Field Experience: Does Context Matter?

Sharon Bramwell-Lalor, Marcia Rainford, and Miguel Ison

Abstract Through the use of the lens of school context, this qualitative study explores how the field experience of pre-service science teachers contributes to the shaping of their conceptions of teaching. Context is described in terms of the institutional, physical, professional, social and personal factors which influence teaching and learning. Four female, secondary teacher candidates in their final year of a university teacher preparation programme participated in the study. A focus group interview was conducted for data collection. The findings revealed that the pre-service teachers understood that management of the learning environment is necessary for effective instruction and that positive interpersonal relationships within the context of a nurturing, supportive school environment will facilitate this outcome.

Introduction

> I really would love to continue this profession and what really drives me is… when I finished my practicum some of the students, they cried; some of them they wrote little notes "I'll miss you… Miss" … (Susan, focus group, May 8, 2018)

Teacher preparation programmes include aspects of theory and practice of education embedded in a variety of courses designed to develop pre-service teachers' (PSTs) content, curriculum and pedagogical knowledge, knowledge of the learner, professional dispositions and pedagogical content knowledge (Shulman, 1987). The field experience or practicum is an essential component of teacher preparation programmes, necessary for teachers' certification and provides authentic conditions for

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PSTs to develop a deeper understanding of teaching and school culture, to demonstrate what they have learnt as they plan and execute lessons, and interact with students, teachers and parents (Yarmus & Begum, 2013). Ideally, teacher educators would like all PSTs to leave the field experience with similar expressions as that in the opening vignette. Different aspects of PSTs' field-based experiences have been extensively researched including the role of personal reflection, perceptions of teaching, classroom management skills, teacher beliefs and communities of practice (e.g. Abas, 2016; Dicke, Elling, Schmeck, & Leutner, 2015; Kaldi & Pyrgiotakis, 2009; Ng, Nicholas, & Williams, 2010; Yarmus & Begum, 2013). Studies have also highlighted the influence of cultural, contextual and personal experiences on PSTs during the practicum (e.g. Du Plessis, Marais, van Schalkwyk, & Weeks, 2010; Flores & Day, 2006).

It is well documented that a disconnect exists between what student-teachers learn in training programmes and what is experienced in the field particularly on first entry (e.g. Dicke et al., 2015). Further, Cabaroglu (2014) alludes to a possible link between the quality of student-teachers' learning experiences and the competencies and dispositions that they display at the end of the training period. A major aspect of PSTs' learning experience is garnered during the practicum. It is in the field that their personal and professional experiences in formal training programmes are 'tested'. Referring to work done by Jones and Youngs, Avalos (2016) argues that the initial encounter of new teachers in the school setting could lead to motivation to continue their career development or demotivation to the extent of leaving the profession shortly after.

Darling-Hammond (2006) argues that preparing teachers for the twenty-first-century classrooms requires greater concentration on training in collaboration with schools. At the same time, field-based experiences should be in contexts that hone pedagogical skills suited for twenty-first-century learners. Posner and Vivian (2010) assert that each school site is unique given the distinctive set of students and teachers. Pre-service teachers enter different school contexts with their own knowledge, expectations, beliefs and values which form a filter for interpreting experiences and interactions that contribute to their understanding of teaching. The relationship between PSTs' personal orientations and the context in which they conduct the practicum corresponds with the bioecological systems theory which speaks to the interplay of several environmental factors on personal development (Bronfenbrenner, 2005).

Although Jamaican science teacher-trainees may be exposed to similar preparation programmes at a given tertiary institution; their field experiences are often significantly different due to the unique factors operating at each local school as well as their personal differences. Selection criteria for school placement in the Jamaican context are mainly based on level (e.g. primary, secondary), the curriculum being used and school location. Du Plessis et al. (2010) suggest that in some countries it is the amount of resources in a school that determines placement. They lamented, however, that schools should be selected based on their ability to provide a nurturing environment rather than on the basis of their resources. While there may be some appreciation for the differences among Jamaican schools, there is little flexibility in placement choice because of the limitations of number of available schools and the number of teacher-trainees requiring placement. Interaction with our students pointed to the possibility that variations in school context might affect the quality of their field experiences. We were not able to find studies from this region that focused on school context as a factor in analyzing PSTs field experience. We, therefore, thought it essential to analyze PSTs' field experiences and opinions about teaching using the lens of the Jamaican school context consisting of five components: institutional, physical, professional, social and personal. It is hoped that this lens can assist teacher educators in understanding how context influences the professional development of PSTs during the field experience in order to better facilitate future training needs.

This study is guided by the question: How do the institutional, physical, professional, social and personal components of school context help to shape pre-service science teachers' conceptions of teaching?

Literature

The Context of Teaching

The literature suggests that school context is a complex concept with many definitions. Turner and Meyer (2000) indicate that one approach to interpreting context is by understanding its components which include beliefs, values, perceptions, classroom management, social relations and physical space. Another study named school location, student demographics, administration, staff and resources as important components of school culture (Fernandez-Río, 2016), which together with climate are broader, well established and researched fields linked to school context (Legewie & DiPrete, 2012). Delaney and Neuman (2016) defined context as "…the social, institutional, political and personal factors that influence teaching and learning" (p. 3).

Drawing on these sources, we are defining school context in this study in relation to five components: institutional, physical, professional, social and personal that will frame the discussion in this chapter. *Institutional* refers to the strategies, policies and rules that govern the way teaching, learning and assessment take place in the institution (Hall & Kidman, 2004), and the teaching norms, values, behaviours and ethos that will likely influence individual departments. *Physical* refers to the appearance, dimensions, layout and available resources of the physical space. The *professional* context describes the discourse and activities which emerge concerning the professional outcomes among individuals, resulting in growth in knowledge and understanding of teaching and learning. The *social* components are those factors which influence desires or motivation (Deci & Ryan, 1985) and include the relationships within the school (e.g. teacher–student, student–student, teacher–teacher). The fifth component is the *personal* component which we are defining as PSTs' bioecological influences (e.g. age, gender, values, beliefs, expectations) that may affect their interpretation of the school culture in which they are placed.

Context is, therefore, more than the school setting with its physical and psychosocial infrastructure (facilities, culture, climate). It also includes the teacher-trainees' biological factors. Hence, context also refers to the dynamic interaction among components internal and external to teacher-trainees that facilitate and/or hinder their development. This view is consistent with Bronfenbrenner's theory who noted that human development is contingent on the reciprocal relationship between the attributes of an individual and his/her environment (Bronfenbrenner, 2005). PSTs have reported both positive and negative experiences in school contexts and Du Plessis et al. (2010) have emphasized the value of the social component of context in the evaluations made by PSTs about their experiences. We are proposing the personal component of context as being central to understanding the interactions of the PSTs with their environment while on practicum (see Fig. 14.1).

Teacher educators seek to build relationships with schools in which the PSTs can be reasonably guaranteed exposure to good teaching, and where the professional ethos supports the induction of the neophyte teacher into the profession. However, placements are not always ideal or standardized and as such the school-based experience will vary according to contexts of placement. Posner and Vivian (2010) argue that one challenge is to get PSTs to excel in the context where they are placed.

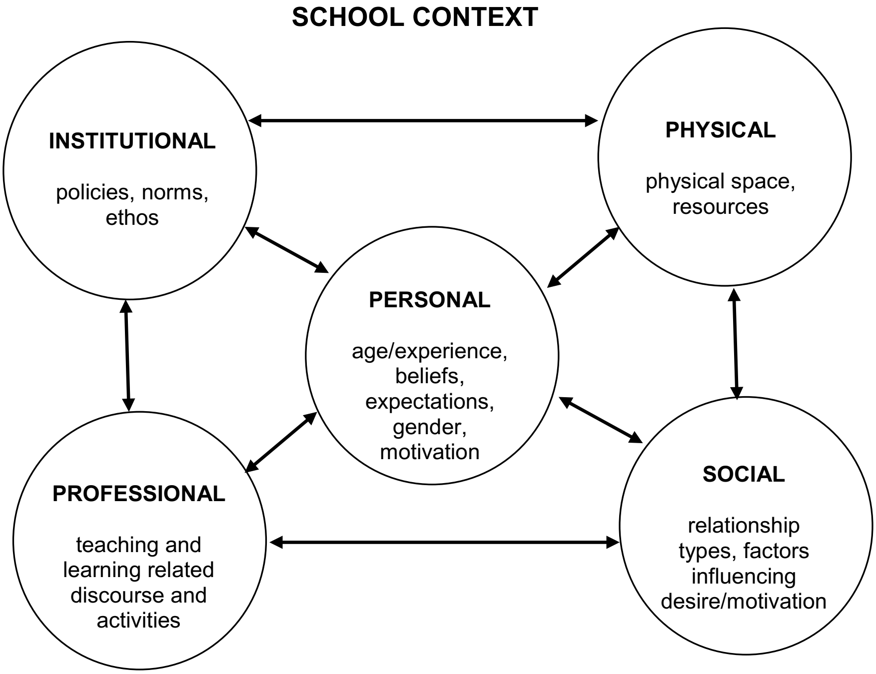

Fig. 14.1 The components of school context and their interactions

In our practice as science teacher educators, we have identified several challenges that may impinge on the professional development of Jamaican science teachers during their field experience. A decline in the number of experienced science teacher-mentors due to migration to more lucrative job opportunities in the United States of America, Canada, United Kingdom, Dubai and Caribbean countries such as the Bahamas, Turks and Caicos and Cayman Islands (Buckley, 2016) sometimes makes it difficult to consistently find nurturing contexts for placement. Additionally, there is competition among teacher education institutions for limited spaces in preferred secondary schools within a confined geographical area. Furthermore, secondary schools are distinct; they vary in available resources and have students with dissimilar academic competence from different socio-economic backgrounds, which may further limit school placement possibilities. Against this background, we have sought to explore how the school context in which PSTs are placed serves to shape their conceptions of teaching.

Pre-service Teachers' Beliefs, Conceptions and Expectations of Teaching

Teacher beliefs are defined as the ideas that teachers have that influence how they conceptualize teaching and learning (Ng, Nicholas, & Williams, 2010). Much of these (beliefs, conceptions, expectations) are developed from the teachers' own experiences when they were students, and are quite resistant (Tang, Lee, & Chun, 2012). Some are related to the classroom environment, instructional strategies and resources, the role of the teachers (e.g., as mentors), students' behaviours and the role of the institution in supporting teachers (Cole & Knowles, 1993). Beliefs about the relationship between classroom management and gender have also been studied; however, the findings are inconclusive (e.g., Caner & Tertemiz, 2014; Martin, Yin, & Mayall, 2006; Okut, 2011).

Having spent extensive time learning content and teaching strategies, PSTs feel armed and ready to enter classrooms. However, Corcoran (1981), Dicke et al. (2015) and Veenman (1984) all highlight the transition or praxis shock that PSTs face when they first confront real classrooms. Additionally, Girardet (2017) hinted that as a result of the dilemmas experienced by PSTs they end up adopting practices based on the school's culture and may lessen or even abandon those learnt in preparation for the field. The "realness" of the experiences and the extent of the "shock" can affirm or cause a PST to re-think his/her decision to pursue teaching as a career (Schaffer & Welsh, 2014). Examining the field experience from the narrations of the PSTs could assist in identifying their existing beliefs and conceptions of teaching based on the context of their practicum placement and whether these change and to what extent.

The Field Experience

The field experience is important in assisting PSTs with understanding the curriculum, the complexities of teaching the subject, the learner and the classroom context (Shulman, 1987). School placements provide PSTs with opportunities to work alongside and collaborate with cooperating teachers who are expected to mentor and help them to hone their craft by modelling good practice and providing information about the specific teaching context. Yarmus and Begum (2013, p. 3) similarly state that PSTs "need field experiences to understand the significance of learning contexts, the diversity of learner characteristics and the complexities of teaching." Teachers' affective and social characteristics and their understanding of pedagogical issues benefit from talking and sharing with each other. Ideally, the relationship between pre-service and cooperating teachers in the context of the field experience should foster such engagements (Duncombe & Armour, 2004; Ng et al., 2010). The field experience is one example of situated learning (Brown, Collins, & Duguid, 1989) where learning is a social activity embedded in context and culture, and is supported by a theory of social constructivism (Vygotsky, 1978).

Given the extended time in the field away from regular contact with the supervisor, teacher-training institutions rely on cooperating teachers to help with mentoring PSTs. However, the experiences of PSTs with the cooperating teachers vary and might not always be positive. Darling-Hammond (2006, p. 308) reports that "practicum organization has been fairly haphazard, dependent on the idiosyncrasies of the selected placements with little guidance about what happens in them." Another dimension that influences PSTs during the field experience is the school's organizational structure and the interplay of relationships among key individuals (Avalos, 2016). These limitations highlight the difficulty in guaranteeing that PSTs will end up in the schools that would afford them the best experiences for their formation.

Methodology

Four female pre-service, final year, science education students—Nolah, Rhoda, Susan and Thelma (pseudonyms), were purposively selected for this study. All were being trained to teach biology and were placed in secondary schools for the 10 weeks field experience. They observed teaching for the first two weeks and taught biology for approximately five hours each week for the remainder of the period. Following the field experience, they participated in a focus group interview facilitated by three researchers in this study. In the interview, the participants responded to questions generally focused on their personal beliefs about teaching, the preparation period for the field experience, the observation period and their experiences in the schools. The interviews were transcribed and then analyzed.

Data Analysis

Qualitative data analysis involves assigning meaning to chunks of data by way of codes, which may be descriptive or interpretive (Miles & Huberman, 1994). Saldana (2016) distinguishes between codes and categories and argues that codes are essence-capturing elements of the data which are organized or clustered according to some discernible patterns into categories. Further analysis of qualitative data leads to the emerging of more interpretive patterns or themes. The data were first coded and then the five components of school context (personal, professional, social, physical and institutional) were used as categories for organizing the data. The interview transcripts were read and re-read by the three researchers until consensus was obtained for the first-level categories. Further reading and interpretation of the coded data led to three explanatory and interpretive "pattern codes" (Miles & Huberman, 1994), or themes (Saldana, 2016) which served to cluster and organize the data for presentation and discussion.

Results and Discussion

The three themes (pattern codes) that emerged from the PSTs' reflections on their field experiences will be addressed, and the various components of school context relevant to each theme explored. The themes are classroom management, the role of the cooperating teacher in PSTs' conceptions of teaching and interpersonal relationships and teaching of science.

Classroom Management

The importance of effective classroom management for teaching was a common thread running through the reports of all the PSTs. The five components of context all influenced their classroom management experiences. The PSTs agreed that teaching should take place in a controlled setting and that teachers should take charge of the learning environment. The ultimate responsibility of the teacher for classroom management is made explicit by Susan in the following extract.

> Well for the second observation I realised that teaching is not just about going to the class and just presenting information to the children… So **you** [emphasis] will create that environment where they will stay focused. (Focus group, May 8, 2018)

The PSTs' personal views were confirmed by the professional activities of the cooperating teachers they observed. They found that when cooperating teachers used instructional strategies conducive to twenty-first-century learning such as engaging students in peer assessment during oral presentations, student engagement was facilitated. Teacher-centred strategies also gave teachers greater classroom management but resulted in more passive student engagement. As shown in the following quotes, Nolah, Susan and Rhoda reported how their cooperating teachers' interactions with students affected the management of the learning environment.

> The teacher is teaching in grade 8 – and I was just sitting at the door and just looking - the teacher was teaching - the students were all over the place she's walking to-and fro-'round the benches nobody was paying her any attention. (Nolah, focus group, May 8, 2018)
>
> I remember observing…one of my cooperating teachers and what she did was …she gave the students an assignment where they would prepare some creative piece whether a poem, a song, a little skit… so I think that was a very effective strategy in maintaining classroom management with respect to those students and the idea of the…activity. (Susan, focus group, May 8, 2018)
>
> …let's start with the classroom management…The teacher had the classroom under control but as the lesson progressed I realised that it was more teacher-centred…yes she asked the students questions but it was kinda limited so she wasn't getting enough feedback from them. (Rhoda, focus group, May 8, 2018)

The experiences of the PSTs supported their view that teachers' professional engagements in the classroom can affect their classroom management as reflected by Susan's and Nolah's expressions. However, classes that are under control may be as a result of passive rather than active learning environments. Rhoda's recognition that highly teacher-centred classes can result in better-managed classes shows that she is associating teaching with students' learning and the teacher's role in facilitating learning.

The PSTs expected that classroom management would be easier in schools where there were much order and greater prestige. Susan's personal view that positive behaviours were associated with certain school types was reinforced by her experience in the field as suggested in the quote below

> I got to observe two high schools one was an elite one, so you notice there was a difference with the behaviour of the students they were more attentive…class management - delivery was good - students were participating – students did their assignments…but when I went to the other school…Chaotic! (Focus group, May 8, 2018)

The negative or positive expectations that PSTs may have about some schools could affect the quality of their experience in the field. PSTs may even feel that they are at a disadvantage if they are placed in some schools. In cases where PSTs' sense of self-efficacy about their classroom management skills is low, placement in some schools perceived to be less orderly will likely impact negatively on their practice in the field.

In addition to their expectations about classroom management in different types of schools, the PSTs had personal views about teacher's classroom management skills and their gender. Both Nolah and Susan felt that male teachers were likely to be better at managing classrooms with disruptive student behaviour. Nolah reflecting on her observation of a female cooperating teacher said, "I don't know if it was because it was a female but in the male cooperating teacher's classroom…the students were more focused in a sense because it was a man…they try their best to come early for class" (Focus group, May 8, 2018).

This view was not always supported by the social dynamics in some classes as Susan discovered. This caused her to question her own self-efficacy in classroom management as a female teacher.

> I experienced the grade 7 teacher - the male teacher- and when I noticed that the students were all over the place and he was just there and no control whatsoever I started thinking and saying "**What would I do** [emphasis] if I…were in his position?" (Susan, focus group, May 8, 2018)

Susan's observation that male teachers are not necessarily able to control the learning environment left her unsure about her management skills in similar circumstances. Her experience of how the effective use of instructional strategies can lead to productive learning engagements described earlier may help to quell her fears and guide her thinking about alternatives for her own practice. Nolah, however, will likely need more positive experiences to improve her self-efficacy about classroom management.

The physical setting such as the number of students in a class, size and location of classrooms, lighting and ventilation were also identified as having an impact on the teachers' ability to maintain class control and therefore affected the professional quality of teaching and learning. Smaller classes were easier to manage. The extract below provides an example of how physical context and classroom management were related.

> The class was better managed because it was small and the students were more mature. In the grade 8 class, the classes weren't really large – the classroom was like a box and then the school is structured in a way that every class faces the quadrangle or the parking lot…In the parking lot that's where every activity takes place, so once something is happening there … you know that no focus is in the classroom…(Nolah, focus group, May 8, 2018)

The physical setting, institutional factors and the varying levels of teachers' interest and ability to 'take charge of the class' confronted Nolah and caused her to reflect on her career choice. She said "after one week I felt like this was it for me in teaching…I was really depressed…stressed and worried" (Focus group, May 8, 2018).

The overall tone of the classroom can be modulated by teachers' professional engagements as well as by personal and institutional factors. The PSTs authentic experiences in the field (Yarmus & Begum, 2013) allowed them to recognize the relationships among classroom management, students' engagement and instruction thereby enhancing their professional learning. In the classroom, they saw these relationships being played out before their eyes and recognized what teaching strategies were most effective in the specific setting. The PSTs' personal beliefs and expectations on the role of gender in classroom management led to some disquiet about their abilities as females to effectively manage classroom behaviour. By using the lens of context, classroom management was revealed to be an important factor to consider in teacher preparation.

The Role of Cooperating Teachers in Pre-service Teachers' Understanding of Teaching

The PSTs' experiences with the cooperating teachers varied depending on the institutional context and the professional activities of the cooperating teachers. Generally, cooperating teachers' professional interactions with the PSTs included enquiring about the outcomes of their lessons, but there seemed to be limits on assistance with planning in the contrasting reports by Susan and Thelma.

> …she was an epitome of true leadership in the classroom…she was with us "day in day out" she would message us, WhatsApp us to ensure that our lesson plans are good…we would send her…if we had any question or if we want any ideas… she'd say …"try this or try this". (Susan, focus group, May 8, 2018)

> They didn't really take…our lesson plans and look at it but they kinda asked us what we were going to teach and ensure that we were on the right path with regards to the syllabus…but it wasn't a case where they would readily offer their help per se but if you asked for it then would have gotten it. (Thelma, focus group, May 8, 2018)

Additionally, Nolah reported that she had experienced negative and unprofessional instances. This did not seem to have an adverse impact on her as she also had a positive experience with a cooperating teacher in another school which she considered a "good school". She also associated the professional behaviour of the cooperating teacher with the quality of the institution suggesting that the institution has a role to play in clarifying the cooperating teachers' role and ensuring that it is carried out as described below.

> When you go in as a student-teacher your cooperating teacher says "wow ok that means that I have time off—this person is going to take over the classroom so I can just sit in the staffroom". So, they ask… "I don't have to come class today?" and then you respond "well if you want" they say "alright I won't come"…but then…at the good school the teacher understood her role she was there. She helped me along the way she ensured that the students played their part, they sit and they listen… (Nolah, focus group, May 8, 2018)

The PSTs benefited from the mentoring and support of the cooperating teachers to varying degrees. In one context, Susan reported a very positive relationship with her cooperating teacher which was aligned with her own beliefs of the leadership roles required for mentoring new teachers. However, in Thelma's experiences, that level of support from the cooperating teacher was significantly reduced. Based on Nolah's experience, school culture and cooperating teachers' level of professionalism seem to be related.

The actions of the cooperating teachers which contributed to the PSTs' understanding of teaching was expressed through positive professional associations and working relationships between both groups (Duncombe & Armour, 2004; Ng et al., 2010). Observations of the cooperating teachers provided opportunities for the PSTs to reflect on the many dimensions of teaching, to consider their own actions in similar situations, and to better understand the contexts in which they were placed. Susan expressed "…you start questioning yourself about certain things 'alright if I am doing this topic what would I do?'" (Focus group, May 8, 2018). Thelma similarly stated "I…saw some of the things that they [cooperating teachers] did and some of the ways that they responded and said…'maybe I shouldn't do that'… some of the classroom management strategies…they were able to help me with some of those (Focus group, May 8, 2018).

There were many instances in which the cooperating teachers displayed good professional behaviours which the PSTs admired and pledged to model in the event that they would one day become cooperating teachers. Nolah's reflections suggest that the institutional and professional components of context interact in that the actions of the cooperating teachers are linked to the school culture. The lens of context suggests that the role of cooperating teachers may be influenced by their institutional context.

Understanding Practice: Interpersonal Relationships and Teaching Science

The field experience provided an opportunity for the PSTs to test what they had been taught. They reported improvement in their time management skills while teaching and also expressed a preference for active teaching and learning in science. The primary focus seemed to have been on their effective use of teaching strategies such as demonstrations and analogies. Rhoda describes how this worked for her in teaching the topic of 'diffusion'.

> …coming back to my example with the analogy and demonstration I did a perfume demonstration for diffusion…and I also used an analogy to back that up to say alright because the canteen was…somewhat close to the particular classroom I said "…during the day you might smell something nice coming from the canteen…food…that smell of the food…that's an example of diffusion. (Focus group, May 8, 2018)

These professional engagements improved the PSTs' pedagogy and helped in the development of their self-efficacy and conceptions of teaching. While mention was made of topics such as "cells" and "diffusion" the conceptual issues involved in teaching these topics were not aired for discussion. This may be a matter for closer attention in the actual training of the PSTs as in the current model of training, the content and the pedagogy are managed in different faculties of the teacher-training institution.

The social component of the field experience led the PSTs to appreciate the importance of interpersonal relationships with students for success in teaching. Teachers' disposition towards having a good rapport with students and respecting them was associated with the teacher's ability to effectively engage learners. According to Rhoda,

> … students don't really like when you are too domineering or bossy over them…because we have that good rapport they tend to participate more in class, they don't really shy away they tend to ask me questions… so I value that about myself. (Focus group, May 8, 2018)

The institutional contexts seemed to influence how acts of indiscipline were addressed and left Susan feeling quite unsure of how to proceed. This institutional culture presents what seems to be many obstacles that prevent punishing students. Susan does not have any tried and proven approaches to fall back on and she is of the view that this serves to tie the hands of the teachers making it virtually impossible to punish the students. She expresses

> I have…been in situations where I start to wonder if what I'm doing is good because I remember one student did something and the only punishment…you can't really punish the students again apparently cause you will get into some whole heap of trouble with their parents and the Board…so basically you cannot punish any student for their wrongs so…we just don't bother to punish them. (Susan, focus group, May 8, 2018)

The extract reveals an attitude of indifference and detachment being developed by Susan as she does not sense that the institutional factors offer adequate support for her to address problems of indiscipline. This has implications for her own self-efficacy development in addressing acts of indiscipline.

As the PSTs became increasingly aware of the socio-cultural issues and the effects they have on teaching, the complexity of teaching and the multiple roles that teachers are required to play became evident (McIntyre & O'Hair, 1996). This resulted in Rhoda's and Nolah's acknowledgements of the nurturing and pastoral roles associated with teaching, by attending to students' physical and emotional needs.

> …you have to realise that you have to be like a parent away from home…, so you have to probably care for that student - probably one of the time that student come and say "Miss I don't have any lunch today" you have to say "alright here is some lunch or some lunch money", so you don't necessarily come with that thought to say ok I'm just coming to give you some information. (Rhoda, focus group, May 8, 2018)
>
> I realised that the teaching process is not just to go in the classroom and give the students notes to prepare them for society, it's like being a mother in the classroom because you have everybody with different personalities, with different interests and something that they want to do and you have to try and curve them towards education while you still trying to teach them something else…you trying to manage the class…it was a lot …in too little time for me. (Nolah, focus group, May 8, 2018)

Students are likely to be less distracted and more engaged in learning if their emotional and physical needs are addressed (Marzano, Marzano, & Pickering, 2003). The PSTs' interactions with students resulted in a broadening of their understanding of their roles as teachers to include addressing students' physical and emotional needs at times. Interestingly, both Nolah and Rhoda described their primary role as passing on information to students, but came to realize that teaching requires attending to many different issues, often simultaneously.

Unresolved Issues

While the field-based experience provided many opportunities for the PSTs to hone their practice, the professional engagement was not able to address some of their personal issues. Thelma who was placed in an all-girls' school expressed fears about teaching boys given the experiences some of her peers had recounted though she remained hopeful that her personality would help her to cope. Susan expressed fear of teaching more mature students who may likely show disrespect, while Nolah was anxious to find employment in a supportive school environment as she had had two different experiences—one resulting from a positive and one from a negative school culture. She surmised that she could end up with a negative outlook about teaching depending on where she gains employment (see extracts from Thelma, Susan and Nolah below).

> My issue is I've never taught males before and I have heard some of our classmates that would have taught males describe scenarios that they've had and I'm kinda worried as it regards to the same classroom management as to how do you react but I think I like the fact that I am flexible. (Thelma, focus group, May 8, 2018)
>
> And I am scared because they are mature most of them are way ahead now in comparison to when I was their age so you don't know how you will react and you know just that alone-just that alone how they will be you know that disrespecting thing is the problem for me. (Susan, focus group, May 8, 2018)
>
> … the good environment led me to believe that teaching was my passion and the bad environment led me to believe that teaching was not my passion so depending on the environment I can say that - cause I might end up in a school where all the teachers and the students - they are so distraught…, that the only thing you can do as a teacher is just go in teach and leave the classroom or you might be in an environment where the teachers are compassionate about learning and the students are interested in the learning process so you might invest more time… it depends on the environment for me. (Nolah, focus group, May 8, 2018)

These various concerns are in line with those studied about PSTs' expectations of teaching. They may also in some way support the reality of the praxis shock that PSTs face on first entry into the field experience (Corcoran, 1981; Cole & Knowles, 1993; Dicke et al., 2015; Martin et al., 2006; Veenman, 1984). At the end of the practicum, the PSTs demonstrated various levels of self-efficacy towards their effectiveness in teaching and classroom management. Their ability to successfully navigate the experiences encountered in the different school contexts appears to be linked to their personal self-efficacy beliefs such as flexibility and resilience.

Conclusions and Implications for Practice

In this paper, we sought to explore how various components of school context operate in shaping PSTs' conceptions of teaching during the field experience. The findings of the study have led us to conclude that school context matters and all components help to shape the PSTs' conceptions of teaching. We observed that the PSTs came away from the field experience with different impressions of teaching which depended on their placement, and some matters—such as their fears about teaching in different learning environments not experienced during the field placement—were unresolved.

Understandably, the ability to manage the classroom environment so as to make it conducive for teaching and learning is a major consideration in PSTs' clarification of their teaching roles. They noted that instructional strategies associated with twenty-first-century learning created more productive learning environments, thereby supporting the thrust towards incorporating those strategies in teacher-training programmes. Additionally, developing positive relationships with students enhanced learning and as such, PSTs are to be encouraged to foster mutually respectful relationships with students.

The institutional component of school context is reflected in the overall tone and ethos of the school. In instances such as existed in this study, where there is little choice in school selection and placement, and there is considerable variation among secondary schools, the teacher-training institution needs to provide greater support and collaborate with schools on ways that can provide a more supportive environment for PSTs. Cooperating teachers in particular are positioned to engage the PSTs in professional dialogue to enhance their initial experience and the results showed both positive and negative examples of these interactions. Ideally, cooperating teachers should be carefully selected. However, this is not always possible as decisions on who will serve as cooperating teachers are made in the schools. Mentorship training programmes for cooperating teachers if already in existence can be broadened to ensure a wider cross section of teachers who participate.

The positive and negative expressions about teaching by the PSTs in this study support the view that consideration of school context is necessary when placing students in the field of practice. Further the unresolved issues point to the necessity to give greater consideration of the personal dimension of school context in teacher preparation programmes. In concluding, in order to ensure PSTs have a fair opportunity to make successful transitions from education programmes into classrooms, school context cannot be ignored.

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Chapter 15
Teachers' View on Replacing Traditional Chemistry Experiments with Green Chemistry (GC) Experiments

Yvonne Kulandaisamy and Mageswary Karpudewan

Abstract Laboratory work is crucial for learning chemistry. What students experience and take away from a laboratory class is a first-hand experience for students. Abstract concepts are made concrete through a good laboratory pedagogical strategy. In this study, secondary school teachers' views on current chemistry laboratory and how green chemistry experiments could possibly address the challenges and shortcomings of the traditional experiments were explored. Following a series of workshops on green chemistry experiments, 100 secondary schools teachers views were gathered on (1) relevance of green chemistry experiments; (2) feasibility of implementing the experiments; (3) nature of green chemistry; the (4) cognitive; (5) affective and (6) psychomotor domains embraced within the experiments using a five-point Likert-scale questionnaire. The teachers were of the opinion that the experiments were aligned with aims of the current syllabus, the experiments were feasible to be conducted, safe, encourages inquiry and relevant. The teachers also agreed that the experiments enhanced cognitive, affective and psychomotor domains of the learners. Additionally, an open-ended inquiry revealed green chemistry experiments are the alternative to the traditional experiments.

Keywords Green chemistry experiments · Secondary schools · Chemistry laboratory learning · Teachers' perceptions

Introduction

As chemistry is regarded as a difficult subject (Taber, 2002; Tsaparlis, 2014; Tumay, 2016), teaching and learning of chemistry are a challenge both for teachers and students. The learning of chemistry requires students' understanding of concepts which are abstract and therefore teachers play an important role in devising ways to

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deliver the subject matter in a meaningful context relevant to students. As such, teachers frequently invest time and effort to assist students in addressing the challenges encountered in comprehending abstract concepts. The chemistry of acids and bases involves integrated understanding of processes and concepts. For example, students collectively need to know about the formula, nature of the matter, knowledge on the bondings, ionization properties, the reactions and state of equilibrium in identifying the compounds as acid, base and amphoteric (Sheppard, 2006). The complexity and abstractness of the concepts consequently hinder the students to comprehend the importance of learning chemistry (Grove & Bretz, 2012). This in turn calls for the use of right instructional strategies to deliver the chemistry content in a way more tangible for students' understanding and also in a context relevant to students (Broman & Parchmann, 2014).

Chemistry Laboratory Learning

In science education, school laboratory work is fundamental in teaching and learning of science. The potential benefits accrued from the laboratory activities have been well documented (Hofstein, 2004; Roth, 1994; Tobin, 1990). Meaningful learning occurs in laboratory settings as students are provided with a platform to interact both physically and intellectually through hands-on investigation and reflection (Hofstein & Lunetta, 2004) since student-centred strategies allowed the students to actively engage themselves (Hofstein & Lunetta, 2004). Additionally, the laboratory setting also provided space for them to reflect. For example, some of the teaching strategies that have been used in laboratories and have resulted in positive outcomes in terms of students' understanding, motivation and also thinking skills are using problem-based and cooperative learning in laboratory practice (Zoller & Pushkin, 2007), inquiry-based chemistry experiments (Qing, Jing, & Yan, 2010), science heuristics writing in chemistry laboratory and green chemistry experiments (Shamuganathan & Karpudewan, 2017); argumentation driven green chemistry experiments, (Karpudewan, Roth, & Sinniah, 2016).

Green Chemistry as a Laboratory Pedagogy

Green chemistry offers an alternative philosophy to the existing chemistry. The application and extension of the green chemistry principles lead to sustainable development. As it is known, green chemistry or sustainable chemistry is a form of chemistry designed to prevent pollution by emphasizing the use of materials, processes, or practices that reduce or eliminate the creation of pollutants or waste (Anastas & Warner, 1998). Green chemistry is guided by 12 principles as below (Anastas & Warner, 1998):

1. **Prevention**

It is better to prevent waste than to treat or clean up waste after it has been formed.

2. **Atom Economy**

Synthetic methods should be designed to maximize the incorporation of all material used in the process into the final product.

3. **Less Hazardous Chemical Syntheses**

Wherever practicable, the synthetic method should be designed to use and generate a substance that possesses little or no toxicity to human health and environment.

4. **Designing safer chemicals**

Chemical products should be designed to effect their desired function while minimizing toxicity.

5. **Safer solvents and Auxiliaries**

The use of auxiliary substances (e.g. solvents, separation agents, etc.*) should be made unnecessary wherever possible and innocuous when used.*

6. **Design for Energy Efficiency**

Energy requirements of chemical processes should be recognized for their environmental and economic impacts and should be minimized. If possible, methods should be conducted at ambient temperature and pressure.

7. **Use of Renewable Feedstocks**

A raw material or feedstock should be renewable rather than depleting whenever technically and economically practicable.

8. **Reduce Derivatives**

Unnecessary derivatization (use of blocking groups, protection/deprotection, temporary modification of physical/chemical processes) should be minimized or avoided if possible, because such steps require additional reagents and can generate waste.

9. **Catalysis**

Catalytic reagents (as selective as possible) are superior to stoichiometric reagents.

10. **Design for Degradation**

Chemical products should be designed so that at the end of their function they break down into innocuous degradation products and do not persist in the environment.

11. **Real-time Analysis for Pollution Prevention**

Analytical methodologies need to be further developed to allow for real-time, in-Process monitoring and control prior to the formation of hazardous substances.

12. **Inherently Safer Chemistry for Accident Prevention**

Substances and the form of a substance used in a chemical process should be chosen to minimize the potential for chemical accidents, including releases, explosions and fires.

Since the introduction, the 12 principles of green chemistry have been adopted in industrial applications. Specifically, the principles were incorporated in adapting alternative pathways in manufacturing processes which use less energy, safer starting materials and produce less waste (Anastas & Warner, 1998). Since this particular knowledge is required by chemists in practicing sustainable manufacturing processes, it is therefore important that students are exposed to such knowledge at various education levels (Hjeresen, Boese, & Schutt, 2000). The green chemistry principles have been introduced into the curricula at different levels of education such as undergraduate courses (Andraos & Dicks, 2012; Cacciatore & Sevian, 2006; Prescott, 2013), teacher education programme (Karpudewan et al., 2009; Karpudewan, Ismail, & Roth, 2012b, 2012c) and also secondary schools (Karpudewan, Ismail, & Roth, 2012a, 2012c; Karpudewan et al., 2015, 2016). The aforementioned studies revealed changes in students' behaviour and values such as an increase in students' motivation and interest to study chemistry and a better understanding of chemistry concepts. This was likely due to the nature of green chemistry as claimed by Braun et al., (2006) that provides a connectedness between the subject matter and students' everyday living. According to meaningful learning takes place when students connect science concepts with real-world context. Andraos and Dicks (2012) also demonstrated that green chemistry laboratory setting provides the stage for meaningful teaching and learning. This has been made clear by several studies adopting green chemistry principles to laboratory work as an alternative to introducing green chemistry in education that brought about positive and fruitful outcomes as mentioned earlier.

In light of the important role of laboratory work in chemistry learning and also the positive outcome that was documented from implementing green chemistry experiments, a study was conducted to examine secondary school chemistry teachers' views on their laboratory experience and the implementation of green chemistry experiments in a Malaysian context. Specifically, the study was performed to examine the views of chemistry teachers on the importance of chemistry laboratory, how chemistry teachers perceive the current chemistry laboratory in secondary schools and how green chemistry laboratories are a possible alternative to the current chemistry laboratories.

Methods

A total of 100 (25 males and 75 females) chemistry teachers participated in a series of green chemistry workshops. The green chemistry workshop series was carried out for five consecutive weeks. During the workshops, teachers were exposed to 10 green chemistry experiments. The green chemistry experiments that were carried out and its aims are shown in Table 15.1.

The teachers were given the experience to engage in hands-on experiments and also in the inquiry. The workshop also presented teachers with information on how green chemistry experiments could be used in place of the currently polluting experiments in more benign laboratory practice. After conducting the series of 10 green chemistry experiments, teachers were required to provide their views on green chemistry experiments as an alternative laboratory learning. A questionnaire with five-point Likert scales ranging from strongly disagree to strongly agree was administered followed by an open-ended inquiry to gauge teachers' laboratory experience and how green chemistry experiments could possibly replace the current chemistry experiments.

The questionnaire responses were categorized into six components:

1. ***Relevance of green chemistry*** *to the current chemistry syllabus and specifications.*
2. ***Feasibility*** *of implementing the experiments in schools.*
3. ***Nature of green chemistry***.
4. ***Cognitive domain*** *involving the students' acquisition of knowledge.*
5. ***Affective domain*** *involving students' emotions or feeling when conducting green chemistry experiments.*

Table 15.1 Green chemistry experiments conducted during the workshop

Title	Aim
Rate of reaction (Vitamin C clock reaction)	1. Determine the rate of reaction between iodine and ascorbic acids
	2. Study the effect of changing the concentration of a reactant on the rate of reaction
	3. Study the effect of changing the temperature has on the rate of reaction
Electron configuration	1. To obtain a general knowledge of what produces different colours in fireworks 4. To write the electron configuration of elements
	2. To observe energy emitted from different energy levels when salt compounds are ignited
	3. To relate the colour shades to wavelength range
	3. To relate the colour shades to wavelength range
Lemon battery	1. To examine the properties of electrolytes and non-electrolytes

(continued)

Table 15.1 (continued)

Title	Aim
Production of biodiesel	1. Prepare biodiesel from cooking oil
	2. Identify the properties of biodiesel
Production of carbon dioxide	1. To prepare carbon dioxide using greener techniques
Acid and base (pH and its application)	1. State the properties of acid, base and Alkali
	2. Explain the role of water in the formation of hydrogen ions to show properties of acids
	3. Describe the chemical properties of acid and bases
	4. State the use of the pH scale
	5. Relate pH value with acidic or alkaline properties of a substance
	6. Relate strong or weak acid with the degree of dissociation
Titration of acidic candy	1. To understand the process of titration
	2. To use titration with a standard NaOH solutions to determine whether Sweet Tarts or Smarties candies require more standard base per gram of candy to the end-point
	3. To use titration with a standard NaOH solution to determine whether Sweet Tarts or Smarties candies have more moles of acid per gram of candy
	4. To acquire the correct technique of titration
Oxidation and reduction (green chunk and foil)	1. State what are oxidation and reduction process
	2. Explain what is a redox reaction
	3. State the oxidising and reducing agents
Filter paper electrochemical series	1. To explain with examples of oxidation and reduction reactions at the electrodes of various electrolytic cells
Detergent from Polylactic Acid (PLA)	1. To learn about renewable “corn” plastics made from polylactic acid
	2. To recycle the polylactic acid cup into new product: a cleaning solution

6. ***Psychomotor domain*** *is demonstrated through the use of physical skills during the experiments.*

The open-ended inquiry focused on three questions:

1. *What is your opinion regarding the importance of laboratory work in learning chemistry concepts?*

2. *How do you perceive the current chemistry laboratory in schools?*
3. *How green chemistry labs could possibly replace the current chemistry lab?*

Results and Discussion

In Fig. 15.1, the mean scores obtained for each component is illustrated.

As shown in Fig. 15.1, for all the six components the mean score obtained was above four. The mean score above four (highest possible mean is five) depicts that teachers were in agreement with the notion that green chemistry experiments were in accordance with the current curriculum; the experiments are feasible to be carried out; the experiments are safe, encourages inquiry among students and also able to reflect students real-life experience; and that the experiments incorporated the cognitive, affective and psychomotor domains to engage the students. Among the six components, the highest mean score was obtained for the psychomotor domain. This indicated that the teachers were of the view that experiencing and engaging in green chemistry experiments permitted the development of psychomotor skills among students. The lowest mean score was obtained for the item whether the green chemistry experiments were in accordance with the current curriculum and specification. However, despite being lowest, the reported mean of above four indicates green chemistry experiments are in accordance with the current curriculum. This implied that the teachers were in agreement with the idea that implementing green chemistry experiments accomplishes the aims of the curriculum as specified by the Ministry of Education. Comparatively, the teachers were more convinced over the other five components than this particular one.

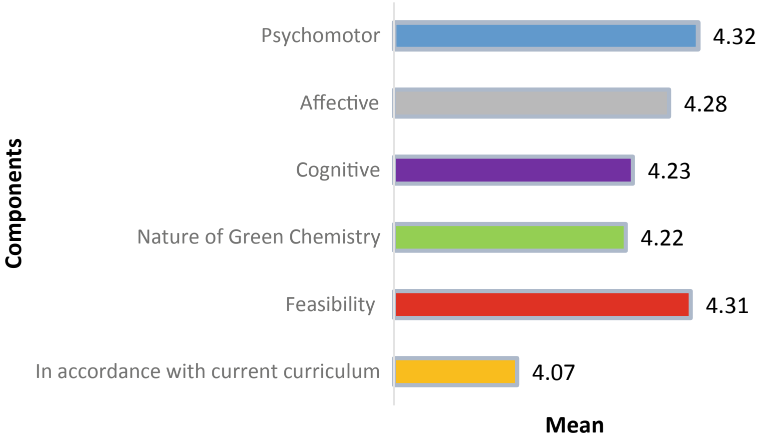

Fig. 15.1 Mean scores of six components for the items in the questionnaire

Table 15.2 Summary of teachers' view on the importance of laboratory work in learning chemistry

Domain	Description
Cognitive	An abstract concept is made more concrete through hands-on experience
	Improves students' understanding and meaningful learning
	Helps students to think and enhances their problem-solving skills
	Help students in critical thinking
	Concept or facts are retained longer as students observe the changes for real
Psychomotor	Improve manipulative skills like handling apparatus and chemicals
	Improve science process skills such as observation, measuring, classifying, predicting and inferring
Affective	Improves communication when students engage in discussions
	Develop students confident in using the laboratory apparatus and on practical work
	Improves self-efficacy and ability to communicate scientifically
	Stimulate interest in chemistry

For the open-ended questions, teachers' opinion on the importance of laboratory work in learning chemistry is categorized into the cognitive, affective and psychomotor domains as presented in Table 15.2.

In terms of the importance of chemistry laboratory work, the teachers emphasized that laboratory work is crucial for the understanding of chemistry concepts and in creating a meaningful learning context. The teachers were of the opinion that laboratory experience for students is an integral part of science learning as students were able to engage with hands-on experience, practice their science process and manipulative skills and develop a better understanding of concepts. The importance of laboratory work is not a new claim but research literature have long supported this notion (Hofstein, 2004, 2015; Hofstein & Lunetta, 1982). Since the laboratory component was emphasized as important for chemistry teaching, teachers' perception about the current chemistry laboratory in schools was explored from the perspective of time allocation, material environment and students' attitude. In Table 15.3 teachers' perceptions about current chemistry laboratory work are presented.

The main constraint that teachers faced was time. The teachers felt the time was insufficient for them to complete all the experiments stipulated in the curriculum specification. Due to this the teachers usually opted for theory lessons rather than practical work. The teachers also felt that completing theory lessons were more important in order to complete the syllabus and prepare students for their exams. In terms of materials used, it was found that chemical reagents and also apparatus were inadequate. This seemed to be a common issue faced by secondary school teachers and concurred with results documented in a study by Che Ahmad, Osman, and Halim (2013). Che Ahmad et al. (2013) employed the science laboratory environment inventory (SLEI) to investigate teachers' perception of the science laboratory learning

Table 15.3 Teachers' perceptions of chemistry laboratory work in schools today

Perceptions	Descriptions
Time	Many experiments to be covered in the syllabus. Some experiments were thought as not necessary to be in the syllabus
	Completing theory is more important than experiment due to exam-oriented mindset and time factor
Material environment	Chemical reagents and apparatus are inadequate
	Substances are hazardous and toxic. Teachers were afraid of students' safety
	Expensive cost involved in the purchase chemicals
Students' attitude	Some students felt bored as the experiments were not interesting
	Less participation when students in large groups involved in the experiment due to lack of chemical reagents and apparatus
	Students developed anxiety when handling hazardous chemical substances and some were not confident doing the experiment
	Some students were not interested in the experiment as they felt some chemicals were alien to them and the experiments did not attract them much

environment and its relationship to teacher satisfaction. Material environment subscale measured the extent to which the laboratory materials and equipment were adequate. Their findings revealed that materials were perceived to be inadequate with the second-lowest mean score. For this reason, teachers selected experiments that were appropriate based on the availability of the materials and also safer with less hazardous substances used. Some of the chemical substances were also not readily available as they were expensive. Teachers also found that some experiments used hazardous chemical substances and found it difficult to carry it out with large groups of students. Teachers felt that some experiments needed attention as they involve harmful substances as well as some dangerous procedures. The experiments currently in the syllabus and also the chemical substances used for that matter also impacted students' attitude towards chemistry. Through the responses of teachers from their experiences of conducting laboratories, teachers perceived that students performing experiments that were irrelevant caused them to lose their interest in learning chemistry. Insufficient availability of the materials for the regular large classes affected the students' participation in learning. Usage of hazardous substances prevalently in the current experiments caused anxiety not only among students but also teachers. Teachers perceived that students were not confident in carrying out the experiment while teachers fear the safety of students, especially when dealing with large group of students.

Upon completing the series of green chemistry experiments through the workshop, teachers' views of how green chemistry experiments could be used in place of the current chemistry laboratory were gathered. As teachers provided responses to their perceptions and concerns of the current chemistry laboratory work in schools as presented in Table 15.3, teachers were inclined to compare the current chemistry laboratories with green chemistry laboratories. Teachers provided their insights on how green chemistry laboratories could address the concerns of teachers in the current chemistry laboratories. In terms of time, teachers perceived that students are able to spend more quality laboratory time when conducting green chemistry experiments that were in accordance with the syllabus and also the experiments were relevant. For example, some of the responses that were given by the teachers were

> There are many experiments to be covered and furthermore some takes time and I don't prefer doing it rather just discuss the theory with them. Similar concepts using green chemistry experiments are interesting and saves time in doing. (Teacher Haslina)
>
> The green chemistry experiments can be used to teach chemistry concepts in schools, the objectives of the experiments conducted were concepts taught in the Form 4 and Form 5. (Teacher Berry)
>
> The use of harmful and toxic chemical substances does not interest them to conduct the experiments but using simple daily life materials in green chemistry experiments to teach the chemistry concepts would be fun and easily understood and attracts them to lab work. They will actually know what they are doing. (Teacher Chang)
>
> When chemistry concepts to be taught can be done in a safer and friendlier manner as in the green chemistry experiments, why complicate them with harmful chemicals and long procedures. The most important thing they learn the concept. I would choose conducting green chemistry experiments in my class (if given a chance) to teach the chemistry concepts currently. (Teacher Kasturi)
>
> The procedures of the green chemistry experiments are feasible and easily done without any complications. This saves much time and students can easily understand what they are doing. Students would be more engaged in doing the experiments. (Teacher Ana):
>
> The experiments are interesting and user friendly for students to learn the concepts they need to know at the secondary level and they would participate more actively. (Teacher Ahmad)
>
> All the green chemistry experiments conducted in the workshop were interesting and they covered the concepts needed for students to know. (Teacher Shahrir)
>
> Students sometimes spend the whole lesson doing the experiment without understanding. They cannot relate to the concept and they are not familiar with the chemicals used. But when they use materials they encounter in daily life, they would be able to relate to the concept to a certain extent. Quality time would be spent in the lab. (Teacher Lisa)

These responses of teachers above depicted that as they conducted the green chemistry experiments they were able to relate the objectives of those experiments with the syllabus and found the experiments to be appropriate and relevant to be conducted in terms of time and materials used that were related to students' daily life. These responses were given by almost all teachers in answering the open-ended question as to how green chemistry labs could possibly replace the current chemistry labs. Teachers also felt that this could encourage active participation of the students (see comments from Teacher 5). This perception of the teachers was also seen to be in line with the documented literature that supported the fact of students interest, mastery level of content as well as active engagement of students that resulted when Miller (2012) used a context-based approach green chemistry/bio-remediation principles among high school chemistry students and as asserted by Braun et al., (2006) on the nature of green chemistry having the connectivity between the subject matter and students' everyday living which leads to meaningful learning. To address the second concern of teachers related to the material environment, teachers strongly felt a sense of security in terms of safer laboratory was assured as materials used in green chemistry labs were more benign in comparison to the current scenario where students and teachers were exposed to chemicals that are hazardous and toxic. This resulted in teachers being afraid of handling big group of students dealing with harmful substances in the laboratories. Additionally, the readily available materials used in green chemistry experiments can reduce the expenses of purchasing chemicals as substances used in green chemistry experiments were more environmentally friendly and were much cheaper in comparison to the cost of purchasing chemicals. This could overcome the issue of inadequate materials for students and provide opportunity for all students to perform the experiments. Teachers were in strong agreement that students' attitude was also a main concern in the current chemistry labs. Most teachers who were involved in the workshop basically had a similar experience in conducting chemistry laboratories in schools. Almost 80% of teachers responding to the open-ended questions stated that students' attitude was crucial during laboratory sessions. This was seen to be described by the responses of teachers. Some of the teachers' responses were

> When students conducted experiments in groups, they did not cooperate fully and remain as spectators. Some students were not enthusiastic in performing experiments. (Teacher Lin)
>
> From observation students did not show much interest and their participation were not encouraging. Students feared using some chemical substances like concentrated acids and performing some experimental procedures. Performing experiments with less harmful effects and safer would reduce students' anxiety. (Teacher Kai En)
>
> Students would ask teachers to just demonstrate the experiments rather than doing it themselves since they were afraid of carrying out the procedures. Some experiments currently had procedures with precautionary steps that students had to follow closely to avoid accidents that freaked them out. Performing the experiments in a greener manner or alternative way would be preferred. (Teacher Amira)
>
> The same students in groups were the ones carrying out the experiments and some did not cooperate. (Teacher Ali)
>
> Students are not confident handling chemical apparatus and also feared dealing with harmful substances. Using more benign substances would be a good alternative as in the green chemistry experiments. (Teacher Fatimah)
>
> The nature of some of the current experiments investigating contexts that were not necessary and relevant added with complex experimental procedures and involving harmful substances. Students would ask why do we need to conduct this experiment, many procedures to be done and it is dangerous too. (Teacher Nila)

From the 80% of teachers that included students' attitude as one of the concerns in the current chemistry labs, 65% of teachers perceived students to be less engaged in those experiments and raised their anxiety level. The responses of teachers were based on observation done during their laboratory class sessions in their respective schools. Students did not participate fully due to reasons such as inadequate materials, experiment was not interesting and afraid of handling harmful chemical substances were depicted from their responses. For example, some of the responses given by teachers are

> Due to materials that needed to be shared, some students just watch their friends do. This involves chemicals that needed to be shared so that all classes have an opportunity to do throughout the week. If possible materials that cost cheaper would be an alternative as such as the green chemistry experiments. (Teacher Suzie)
>
> Students were afraid of handling acids especially when done in the fume cupboard and they do not seem to being doing the experiment with much interest (not all). They do enjoy some experiments too. (Teacher Chow)

From the responses, teachers believed that green chemistry laboratories are pedagogical strategies that will promote students' engagement and eases anxiety through learning with more familiar substances which are less harmful. The teachers were in the opinion that when daily life materials were used in the green chemistry laboratory, it would attract students attention, promote learning and students would appear more confident in conducting the experiments as materials are less harmful. The opinion of teachers was also found to be in line with findings of some past studies conducted with green chemistry (Karpudewan et al., 2015; Mandler, Mamlok-Naaman, Blonder, Yayon, & Hofstein, 2012; Miller, 2012; Tan & Karpudewan, 2017). Teachers also believed that green chemistry laboratories brought about positive effects on students' environmental values in which almost 95% of teachers in their responses stated using green chemistry experiments can create an environmental awareness for students to sustain the environment, as more benign substances were used in place of the current experiments to study the respective concepts. The views of teachers were also in line with the findings of past studies (Karpudewan et al., 2009; Karpudewan et al., 2012a, 2012b, 2012c; Shamuganathan & Karpudewan, 2017). From the responses of teachers, green chemistry laboratories were seen to significantly address the concerns and challenges faced in the current chemistry laboratory particularly involving time factor, materials and attitude of students.

Conclusion

The findings of past studies, frequently regarded chemistry as a difficult subject due to its abstract nature. The right teaching pedagogy ultimately determines students' ability to grasp the abstract concepts in a meaningful way. Previous studies also highlighted the essential role of laboratory work in supporting students' learning in science and hence the choice of the right pedagogy in the laboratory is of utmost importance to provide fruitful learning. On the other hand, many studies revealed green chemistry laboratory have provided positive outcomes in students' understanding of chemistry, as such it is imperative to expose the curriculum in secondary schools. Teachers are determinant in making ways for having green chemistry in education. Teachers' views on green chemistry curriculum are crucial particularly for a centralized education system such as Malaysia where the Ministry of Education entirely governs the education. In this study, teachers are strongly inclined that green chemistry curriculum is in accordance with the aims of the existing curriculum, it is feasible to be conducted, and able to embrace the domains of cognitive, affective and psychomotor through its implementation. In addition, teachers also viewed green chemistry labs as being able to address the challenges faced in the current chemistry labs. Views of teachers are informative in suggesting green chemistry as a laboratory pedagogy to teach secondary level chemistry and to propose green chemistry to be in the mainstream education system. More workshops on green chemistry implementation in secondary schools could be carried out in bigger scales involving curriculum planners from the Ministry of Education to put forth the idea and adopt their views. Educating teachers on using green chemistry as a laboratory pedagogy is another means of ensuring the implementation of green chemistry. Providing in-service training to educate the teachers about implementing green chemistry in laboratories is essential.

The emphasis on the importance of laboratory learning in science has long been given and therefore may not be a new issue to be encountered. Rather ways in which the laboratory instructional strategies may be diversified to meet the needs of teaching in the twenty-first century and opting for various ways to enhance teaching and learning in the laboratory are crucial. As such, implementing green chemistry experiments in laboratory work is seen as means of looking into laboratory work from a new lens in which this would be in line with the focus of Re-searching issues from different lenses.

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Chapter 16
Preliminary Results on the Value of Investing in Training for Practicing Chilean Life Science Teachers

Marjee Chmiel and Rodrigo Tapia Seaman

Abstract While Chile has been called an economic success story in the making, its educational system is challenged by inequalities, an under-prepared workforce, and inconsistency in teacher preparation. In 2016, a Chilean scientific research organization collaborated with philanthropy in the United States to offer curricular resources, professional development workshops, and leadership training to high-school life science teachers throughout Chile. Through a developmental evaluation lens, this study examines how an international collaboration provides professional development for practicing life science teachers. Our findings suggest this professional development contributed to teacher gains in content knowledge, their perceptions of professional growth, confidence, and students engagement upon implementing their newly acquired resources and practices.

Introduction

In 2017, the Organization for Economic Cooperation and Development (OECD) published a report on the state of education in Chile. Among their key findings was that Chile's educational system was holding the nation back from reaching its economic potential. As the OECD report notes, "Chile is an economic success story in the making" (OECD, 2017b, p. 37).

Chile has the third lowest performance on the 2015 Programme for International Student Assessment (PISA), among OECD countries (OECD, 2017a). As the economy grows and diversifies, the Chilean workforce has not been prepared with the skills needed to fulfill the professional roles of these growing economic opportunities. Furthermore, socio-economic status explained student performance to a degree greater than other nations, with one of the most unequal educational systems. Given

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these findings, Chile has been undergoing educational reforms for over a decade, and this effort demonstrates that there is a reason for optimism. Student performance on the PISA has increased dramatically since 2006 with the implementation of educational reforms in 2005. Many of the OECD recommendations to further improve Chile's education system focussed on teacher training and development, including the need for developing a cadre of professional leaders.

It is in this context that in 2016, one of the leading scientific research centers at University of Chile, Biomedical Neuroscience Institute (BNI), initiated an education and outreach program that provides professional development to high-school life science teachers via full-day workshops conducted on Saturdays. To complement major national investments for overhauling the system for recruiting and training new teachers, BNI made a commitment to work with current, practicing teachers. BNI identified a repository of free, online resources developed and maintained by the Howard Hughes Medical Institute (HHMI) BioInteractive program in the United States and reached out to the philanthropy for a collaboration. This partnership afforded BNI two important components to their professional development initiative: it provided a set of high-quality, free resources that were consistent with the Chilean curriculum and a roadmap for including effective principles for the professional development workshops.

The BioInteractive resources are unique in that they were developed and maintained through scientific research philanthropy. The content came directly from the frontiers of modern scientific research and was developed without the usual market constraints faced by commercial or nonprofit resource providers. It emphasizes the use of narrative and storytelling as a way to stimulate student engagement and unify several threshold concepts (Stokes, King & Libarkin, 2007) into multi-media with high production values. HHMI agreed to invest in Spanish-language translation of the resources and work with BNI to design workshops and a teacher leadership program based on a similar model implemented in the United States. In turn, the work in Chile provided HHMI program officers and directors with something we affectionately termed a "model organism" to better understand how our resources and programs work together to affect change. HHMI was able to test their theories of action and change in a novel, relatively controlled setting.

Through many years of informal feedback, BioInteractive has heard teachers in the United States comment on the effectiveness of BioInteractive resources and community on their own professional learning, but there had not been a large-scale evaluation to systematically investigate evidence to support this feedback. To this end, the program in Chile provided an ideal opportunity to learn more about the resource-community professional development dynamic in an entirely new context. Because Chile's population is in orders of magnitude smaller than the United States and because Chilean teachers work under a single, homogenous, national curriculum (in contrast to the United States, where the curriculum is driven primarily at the state level), Chile offered a new context and perspective.

To this end, the relationship between BNI and HHMI followed Patton's (2010) model for developmental evaluation and what he called "navigation in the middle."

This navigation in the middle emerged as a way to bridge previous debates in evaluation, according to Patton. On the one hand, traditional models of evaluation sought to discover best practices and strove for the fidelity of implementation. Failures to meet these practices or exhibit fidelity would be perceived as failures by local actors to carry a program out according to specifications. For Patton, this specific approach to evaluation fell short because this sort of "franchise" approach could only apply to simplified systems. It failed to recognize the complexity of many social innovations. It also failed to take into account the natural inclination that people had to tinker with models and adapt them to their local context. Top-down approaches to evaluation failed to take human nature into account.

On the other hand, some evaluation paradigms emphasized the viewpoints of participants and prioritized local knowledge and local wisdom. Overly focusing on local instantiation ran the risk of missing the big picture, discovering unifying phenomenon, and uncovering the persistent patterns that allowed an evaluation to uncover the effective principles of a program. This paper represents our first step in "navigating the middle." By using Patton's developmental evaluation model as a framework, we were able to examine theories from the literature on professional development and put to the test the components of our program that we believed to have been successful in the United States to the test in Chile. In applying this developmental evaluation lens to familiar problems and established theories, we upheld the theme of the 2018 International Science Education Conference of "re-searching science education: same issues from different lenses".

Designing and Implementing Resource-Driven Workshops

Prior to the start of the workshop, an informal needs assessment conducted by BNI found that secondary life science teachers identified the following challenges to their professional growth:

- Skills and knowledge: Teacher preparation was insufficient in keeping with the demands of teaching science at the secondary level. This included content knowledge, as well as knowledge around pedagogical practices in science, particularly in the area of inquiry-based, skills-building science.
- Teacher time: Teachers were not given sufficient time to plan and collaborate. Teachers saw this as a limiting factor to their ability to learn about new teaching strategies, plan new approaches, and innovate.
- Lack of confidence: Teachers did not feel empowered as professionals.

BNI offered monthly workshops during the school year, available for free on Saturdays in Santiago. These workshops attracted teachers throughout Chile. Each workshop focused on specific BioInteractive resources including student activities, datasets, case studies, short films, online interactives, and assessments. These resources were organized around topic storylines in areas such as evolution, natural selection, genetics, and ecology. In two years, the workshops included over 380 teachers (reaching approximately 10,000 students), most of whom paid their own way to travel to the workshops, some taking bus rides in excess of 10 hours.

In 2017, a special, three-day leadership academy was organized in order to provide focused training for frequent workshop attendees and strategically selected teachers to give them opportunities to become teacher leaders in their own regions. The overall workshop program has now completed its third year.

A critical feature of these workshops was that they were anchored in a collection of free, online resources developed by a scientific research institute. The BioInteractive resources were designed to address challenging scientific concepts through narrative and rich media from the point of view of practicing scientists, recognized storytellers, and expert media developers. These media resources were key as they focussed on presenting scientific discoveries on location and as such provided students with opportunities to "escape" to different locations, whether it was tracking finch populations on the Galapagos island or discovering a genetic variation in humans across sub-Saharan Africa. The resources aspired to not only be effective student-facing materials, but also to be educative (Davis & Krajcik, 2005) in that teachers improved their own pedagogical knowledge (Cochran, 1997) through the implementation of these resources in the classroom. While resource content development was driven by scientists, the surrounding lessons, activities, and implementation techniques were developed and tested by practicing teachers. Although BioInteractive resource implementation was the fulcrum of the professional development workshops, there were other aspects of the workshops worth noting. Group activities and collaboration fostered a learning community and workshops were teacher-led, providing leadership opportunities and career advancement for teachers. This workshop dynamic arose over the years of iteration and collaboration.

Research Questions

This paper presents the findings for the following questions:

- Were the workshops effective in increasing teacher knowledge about natural selection?
- What were the evidence that the workshops were addressing challenges to implementing inquiry-based approach in teaching?
- How did teachers perceive the outcomes of the workshop in terms of their own practice and ability to improve students' scientific engagement, attitudes, and skills?

Conceptual Context

DeSimone (2009) and Borko (2004) recognized a myriad of experiences that comprised a teacher's professional development. The workshops presented in this study represented one node in this myriad of experiences and were designed according to the following best principles (Hawley & Valli, 1999; Wilson & Berne, 1999):

- Content: For professional development to be effective, content should be accessible and relevant to participants. The workshops engaged teachers in specific resources available for free on the internet but did not require internet access to be implemented with students. The content was aligned with Chile's life science curriculum.
- Active learning: These workshops engaged participants in active learning by asking teachers to take on the role of students in their classroom as they engaged in sense-making during life science activities. Teachers also engaged in discussions.
- Coherence: For professional development to be effective, it needs to align with the teacher's professional priorities. These workshops achieved coherence by offering content that was relevant to the curriculum, but they also appealed to teachers because of their emphasis on a type of pedagogy known as "indagación." The term mapped on to what, in the United States, was called inquiry-based teaching. Another element of coherence came from the fact that the workshops were centered around fully developed lessons that integrate media. Unlike textbooks or traditional resources, the BioInteractive resources included fully developed lessons written by curriculum designers and practicing teachers but were anchored in rich media such as films and animations. Having these pre-designed lessons allowed teachers to focus on planning and implementation. Teachers did not have to spend as much time designing a lesson, preparing teaching materials, searching for resources, and thinking about how to turn the content into an indagación experience.
- Duration: Teachers should have multiple opportunities to learn and practice what they learned. Each workshop occurred over 6.5 hours on a Saturday, and many teachers attended one workshop per month, with eight workshops offered each year. This provided teachers with the opportunity to have frequent contact with substantial duration. Naturally, this structure impinged on teachers' free time and the teachers who attended the workshops were a select group who were committed to their development.
- Collective participation: This principle reflected the importance of designing professional development experiences that facilitate sharing and collaboration among teachers with common professional goals. In the case of the workshops presented in the current study, the teachers involved teach life science at the high school/secondary level and were motivated to become better practitioners of indagación. This was the primary feature they shared and the evidence (presented later in this paper) suggested that this was a powerful unifier for the teachers who were geographically dispersed and were from a variety of institution types.

Another perspective in our study was that of Pedagogical Content Knowledge (PCK) in science teaching. One of the questions we had about the BNI's workshops was the extent they were serving to build teachers' content knowledge. Content knowledge was the basis for building teachers' confidence and expertise in PCK (Van Driel, Verloop, & De Vos, 1998; Wilson, 2013), but science education lacked sufficient validated assessment tools for teacher knowledge. This "lack of sound measures of teachers' knowledge for the science classroom" impeded the progress of research in the professional development of science teachers (Wilson, 2013, p. 311). We were selective about which workshops we assessed for content knowledge gains as we wanted to be mindful of instrument validity. The topic of natural selection was central to understanding the life sciences and, as a result, extensive research on expert versus novice reasoning in natural selection resulted in the development of validated assessments that were appropriate to use with our teacher population.

Methodology

To answer the research questions, "What were the evidence that the workshops were addressed the challenges identified by these teachers?" and "How did teachers perceive the outcomes of the workshop in terms of their ability to improve students' scientific engagement, attitudes, and skills?", we conducted semi-structured interviews over a web-conferencing service. We recruited teachers from the pool of workshop participants over the past three years, with an aim toward diversifying the sample in regard to how many workshops they participated in and led as well as the geographical distribution of the teachers. Interviews were semi-structured so that data collection could go more deeply in areas of interest that emerged. Follow-up observations with these teachers were also conducted, and while that data was outside the scope of this paper, the findings were used to triangulate some of the reporting in the interviews. A total of five teachers were interviewed over March, April, and May of 2018. Interviews were conducted in Spanish with a native Spanish-speaker as the interviewer. Each interview lasted one hour and was recorded and transcribed. Emerging themes were identified and committed to a codebook developed internally that was used to evaluate all of BioInteractive's research efforts, but we also looked for novel and emerging themes. Once these were identified, the interviews were translated into English to triangulate the analysis, and the classifications (Seidman, 2013) and their supporting quotations were selected when there was a total consensus between both analysts.

To determine knowledge gains, we used the Assessing Contextual Reasoning on the Nature of Science (ACORNS) short-answer diagnostic test that allowed for different prompts in the pre- and post-workshop. This tool was designed for use with undergraduate students majoring in biology, but we believed it could offer insights into our work. ACORNS is also a diagnosis of explanation building, providing a richer understanding of scientific skills than other available assessment instruments (Nehm, Beggrow, Opfer, 2012). ACORNS assessments were graded via an online tool called Evograder, built on interview data that track novice through expert reasoning in natural selection and provided an analysis of how much a response depended on non-scientific explanations versus scientific explanations of the evolutionary phenomenon. This assessment was administered to all 38 teachers who attended a workshop focused on natural selection in late March of 2018

Results and Discussion

Are the workshops effective in increasing teacher knowledge about natural selection? The results of the ACORNS assessment indicated that there was an overall growth in participating teachers' use of "pure scientific" explanations from the pre- (Fig. 16.1) (38.46%) to the post-test (62.86%), while naïve explanations and mixed naïve and pure explanations reduced, suggesting that teachers were able to incorporate elements of the type of reasoning employed by evolution scientists at the end of the workshop. We saw this as a positive indication that the workshops were providing teachers with growth opportunities for their skills (scientific explanations) and knowledge (natural selection) that warranted further investigation.

What was the evidence to show that the workshops had addressed challenges in implementing inquiry-based teaching? We were able to find some evidence in the interview data presented in Table 16.1. Among the major themes presented, all of the teachers spoke in depth about how they saw their classrooms and students changing. Many readily admitted that change was challenging at first, but by the time of the interviews, they were reporting positive changes in classroom culture. They reported noticing students building higher level thinking skills, a change that addresses one of

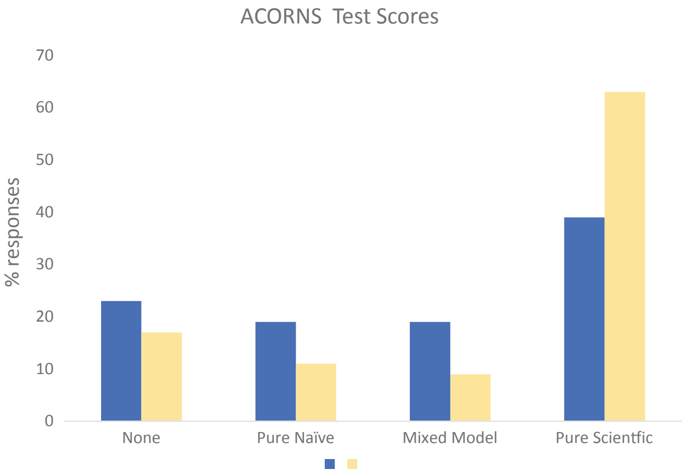

Fig. 16.1 ACORNS pre and post scores

Table 16.1 Interview data

Code	Supporting sample quotation (translated into English)
Changes in practice	The workshops helped me realize that this was the way to teach science, to teach skills
	I used to give them all the content and they only listen. Now I've learnt to not tell everything, to push them to think, to give them time. It's been a big change for me and I like to share my experience with my colleagues
	The structure of my classes has changed. It's not monotonous anymore, I do "inquiry" and I try to use these activities as much as I can because I know my students like them
	I've been able to promote collaborative work with other teachers, from different areas
	Before this experience, my classes were focused on me, I delivered all the content, everything explained in a "ppt presentation". Then I started to give less and demand a little bit more. Now I barely give them the "digested content", I make more open questions. I do more teamwork. I stopped being the center of the class
	Now I want them to think and I search for activities that help me to do that
	Now the classes are more challenging and engaging, for the students and myself
	I like the fact that we work like students, it helps us to put ourselves in their place
Collective participation	It is very helpful to share experiences with other teachers, they give you examples and tips. It's a teamwork
	There's room for sharing experiences and see how other colleagues have implemented the activities
	There is a supporting network, solidarity, we create a very special bonding
	I lost the fear to share my experiences
	I've been able to promote collaborative work with other teachers, from different areas
Confidence	The workshops have helped us to lose the fear to change
	I like the idea that teachers who are participating in the workshops have the opportunity to dictate workshops. That is empowering. We can't teach in the University if we don't have a master's degree, but here we have the opportunity to share our knowledge and experience with other teachers
	I used to feel insecure about new practices, I didn't know to make my classes more engaging. These workshops helped to overcome that. Now I feel confident, with more tools to teach

(continued)

Table 16.1 (continued)

Code	Supporting sample quotation (translated into English)
	We do the activities in the workshops which helped me to understand well the activities and feel confident using the material in my classes. We also shared ideas and experiences with other teachers, that´s very useful
Perception of students	The students see the benefits, they understand that science is not only about experiments, but it's also about analysis, reflection, inferences. They developed "scientific thinking"
	In the beginning, it was hard to make this change, they were resistant, they were used to get all the answer from me. But later they realized that it was a different logic, they learnt to observe and search for the answer by themselves
	They used to talk content by memory, now you see them making connections, they use their own words to explain things, they make associations and their answers are well founded
	It is incredible for me to see them discuss, getting to conclusions. Now I see them think, and it's been an amazing process
	They have a more scientific attitude now. They are motivated, and they learn
	The students really enjoy the classes, they feel motivated. It is a very powerful experience
	They learned skills, to discuss and argument. They learned groupwork. Stronger students mentored weaker ones. They learned to seek, interpret, and analyze information
	It was challenging to implement this "new methodology", we all were used to expositive content-based lectures. At first, the students thought they were not learning anything, but with time they realized they have learned new skills. They work in groups, discuss better, they express themselves better
	My students are chaotic but when I played the film they just watched it very focused. It was impressive. And they did all the activities by themselves
Coherence: Saving time	The resources are very useful, everything is ready for the classroom, so I saved time
	I feel that the time spent in the workshop is well spent, they are efficient, well organized. It is a good time investment
	The workshops not only give us new strategies, like using inquiry-based learning in the classroom, but they also give us activities ready to use in the classroom and tips on how to use them. And that, considering the little time we have, is essential for us to use this resource

the OECD recommendations. Other themes that emerged strengthen existing theories about what makes an effective professional development, as the teachers discussed the community they had built in the workshops, as well as the importance of having strong resources grounded in their content area.

The interviews also helped us address the question, "How were the teachers' perceived outcomes of the workshop in terms of their own practice and ability to improve students' scientific engagement, attitudes, and skills?"

Based on the interview data, teachers from the workshop expressed feeling more confident about emphasizing the role of science skills in their classroom as a result of the workshops. They saw their colleagues, who also participated in these workshops, tried new strategies and empowered one and another to do the same. Teachers reported that students were more engaged, independent, and used more scientific skills. Observations done during this same time period with teachers confirmed that students were in fact engaged in scientific habits of mind (such as explaining data tables and planning investigations). Teachers reported that the workshops had paved a road for them to become local leaders in their region, and we hope to follow these teachers to better understand what potential effects they had on their colleagues and school communities.

It is important to note a limitation of these interviews and observations is that data collection was restricted to teacher implementation of BioInteractive resources. At the time of this writing, most of the BioInteractive resources focused on a few areas in biology such as evolution and genetics and it was in these areas that the teachers reported greater confidence with implementing indagación. To this end, it is important to acknowledge that teacher development is a slow transition that may not happen evenly across the science curriculum. The workshops gave teachers an opportunity to experience some of the resources from the students' point of view, and these were the areas where teachers naturally felt most comfortable to change their practice. It remains to be seen how this translates into other parts of their curriculum.

Conclusions and Implications for Practice

As Chile invests in developing a stronger teaching force, there is little information about the impacts of such investment on practicing teachers. This preliminary study demonstrated that a motivated, self-selected cohort of life science teachers showed professional gains as a result of participating in professional development workshops, and preliminary inquiry into their skills and content knowledge development show promising increases. As part of our evaluation initiative, we will continue to monitor these teachers' growth to determine whether they have the potential to be change agents in their regions and schools. Such findings could point to these teachers being the real leaders in affecting the change that catalyzes Chile's story of success. A modest investment toward training and workshops produced promising results, suggesting the value of investing in the development of practicing teachers.

Many national science curricula are wrestling with the problem of how to integrate higher order thinking and scientific practices along with rigorous scientific content. To be sure, neighboring Argentina's and Peru's struggles with PISA scores have been well documented (Hanushek & Woessmann, 2012), resulting, in part, from science curricula that under-emphasize indagación.

Too often, there is a perception that this type of teaching and learning is very resource intensive. There is a belief that teachers need classrooms outfitted with laboratory equipment and extensive materials such as inquiry "kits" and other consumable supplies. Access to such resources is limited in developed economies, to say nothing of those economies that are developing. Implementation of BioInteractive resources demonstrated that scientific skills and habits can be fostered among students with no additional materials. All that is needed are thoughtful resources; skilled, confident teachers, and engaged students. With that noted, we acknowledge that free, high-quality resources are difficult to come by and our research suggested that the quality and comprehensiveness of these resources are pivotal in the success of the workshops.

Building on these workshops, BNI and HHMI partnered to conduct a first-of-its-kind conference for secondary life science teachers to network, attend professional development workshops, and interact with scientists and policy makers. Around 170 teachers from throughout Chile attended the conference in Santiago on October 5, 6, and 7 of 2018. Teachers kept journals during the three-day conference, which are currently being analyzed in an effort to better understand the needs and opportunities of this community, especially with an eye toward building a national network of educators. The BNI program aspires to continue to build, especially in major population hubs outside of the Santiago metropolitan area. Future evaluation efforts will focus on the development of the pipeline of teacher leaders that emerge from the existing network.

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Chapter 17
Teaching Integration of 5E Instructional Model and Flower Components

Thasaneeya Ratanaroutai Nopparatjamjomras and Suchai Nopparatjamjomras

Abstract This action research aimed to develop graduated students' understanding of teaching biology based on the 5E instructional model using a flower components lesson in a higher degree Biology Education course. The 5E instructional model was promoted in this study in view of the educational policies of the participants' countries which supported the student-centered learning approach. Flower components topic was selected as it is a common topic in the science curriculum of participants' countries and all participants studied this topic when they were students at the primary level. The data was collected from two student cohorts of a Biology Education course. Each cohort comprises five and six students, respectively. Students' reflection sheet and activity sheet were analyzed using content analysis. The analysis of data indicated that the instruction enhanced students' understanding of 5E Instructional model and flower components topic. Students were also able to plan for lessons using the 5E instructional model in other biology topics. Results of the reflection sheets also showed students' appreciation for putting theory into practice in biology education.

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Introduction

From Policy to Practice

Office of the National Education Commission (ONEC) (2000) stated that teacher is the key element in teaching and learning reform especially incorporating teaching and learning theories into classroom practice. A high quality of teaching is the basic element for success in education (Pelzang, 2012). Thus, teachers can be counted as the most important asset in the classroom (Nopparatjamjomras, 2012). A good science teacher should have knowledge both in content and pedagogy (Institute for the Promotion of Teaching Science and Technology (IPST), 2004), which relates to Shulman's (1987) idea of pedagogical content knowledge.

Over the years, the education systems of Bhutan, Myanmar, and Thailand have shifted toward a student-centered learning approach (Ministry of Education, 2004; ONEC, 2000; Tenzin & Maxwell, 2008). Many teaching and learning approaches including 5E instructional model are promoted as a student-centered learning approach (Pelzang, 2012).

5E Instructional Model

The 5E instructional model is an important instructional approach in teaching and learning of science. Biological Sciences Curriculum Study (BSCS) launched the BSCS 5E Instructional Model by Rodger W. Bybee since the late 1980s (Bybee et al., 2006). The BSCS Model consists of five phases: Engagement, Exploration, Explanation, Elaboration, and Evaluation. For the *Engagement phase*, the teacher can use short activities that promote curiosity and elicit prior knowledge of students. The teacher may use lab activities to identify and facilitate the conceptual understanding of students in the *Exploration phase*. In the *Explanation phase*, students should have chances to demonstrate conceptual understanding, process skills, or behaviors. New experiences through additional activities should be used to challenge and extend students' conceptual understanding in the *Elaboration phase*. The last phase, *Evaluation*, encourages students to assess their abilities. The teacher also has opportunities to evaluate students' progress toward educational objectives. Some educators named the 5E phases as a learning cycle (Arslan, Gebun, & Saglam, 2015).

The 5E instructional model encourages students to think creatively and critically and to facilitate a better understanding of scientific concepts (Cakiroglu, 2006; Kaynar, Tekkaya, & Cakiroglu, 2009; Pelzang, Nopparatjamjomras & Nopparatjamjomras, 2014). It is effective in bringing about conceptual change or removing alternative conceptions in the teaching of the circulatory system (Cardak, Dikmenli, & Saritas, 2008), cell concepts and its organelles (Kaynar et al., 2009), and cell cycle (Urey & Calik, 2008). The 5E model also enhances retention of science learning (Fazelian, Ebrahim, & Soraghi, 2010) and improves students' attitudes and interest toward learning of science (Balci, Cakiroglu, & Tekkaya, 2006). A number of studies support the efficacy of the 5E instructional model as a teaching and learning approach to enhance students' mastery of subject matter (Bybee et al., 2006).

Why Did We Do This Research?

One learning outcome for both masters and doctoral degree students in the Science and Technology Education international program of University A was "to develop innovations and learning processes in an ethical and appropriate manner compatible with the society and the educational needs". Required courses and elective courses aimed to promote this main learning outcome of the programs. Biology Education course was a selective course with two credits. All students who would like to complete a thesis with biology education-related content were recommended to register for this course.

Two of the main learning outcomes of the course were: (1) "to demonstrate the different approaches in teaching and learning biology" and (2) "to develop classroom instruction including the integration between teaching and learning approaches with biology contents". For example, the teaching and learning approaches in the course were problem-based learning, project-based learning, inquiry, and 5E instructional model, etc. Each approach was taught within 2 h. Based on evidence from the course outcomes, when students could not achieve the first learning outcome, they did not achieve the second learning outcome. The other problem was some students seemed able to demonstrate the first learning outcome, but could not integrate biology content with the teaching and learning approach. These situations match the statement from Asian Development Bank (2002): a number of teachers in Thailand lacked the understanding to associate learning theories with knowledge and skills. The document also presented that the majority of Thai teachers lacked a good understanding of the concepts, principles, and processes involved in the new approaches of teaching and learning.

The situations in the course were related to the views of teacher development articulated in Bell (2003). Using data from a three-year research project of teacher development in New Zealand funded by the New Zealand Ministry of Education, Bell (2003) found that "After attending in-service courses or professional association meetings, or studying for university qualifications, in-service teachers still feel unable to use the new teaching activities, curriculum materials, or content knowledge to improve the learning of their students" (p. 681). In Thailand, Nopparatjamjomras, Nopparatjamjomras and Jittivadhna (2011) reported that both school principals and science teachers in welfare schools of Thailand agreed that science teachers should be developed in terms of the teaching and learning strategies. Moreover, the teachers needed to develop themselves in science content. At the national level, ONEC (2001) and IPST (2004) suggested that good science teachers should have knowledge of teaching and learning and should be able to use teaching strategies that fit with content and students. Furthermore, Geddis, Onslow, Beynon, and Oesch (1993) found that science teachers who could integrate content knowledge and pedagogies were the teachers who understood student's conception and succeeded in their teaching.

In the previous cohort, lecturers of each topic taught the content of instructional model through PowerPoint. When the lecturers taught the instructional model before following by giving an example of implementation, students could not show the ability as mentioned in the course learning outcome. Therefore, this study focuses on the ability of master and doctoral students to develop a 5E instructional model for teaching biology by using a lesson plan integration of a flower component case. Hence, the research question of this study is "How does the teaching integration of 5E instructional model using flower components lesson as an example affect the learning of graduate students in terms of flower components knowledge and 5E instructional model knowledge?"

Methodology

Action research is defined by Wiersma (2000) as research that is usually conducted by teachers, administrators, or other educational professionals for solving a specific problem. It can be undertaken by the individual teacher, a group of teachers working co-operatively within one institute, or a teacher or teachers working alongside a researcher or researchers in a sustained relationship (Cohen, Manion, & Morrison, 2000). This study is an action research because the process owner realized the problems and tried to find a way to solve the problems.

The 5E instructional model was promoted in this study in view of the educational policies of the participants' countries which supported student-centered learning approach. Flower components topic, which was including complete flower, incomplete flower, perfect flower, and imperfect flower, was selected as this topic is a common topic in the science curriculum of participants' countries and all participants had studied this topic when they were students at the primary level. The science contents of flower components are (a) Complete flower: a flower which composes of four main components: stamen, pistil, petals, and sepals; (b) Incomplete flower: a flower which does not have the four components completely; (c) Perfect flower: a flower which has both male and female gametes; and (d) Imperfect flower: a flower which does not have the two gametes in the same flower.

To study the 5E instructional model topic in the Biology Education course, the students should understand 5E instructional model. Then, they should be able to develop a biology classroom instruction which is based on 5E instructional model. However, the main problems in studying the 5E instructional model in the Biology Education course in the cohorts prior to this research study were (1) knowledge of 5E instructional model and (2) using 5E instructional model in developing a biology instruction. Before the beginning of the first cohort in this study, one of the authors who taught the Biology Education for more than 5 years as a process owner responsible for the 5E instructional model section planned to change the instruction to address these 2 problems. The instruction had been changed from only explaining the sequence of 5E instruction model step by step to integrating an example of biology topic into the sequence of 5E instructional model with a hands-on activity.

Methods

The Biology Education course was delivered in English following the requirement of the international study program. The course content included a variety of teaching and learning strategies including the 5E instructional model, which can be used in teaching biology. The idea for developing the 5E instructional model lesson was based on Loucks-Horsley, Love, Stiles, Mundry, and Hewson (2003), which stated strategies for professional learning as follows: (a) commit to vision and standards, (b) analyze student learning and other data, (c) set goals, (d) plan, (e) do, and (f) evaluate. During the period of the lesson development, some steps may go forward and backward. They stated that professional development strategies are chosen and combined based on goals, needs, and the context.

According to the reality in the classroom, the hands-on activity was created based on the condition that it should be able to work in typical classrooms without any extra facilities settings. Moreover, learning materials which students have to work with during the classroom lesson should not be too complicated for the teacher to prepare. Phases in the Biology Education course lesson where the study took place are described in Fig. 17.1. The example of flower components with 5E instructional model is in the *Exploration phase,* which took place over approximately 50 min out of the two-hour lesson. Details in brief of the lesson activities are shown as following.

Participants

The participants of the first cohort were four Bhutanese students at the Master's degree level and a Thai doctoral degree student. All of them were scholarship recipients with at least one year's experience in teaching basic education in their home countries. The participants of the second cohort were four Thai students and a Myanmar student at the Master's degree level and a Thai doctoral degree student. The four Thai students at the Master's degree level had at least one semester of teaching experience. Myanmar student did not have any teaching experience. He was a medical doctor in Myanmar. The doctoral degree student had over two years of teaching experience. Most students in the second cohort were scholarship recipients except for a Thai Master Degree level student. To apply and study in this program, all participants had to have science- or education-related background.

Engagement phase

Each student was asked to take short note about their prior knowledge of 5E instructional model.

Exploration phase

Main activities of each phase following by 5E instructional model were launched to students.

Engagement: Hibiscus flowers together with a basket of flowers were showed to the class. They were asked to draw and label complete flower and perfect flower from their understanding.

Exploration: Hibiscus was delivered to each group of students together with razor blade and cutting plate. There were 2-3 students per group. They had to explore flower components of Hibiscus. Tablet computer with internet connection and textbooks were provided to students. They were allowed to search either from textbooks or from reliable URL sources.

Explanation: The representative student(s) from each group explained about components and type of Hibiscus. Teacher provided more information using PowerPoint slides.

Elaboration: Other local flowers were delivered to each group of students together with razor blade and cutting plate. There were 2-3 students per group. They had to study the components of the flower.

Evaluation: Each group selected their ways to conclude the type of flower which they were given with reason. The possible answer could be complete flower, incomplete flower, perfect flower, or imperfect flower.

Each phase took about 10 minutes.

Explanation phase

Video clips of 5E instructional model originally provided by BSCS were modified to include guided questions for the class. The original URL of the video clips are: https://www.youtube.com/watch?v=WDAtdpQhxYk, https://www.youtube.com/watch?v=c242mIDLgUE, and https://www.youtube.com/watch?v=G4J4Am8vLrY

Each student had to discuss to the whole class about each step that they had finished in the flower components case comparing with 5E instructional model.

Elaboration phase

Each group of students had to create a brief 5E instructional model teaching and learning activity based on their national science curriculum.

Evaluation phase

Each group presented their activities plan to the whole class. The whole class discussed interesting points of each plan. Teacher raised the point for students to think about the a) - e) step of Loucks-Horsley et al. (2003) in relation to using the 5E instructional model. Each student was asked to check their understanding with the short note they took in the beginning of the lesson and to complete a reflection sheet.

Fig. 17.1 Phases in the Biology Education course lessons where the study took place

Data Collection

The qualitative data of this action research was collected from two cohorts of Biology Education course in Science and Technology Education program study. Data was collected by the first author who taught in the class using activity sheets and reflection sheets. Reflections from the first cohort participants were collected as a whole class reflection, so individual reflections were not collected. However, the authors needed to clarify the effect of the teaching integration on individual participants. Therefore, participants from the second cohort were asked to reflect their learning individually. In this university, informed consent from participants is not required for action research. However, the first author, who was a lecturer in a class, conveyed the ethical information to participants. Each participant was asked to participate in the research and was given a participant information sheet which explained any risks that may occur during the data collection periods. Their personal information will be kept confidential. The participants had the right to withdraw from the research at any time prior to publication of the research.

Data Analysis

The authors read through participants' activity sheets and reflection sheets. All textual contents of the reflection sheet and activity sheet of participants were analyzed. To answer the study's research question, the data were analyzed using two predetermined themes: (a) *science content knowledge of flower components* and (b) *knowledge of 5E instructional model*. For science content knowledge of flower components, authors looked for evidence of participants' understanding of components in a complete flower, incomplete flower, perfect flower, and imperfect flower. For the knowledge of 5E instructional model, authors looked for evidence of participants' understanding of the engage, explore, explain, elaborate, and evaluate stages.

In addition, the authors found an additional theme emergent from the data that could be named as *attitudes toward the 5E lesson*. For this emergent theme, the authors worked through approximately 30% of the data set together to identify and define the codes and their descriptions together. The data were segmented into meaningful expressions (Strauss, Corbin, & Corbin, 1998) which were coded as shown in Table 17.1.

The remaining data were coded individually. Finally, the inter-rater reliability based on a simple agreement was 90%. The differences were resolved by discussion until reaching an agreement. The analyzed data were discussed, shared, and reported to the director of the study programs for further development of the course.

Table 17.1 The codes of attitudes toward a 5E lesson

Open code	Properties	Examples of participants' words
Theory of 5E into Practice	Summarize concept	Could summarize concept by myself
	Understand	Clearly understand about 5E model
Lesson Plan	Using the video	The video can explain about 5E well
	Instructional materials	Explain the concept with the picture
	PowerPoint Slides	Handout help to understand 5E
	Hands-on laboratory	Hands-on activity is good stage
	Group discussion	Every student has chances to participate in the class
	Whole class discussion	
Implementation in the future	Apply to teach	Will apply to teach in other topics
	Adapt to teaching	Will adapt the theory to new class

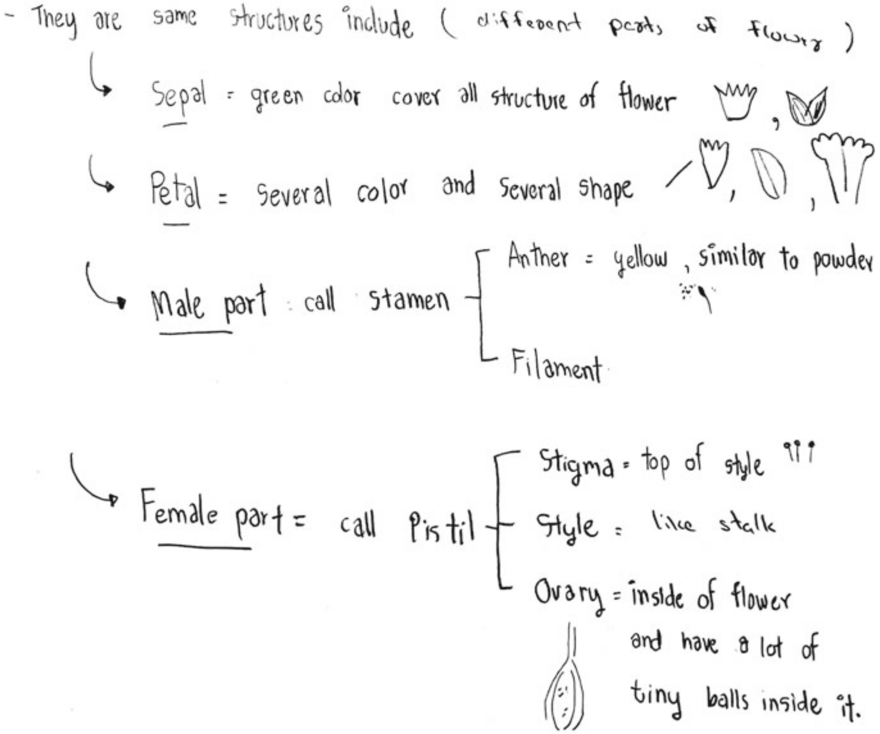
Results and Discussion

When the class started, the first author who was a lecturer in the class used questions to probe students' knowledge of "flower components" as well as "5E instructional model". All participants could not mention about both terms in detail. For example, components of flower and steps of 5E instructional model.

In the end, results are presented in three parts which are science knowledge, 5E instructional model knowledge, and attitude toward a 5E lesson plan which included flower components topic in the exploration phase.

Science Knowledge

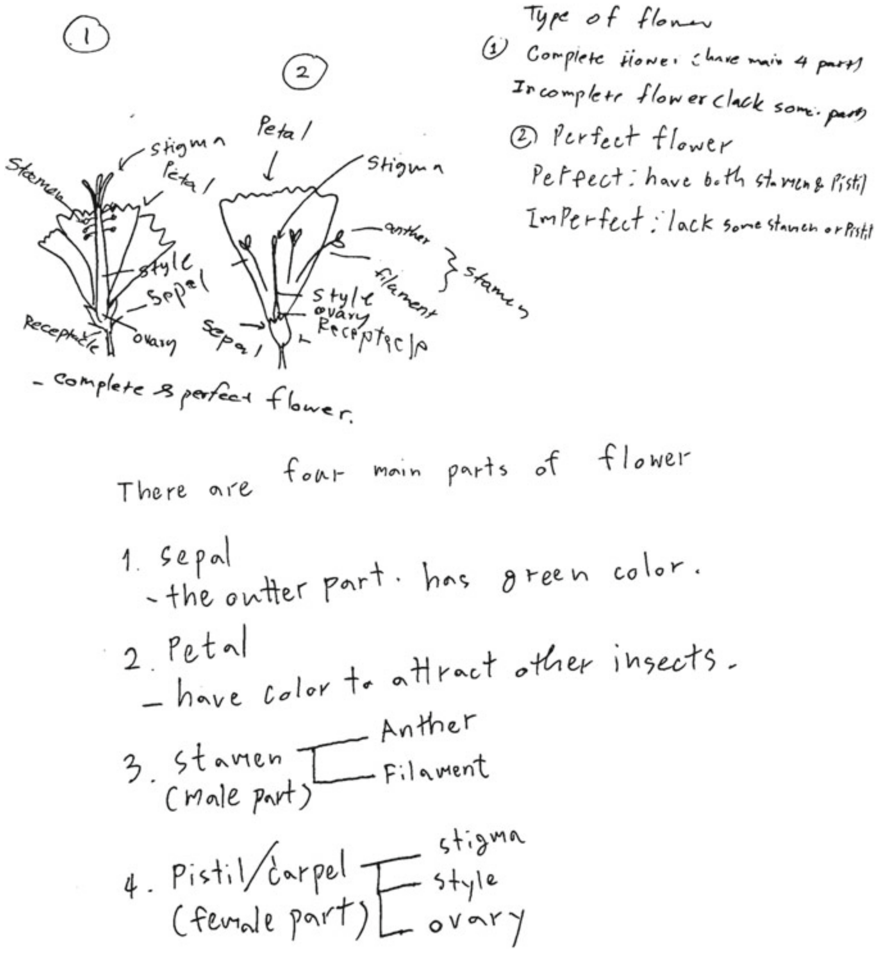
Results from the activity sheet showed that all participants were able to describe the main components of a flower. For example, participants MM04 and MF05 mentioned that flower components were composed of sepal, petal, stamen or male part, and pistil or female part (Fig. 17.2). They were also mentioned that stamen had anther



- They are same structures include (different parts of flower)
  - Sepal = green color cover all structure of flower
  - Petal = Several color and Several shape
  - Male part : call stamen
    - Anther = yellow, similar to powder
    - Filament
  - Female part = call Pistil
    - Stigma = top of style
    - Style = like stalk
    - Ovary = inside of flower and have a lot of tiny balls inside it.

Fig. 17.2 Some parts of an activity sheet of MM04 and MF05 and filament. For pistil, they stated it composed of stigma, style, and ovary.

Results from the activity sheet also showed that all participants could describe components of flower in a complete flower and a perfect flower. For example, participants MM03 and MM06 explained their understanding about components of a flower through written explanation and drawings in Fig. 17.3.



Type of flower
① Complete flower (have main 4 parts)
Incomplete flower (lack some parts)
② Perfect flower
Perfect: have both stamen & Pistil
Imperfect: lack some stamen or Pistil

There are four main parts of flower

1. sepal
- the outter part. has green color.

2. Petal
- have color to attract other insects.

3. stamen (male part) — Anther, Filament

4. Pistil/carpel (female part) — stigma, style, ovary

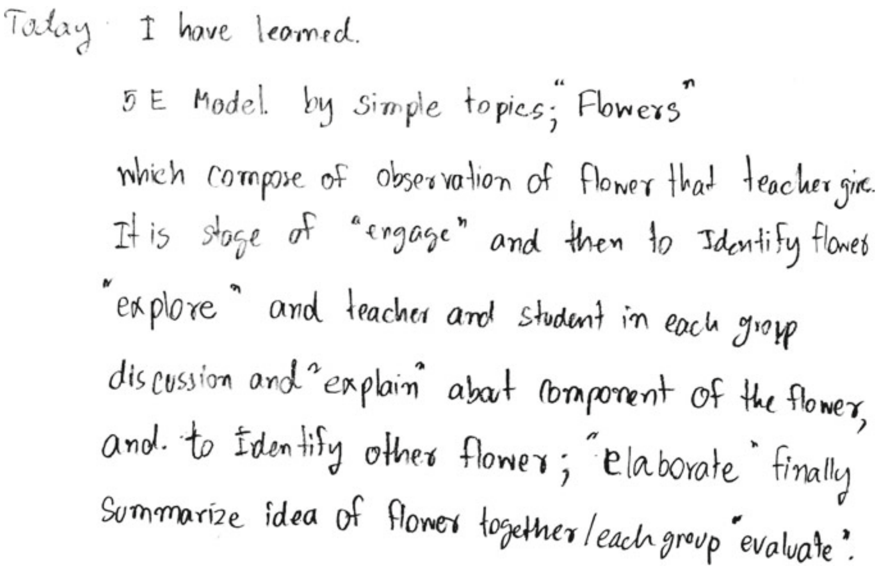
Fig. 17.3 Some parts of an activity sheet of MM03 and MM06

5E Instructional Model Knowledge

From the classroom presentation, it seemed that participants as a group could demonstrate the 5E instructional model in teaching and learning of a selected biology topic. Knowledge of 5E instructional model was improved when compared with students' short notes on the Engagement phase. An example of participant MM04, who had limited prior knowledge of 5E instructional model, is elaborated here. In the beginning, MM04 only realized that 5E instructional model should have 5 steps without any idea of details in each step. However, at the end of the activity (the Evaluation phase), he volunteered to present an activity plan which included 5E instructional model to the class. His presentation suggests that he had a correct understanding about 5E instructional model. Moreover, other participants' understanding about the steps of the 5E instructional model was presented in their reflection sheet. A sample of participant DM02's reflection is shown in Fig. 17.4. As shown in Fig. 17.4, participant DM02 could describe each step of 5E instructional model which are engage, explore, explain, elaborate, and evaluate in brief.

Attitudes Toward a 5E Lesson

The results of the reflection sheet also provided information on students' attitudes toward the 5E instructional model. Three themes of the attitudes toward a 5E



Today I have learned.

5 E Model by simple topics; "Flowers"

which compose of observation of flower that teacher give.

It is stage of "engage" and then to Identify flower

"explore" and teacher and student in each group

discussion and "explain" abat component of the flower,

and. to Identify other flower; "elaborate" finally

Summarize idea of flower together/each group "evaluate".

Fig. 17.4 A part of a reflection sheet of DM02 lesson were classified as (a) theory of 5E into practice, (b) lesson plan, and (c) implementation in the future. The details are as follows:

(A) Theory of 5E into practice

Three from six of the participants in the second cohort appreciated about how the lesson translated the theory of the 5E instructional model into practice. Most of them reflected that they had more confidence to implement 5E instructional model into their classroom, as illustrated in the following participants' comments.

> I could summarize concept by myself. All the steps make me get more understanding about 5E (MF01).
>
> The way you teach make me clearly understand about 5E model. (MF05).

(B) Lesson plan

Three from six participants had positive feedback on the 5E instructional model and flower components lesson plan (based on phases outlined in Fig. 17.1), including the use of video, instructional materials, PowerPoint slides, hands-on laboratory, as well as group- and whole-class discussions. For example, one participant thought the video could explain 5E well (MF05). Another participant found the activities "very interesting and happy" (MM04).

(C) Implementation in the future

Three from six participants in the second cohort agreed that the development of a lesson plan which was integrated teaching and learning approach and biology content would be useful for them to implement in their countries in the future. One participant mentioned the lesson was good and simple. He would apply the lesson to his classroom for teaching other topics (DM02). Another participant thought he would adapt the 5E instructional model to his teaching in the future (MM03).

The only participant who came from science subject field in the second cohort wondered about the complication of Hibiscus and suggested to use a simpler flower in the exploration phase. His comments were opposite to those of other participants from the same cohort. They commented that the Hibiscus is a simple flower which many people are familiar with, which is related to the sample flower for teaching flower components in science textbooks of Bhutan, Myanmar, and Thailand.

During the study, we found one additional point beyond our research purposes which might be useful for other instructors who would like to adapt this research into other topics. We found that the Elaboration phase of the second cohort took longer than the plan. A group of two participants in the second cohort spent a longer period to develop brief teaching and learning activities. It might happen because the participants in that cohort did not have a chance to study how to create lesson plans, which normally should be taught in the other course that parallels with the biology education course. If this 5E instruction lesson plan will be used in the future, time would be spared for the Evaluation phase as Bybee (2014) mentioned that the evaluation is needed at the end of the unit.

The integration of scientific contents and learning approach in our research gave the participants a chance to experience and think like their future students during the Exploration phase. This could help them understand what their future students had to face during the 5E learning activity in the class. This experience could help the participants to prepare their science content knowledge and pedagogical knowledge of the 5E instructional model, which in turn will help enhance their students' understanding in the future.

Conclusions

From the results, the data indicated that the implementation of a Biology Education course lesson based on 5E instructional model using flower components was able to enhance participants' understanding of the flower components content and 5E instructional model. The results of this study agree with Marx, Freeman, Krajcik, and Blumenfeld (2003) who suggested that results of teaching may lead to different learnings when teachers construct their knowledge by integrating new learning with prior knowledge and beliefs, by applying ideas to practice, and by reflecting on the students' learning. To use (1) the flower components section as a part of using real teaching and learning activity in the 5E lesson together with (2) analyzing teaching and learning sequences in the flower components section and (3) applying these two types of knowledge to create biology teaching and learning activities based on 5E instructional model are parts of an inquiry approach. This inquiry approach is one of the common approaches to prepare teachers according to Darling-Hammond (2006). In this study, the authors used the flower components as an example of 5E activities. All participants had a chance to analyze teaching and learning through the reflection sheet. The participants had the opportunity to apply 5E instructional model in the activity sheet to teach other biology topics. When the participants who are going to be teachers could integrate the instructional model into their teaching and learning process as they did in the Biology Education lessons in this study, they would have more confident in real situations in their classrooms as teacher confidence is a key element of teacher professionalism (Nolan & Molla, 2017).

It can be concluded from this study that the integration of scientific contents and learning approach might be a solution for one of the existing problems in science teacher education, which is some teachers lack confidence integrating a new instructional model into their teaching and learning process even though they had been trained for the new instructional model many times (Bell, 2003). Our study findings suggest this alternative way could promote both knowledge of the instructional model as well as the confidence to implement the model in their own classroom. Therefore, integrating a science topic into the sequence of the instructional model as a hands-on activity rather than explaining the sequence step by step could be an alternative way of teaching or alternative new lens in science teacher preparation education especially for novice science educators.

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Chapter 18
Crafting Literature-Based Task—Our Journey on Viva Voce and Thought Processes

Chorng Shin Wee and Gah Hung Lee

Abstract Since 2010, the Chemistry Department at Hwa Chong Institution in Singapore begun exposing students to contemporary literature on various platforms. We started with students in the senior high school science special programmes and Pharmaceutical Chemistry course where we shared with them the research papers. The students were required to discuss and answer some open-ended questions after reading the research papers. At an appropriate juncture, we conducted an oral examination with the students to assess their appreciation and understanding of the literature. This chapter focuses on our journey in crafting learning and assessment tasks based on existing relevant scientific literature, with a focus on tasks related to oral examination and literature appreciation. We will also discuss how these tasks improve students' learning using students' survey results and, most importantly, how their results improve significantly as compared to the earlier cohort of students before viva voce using literature was implemented. The conceptual, epistemic and social benefits of viva voce were also examined and discussed.

Introduction

The chemical education landscape at the Junior College level (equivalent to Grades 11–12, aged 17–18) in Singapore is generally being perceived as demanding. Based on our experience teaching chemistry to this group of students for the past decade, we observed that a significant number of students were not able to relate what they learn to the real world. The Ministry of Education in Singapore has a six-year cycle of curriculum and syllabus review to ensure that what the students are learning is keeping abreast to the development in the world. A key change made recently was the inclusion of examples or suggestions on learning experiences related to the topics is added into the syllabuses to help refine in the learning and teaching of chemistry. This

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change underscores the twenty-first Century Competencies (Ministry of Education, n.d.), which the Ministry of Education (MOE) in Singapore espoused to develop in our students. In order to achieve the goal set up by MOE, the assessment for The Singapore–Cambridge General Certificate of Education Advanced Level (GCE A-Level) Chemistry has also been updated to include more application questions based on unfamiliar context (Singapore Examinations and Assessment Board, 2015). There are more data-based response questions that require students to make inferences from given information (e.g., descriptive text, graphs and diagrams) to answer the questions.

Since 2010, the College Chemistry Department of Hwa Chong Institution (a school in Singapore that offers a six-year (Grade 7–12, aged 13–18) middle to high school programme for students) begun exposing students to contemporary literature in various platforms. Contemporary literature includes research articles which highlight the latest research findings which adds a twist to what the students already knew from their curriculum (see e.g., Zhang, et al., 2019) to review papers which provide a snapshot on the latest happening within the industry (see e.g., Campos et al., 2019). The initial intention was to provide highly competent students in the science special programmes as well as Higher 3 (H3) Pharmaceutical Chemistry, an advanced and elective chemistry course, with assigned readings from peer-reviewed publications. This was aimed at challenging the potential of these highly talented and capable students, and to develop higher order cognitive skills in critical thinking and making scientific inferences based on the materials given. The use of scientific literature for teaching and learning is not new; it is widely adopted in tertiary education (Forest & Rayne, 2009; Beall, 1993; Parker, 1973; Ferrer-Vinent, Bruehl, Pan, & Jones, 2015) but less used for pre-university education, as the content involved were largely of a more sophisticated level and thus beyond the reach of most pre-university students. The more palatable readings for pre-university students are from Chemistry Reviews and Scientific American as these were mainly written by authors with the end goal of bringing scientific knowledge to the masses and thus less technical terms are used. However, not many students have access to them or will read them on their own accord. In order not to let these contents go to waste, it is possible to craft activities or tasks based on these articles and let the students work on them to make learning chemistry more interesting and ‘real’ (based on real-world context). Students can also work together in groups as such tasks usually promote collaborative learning.

Viva Voce

The use of oral examination in teaching and learning is not new and the most familiar form would be an oral defence for graduate students where an assessed Questions and Answer (Q&A) component was conducted following an oral presentation. In our literature search, we found that viva voce, an oral examination which is traditionally being used in medical school assessments as well as in graduate school, may be a good alternative to address these difficulties (Harper Adams University, 2017). Medical schools often use this mode of assessment with both their undergraduate (Epstein, 2007) and graduate students (Memon, Joughin, & Memon, 2010) as this mode of assessment could test the limits of a students' knowledge as written assessment might not be able to perform such differentiation effectively. Oral assessment was also used in elementary school science education (Evans, 2001) and high school physical education (Thorburn & Collins, 2006) but their focus are usually on the lower cognitive level skills as opposed to those in universities. The advantage of viva voce has been reported in the study by Pearce and Lee (2009). They found that in comparison to traditional written examinations which focus on the regurgitation of content, the process of preparation for viva could encourage students to gain a better understanding of the subject matter.

Viva voce is a good way for teachers to assess the required learning outcomes as feedback could be given almost instantaneously (Duschl, 2008). Through dialectic communication, it also allows the teachers to probe the depth and extent of students' knowledge and thus, serves as a great platform to assess the overall competency of the students (Joughin, 2010). Most importantly, ambiguous questions, which are sometimes unavoidable in traditional written tests, may be clarified by the students. Appropriate guidance and scaffolding may be provided by the assessor when required. Disadvantages of viva voce such as biasness (Birley, 2001) and the presence of incompetent examiners and stress (Arndt, Guly & McManus, 1986) could be avoided with proper training and guidance from the more experienced teachers.

In this chapter, we will describe the thought processes on how we use chemical literature to craft out oral examination tasks for students in H3 Pharmaceutical Chemistry course and we observed an improvement in their year-end GCE 'A' level results. To the best of our knowledge, there were no published reports about viva voce for pre-university students in areas of chemistry that require higher cognitive level skills.

In what follows, we first discuss the problems that we identified our students' learning. Then, we describe how we tackled these problems by implementing tasks based on literature, with a focus on oral examination. We also present our observation about how the learning experience of the students has improved, culminating in their excellent results in GCE 'A' Level examination for this particular course. Finally, we discuss our analysis of the conceptual, epistemic and social (Duschl, 2008) benefits of viva voce for our students using the data gathered from students' feedback.

Identifying the Problem

Within the H3 Pharmaceutical Chemistry curriculum, we identified three difficulties which every cohort of students encountered—proposing reaction mechanism, structural elucidation via evaluating spectroscopic data and the integration of prior knowledge and either the stimulus or data provided by the question to come out with reasonable responses (Bhattacharyya, 2013; Graulich, 2015; Webber & Flynn, 2018). It is difficult for the teachers to address these difficulties in summative assessments because solving these problems involves complex cognitive processes and it is difficult to identify which part of the thought processes the students have difficulty. Moreover, if the feedback is only given to the students after they have received the scripts, the students would usually not remember the question clearly as it is no longer fresh in their mind.

The Viva Voce Journey—Implementation, Planning and Thought Processes

Pre-literature Appreciation Phase (2008–2012)

The thoughts of implementing viva first came about in 2008 when H3 Pharmaceutical Chemistry was in its second year of implementation. In 2009, the implementation of viva was pioneered by a group of dedicated teachers focusing on structural elucidation of chemical compounds using spectroscopic data. The students were made to interpret the mass spectrometry (MS), ultraviolet (UV), infra-red (IR) and nuclear magnetic resonance (NMR) spectroscopic data of an unknown compound and derive its structure. On the day of the assessment, the data were printed on the same sheet of paper, folded into half and placed into a common pool for the students to draw. Students randomly picked one sheet of paper and were given 10 min to decipher the structure of the chemical compound. After that, the students met their assigned assessor (teacher) and explained how they arrived at their answer. The students' performance was assessed based on a set of rubrics and the assessment was typically completed within a day for a group of 80 students.

After the initial success of viva with the topic on spectroscopy, we proceeded to include the reaction mechanism in our assessment in 2010. On the day of the assessment, similar to what was described above, the students randomly picked one sheet of paper but this time around, there were two questions—one required them to derive the chemical structure of an unknown via spectroscopic data and another required them to draw a simple addition–elimination mechanism under acidic or alkaline medium using the substrate provided in the question. The students were given 15 min to complete the task before being assessed by the assessor to whom students verbalized their thought processes. The same format was used in 2011 and 2012. Although the viva voce was met with good success, we asked ourselves whether we could introduce more authentic context to the assessment so that it would be more beneficial for students.

Literature Appreciation Phase (2013)

In 2013, a new viva voce format was introduced by incorporating the component of literature appreciation—this marries the real-world context (literature appreciation of contemporary literature) with the drawing of a reaction mechanism. The difficulty of the viva was thus enhanced significantly and to ensure fairness, the students were given up to five days to read and research on a peer-reviewed publication assigned to them before the actual assessment day. They were also encouraged to discuss the content of the article with their peers, thus promoting collaborative learning among the students. The implementation was a little more laborious than previous and it had to be completed over two days with six to eight examiners per day. The students were first housed in the holding area as shown in Fig. 18.1 before the first two students in each group were asked to move to the preparation room.

Three different structural elucidation questions (printed on one sheet) and three different sets of reaction mechanism and literature appreciation questions (printed on another sheet) based on three different journal articles were used for each day. Similar to before, the two sheets of papers were stapled and folded before placing them into boxes for the students to draw in the preparation room as shown in Fig. 18.2. The boxes were labelled clearly (with the article number) so that the students only drew from the boxes containing questions from the article they prepared. Owning to the increased rigour of the reaction mechanism question, the preparation time for the students was increased to 20 min. In order to ensure fairness, the students were not allowed to bring along the printed copies of the journal articles as they are likely to

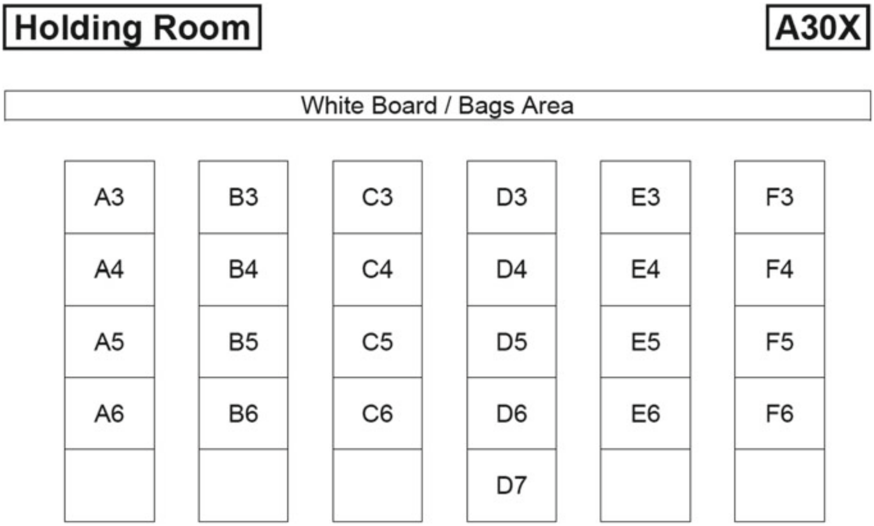


Fig. 18.1 Holding room. This figure illustrates the furniture arrangement of the holding room

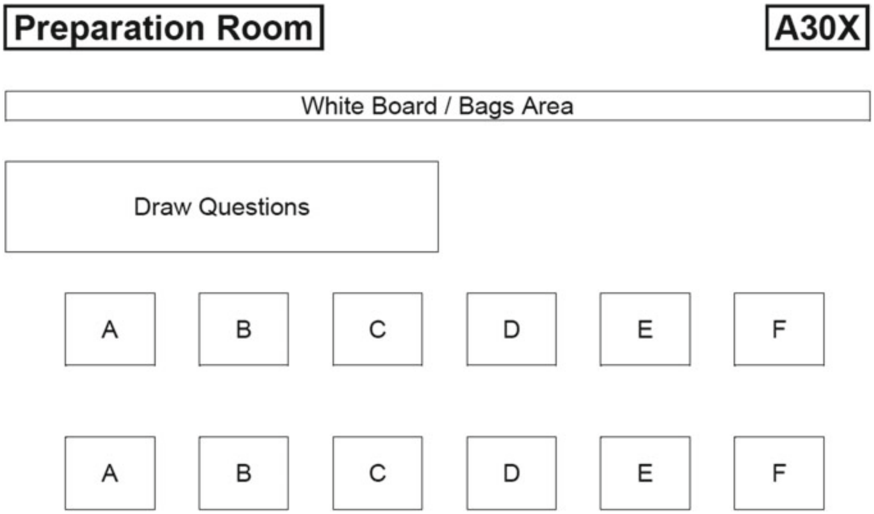


Fig. 18.2 Preparation room. This figure illustrates the furniture arrangement in the preparation room

be fully annotated and highlighted. Instead, a fresh copy of the journal article was provided for them.

When the preparation time is up, the student proceeded to the testing room (Fig. 18.3) to present and verbalize their thought processes to the examiner within 25 min.

Figure 18.4 shows a photo enacting the actual viva voce scene.

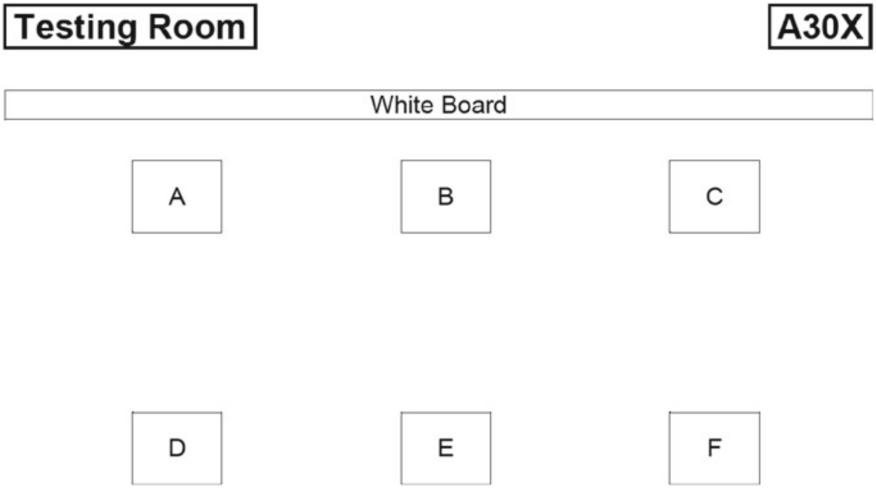


Fig. 18.3 Testing room. This figure illustrates the furniture arrangement of the testing room

Fig. 18.4 In the actual testing room, faces of assessors and students are masked with a black circle for privacy

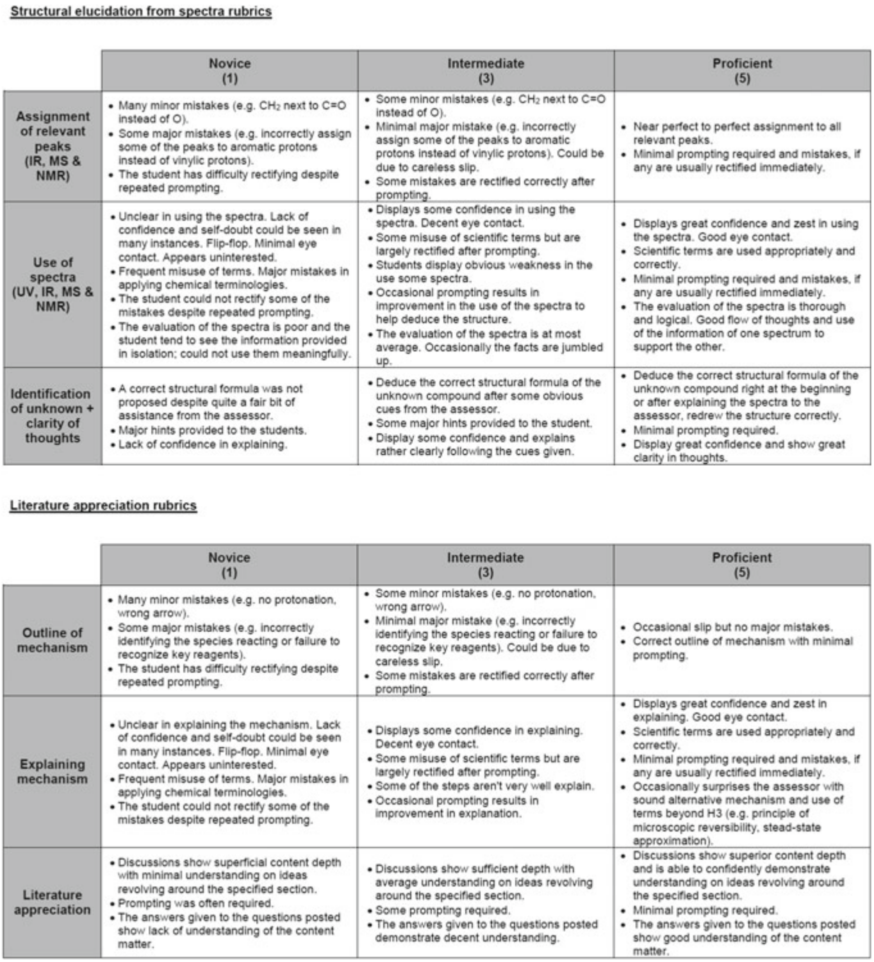
Key Insights Gleaned from the Two Phases

The selection of journal articles was a key consideration in viva voce as it should not be too lengthy (ideally between four to five pages) or too contextually demanding. By contextually demanding, we meant papers that contained too many chemical reactions and concepts that were way beyond the requirement of the syllabus. We tended to favour journal paper showcasing a synthetic route towards the making of a drug or those that included studies that were done to make different variants of a drugs and testings were done on them to find out about their efficacies. This allowed us to scope our reaction mechanism questions by drawing the students' attention to the synthetic route. Literature appreciation questions could also be scoped by focusing the students' attention on the strategies employed by the researchers and general procedures provided by the papers, when deemed fit.

There was also a need to consider the practicality of implementation (e.g., one or two days depending on the number of students and assessors) and also the implementation period (e.g., whether the students have minimal co-curricular activity commitments during that period).

The readiness of the assessor was also an important consideration. Some guidance and briefing for new assessors were provided and they may be mentored by more experience assessors on the first day to learn the rope.

Finally, for the assessment to be valid and rigorous, a suitable set of rubrics was important and extensive resources were referenced (Brookhart, 2013; Chan, 2009) in the development of the rubrics. The rubrics were designed to distinguish students in their level of competencies based on our defined criteria for success. We identified the three most important criteria of success for both tasks. The fine-tuned version of the rubrics for structural elucidation and literature appreciation is shown in Fig. 18.5 below and it is based on a three-point rubrics, which we found most suitable for our use.



Structural elucidation from spectra rubrics

	Novice (1)	Intermediate (3)	Proficient (5)
Assignment of relevant peaks (IR, MS & NMR)	• Many minor mistakes (e.g. CH_2 next to C=O instead of O). • Some major mistakes (e.g. incorrectly assign some of the peaks to aromatic protons instead of vinylic protons). • The student has difficulty rectifying despite repeated prompting.	• Some minor mistakes (e.g. CH_2 next to C=O instead of O). • Minimal major mistake (e.g. incorrectly assign some of the peaks to aromatic protons instead of vinylic protons). Could be due to careless slip. • Some mistakes are rectified correctly after prompting.	• Near perfect to perfect assignment to all relevant peaks. • Minimal prompting required and mistakes, if any are usually rectified immediately.
Use of spectra (UV, IR, MS & NMR)	• Unclear in using the spectra. Lack of confidence and self-doubt could be seen in many instances. Flip-flop. Minimal eye contact. Appears uninterested. • Frequent misuse of terms. Major mistakes in applying chemical terminologies. • The student could not rectify some of the mistakes despite repeated prompting. • The evaluation of the spectra is poor and the student tend to see the information provided in isolation; could not use them meaningfully.	• Displays some confidence in using the spectra. Decent eye contact. • Some misuse of scientific terms but are largely rectified after prompting. • Students display obvious weakness in the use some spectra. • Occasional prompting results in improvement in the use of the spectra to help deduce the structure. • The evaluation of the spectra is at most average. Occasionally the facts are jumbled up.	• Displays great confidence and zest in using the spectra. Good eye contact. • Scientific terms are used appropriately and correctly. • Minimal prompting required and mistakes, if any are usually rectified immediately. • The evaluation of the spectra is thorough and logical. Good flow of thoughts and use of the information of one spectrum to support the other.
Identification of unknown + clarity of thoughts	• A correct structural formula was not proposed despite quite a fair bit of assistance from the assessor. • Major hints provided to the students. • Lack of confidence in explaining.	• Deduce the correct structural formula of the unknown compound after some obvious cues from the assessor. • Some major hints provided to the student. • Display some confidence and explains rather clearly following the cues given.	• Deduce the correct structural formula of the unknown compound right at the beginning or after explaining the spectra to the assessor, redrew the structure correctly. • Minimal prompting required. • Display great confidence and show great clarity in thoughts.

Literature appreciation rubrics

	Novice (1)	Intermediate (3)	Proficient (5)
Outline of mechanism	• Many minor mistakes (e.g. no protonation, wrong arrow). • Some major mistakes (e.g. incorrectly identifying the species reacting or failure to recognize key reagents). • The student has difficulty rectifying despite repeated prompting.	• Some minor mistakes (e.g. no protonation, wrong arrow). • Minimal major mistake (e.g. incorrectly identifying the species reacting or failure to recognize key reagents). Could be due to careless slip. • Some mistakes are rectified correctly after prompting.	• Occasional slip but no major mistakes. • Correct outline of mechanism with minimal prompting.
Explaining mechanism	• Unclear in explaining the mechanism. Lack of confidence and self-doubt could be seen in many instances. Flip-flop. Minimal eye contact. Appears uninterested. • Frequent misuse of terms. Major mistakes in applying chemical terminologies. • The student could not rectify some of the mistakes despite repeated prompting.	• Displays some confidence in explaining. Decent eye contact. • Some misuse of scientific terms but are largely rectified after prompting. • Some of the steps aren't very well explain. • Occasional prompting results in improvement in explanation.	• Displays great confidence and zest in explaining. Good eye contact. • Scientific terms are used appropriately and correctly. • Minimal prompting required and mistakes, if any are usually rectified immediately. • Occasionally surprises the assessor with sound alternative mechanism and use of terms beyond H3 (e.g. principle of microscopic reversibility, stead-state approximation).
Literature appreciation	• Discussions show superficial content depth with minimal understanding on ideas revolving around the specified section. • Prompting was often required. • The answers given to the questions posted show lack of understanding of the content matter.	• Discussions show sufficient depth with average understanding on ideas revolving around the specified section. • Some prompting required. • The answers given to the questions posted demonstrate decent understanding.	• Discussions show superior content depth and is able to confidently demonstrate understanding on ideas revolving around the specified section. • Minimal prompting required. • The answers given to the questions posted show good understanding of the content matter.

Fig. 18.5 Rubric for viva

An Illustration of How a Suitable Article Was Selected

The choice of the article used for viva voce was instrumental in its success and in this section, we explain how an article was selected. We use the research publication by Biber, Möws and Plietker (2010) to illustrate the thought process behind how a paper could be used as a source of material for viva voce. This work was chosen because it was not too lengthy and most of the reactions were accessible to the students (such as alpha hydrogen deprotonation, nucleophilic aliphatic substitution, addition–elimination, conjugate addition and first-order elimination conjugate base). There was also some element of interest as the chemical structures of the compounds were rather aesthetically pleasing and related; they were also known to show anti-cancer properties. This article also highlighted some of the explicit learning which the researchers went through and the motivation of carrying out the research was clearly spelt out. All these factors made the paper appealing and offered a holistic learning experience for students. Finally, possible (extension) appreciation questions could be asked based on the context of the paper (such as the use of crown ether—which was covered in chemical bonding under the H2 Chemistry curriculum).

Coming up with the mechanism questions required giving the students some scaffolding and contextualizing it for them with appropriate hints was important in addressing the learning objectives of the topic. We had to keep in mind that the students were not undergraduates and could simply draw mechanisms from the reaction scheme in the paper (even advanced undergraduates experienced difficulties doing that). An example of possible questions that could be asked, based on the work by Plietker and co-workers could be obtained from the authors upon request.

The new viva voce format begun in 2013 and it was implemented until 2018. A new revised H3 syllabus began in 2019. We foresee the continued implementation of the viva voce as a large part of the reaction mechanism and structural elucidation using spectroscopic data is retained in the new syllabus.

Results and Discussion

When Duschl (2008) reviewed major reforms in science education since 1950, he proposed that the learning of science could be centred on three learning goals—conceptual, epistemic and social. From our survey results and feedback from the students, there were strong indications that viva voce was able to fulfil all three learning goals. In what follows, we used these three broad learning goals to frame our analysis of the outcomes of the implementation of viva voce.

Conceptual Learning Goal

Six batches of students have gone through the new viva voce format and we asked them for feedback via a Google form. Many have highlighted that they liked such an assessment format despite the anxiety and treasured the conversation which they had with the assessors. A lot of rich discussions and learning took place and these cannot be replaced by a written exam. Quoting one student, "…the viva was a very enriching experience as we got to have time to have a close discussion with the H3 teachers and had many of our misconceptions clarified …" (Student 1, google survey; July 9, 2018). The students' improvement in reaction mechanism drawing could be seen from the quality of the answers in subsequent assessments and it was common to find students' feedback highlighting that "viva helped me greatly in sharpening my skills in drawing mechanisms" (Student 2, google survey; July 23, 2018). Indeed, many students who graduated from the course had fond memories in their learning and this was aptly summed up by a former student as follow:

> A range of various possible factors that could affect mechanisms were taught under different topics and it was up to us, in our very challenging homework and exams, to use the factors creatively and critically to come up with a feasible mechanism. What I appreciated was that there was usually no fixed answer that the teachers provided immediately, but rather we were encouraged to explain our thought process behind each step, and there was room for us to defend our cases (and occasionally, win) for our answers. The emphasis on this critical thinking and flexibility is particularly evident in the oral tests that we had –Viva. The test itself was effectively to articulate our entire case for the mechanism we drew out on the spot. This entire process allowed me to engage more critically and closely with subject, and to truly internalize our learnings in order to actually present a convincing case and mechanisms. I felt that the active use of the knowledge acquired was a fresh change from the usual didactic teachings and memorization of standard answers in science exams. Additionally, the in-depth exploration of Chemistry enlightened our understanding of H2 Chemistry too. The class made the study of Chemistry a lot more meaningful, since I could understand the workings behind it better. (Student 3, email correspondence; October 18, 2018)

As mentioned under 'identifying the problem' section, we set out to testbed viva to solve three critical problems and from the example students' feedback given above, there was an improvement in their understanding of the subject matter. The proxy to this would be the more refined written answers to integrated questions and the drawing of mechanisms during the preliminary examination (usually takes place in late September towards the end of the school year) as compared to their very first written assessment (usually takes place in the beginning of March, nearer the start of the school year).

Epistemic Learning Goal

The students were also better able to appreciate and draw links between the reactions and mechanism which they had learnt in H2 and H3 to real-world context. This was summed up very neatly by one student:

> Honestly, I initially detested this form of unconventional assessment as I felt that this would adversely affect my scores for the lecture test and that it was 'unfair' that I had to interpret and understand papers written by professionals. However, in retrospect now I feel that this form of assessment was indeed enriching and an interesting experience. Firstly, I like how the mechanisms or reactions that are present in the articles are not completely novel and often encountered in H3/H2. I feel that whatever Chemistry we learnt in school should not be absorbed in a vacuum and this viva experience allowed us to apply our knowledge to a fresh context of a research paper, showing us that what we learn is very much applicable to the scientific community out there. Secondly, this viva assessment forces students (in a good way) to read research papers and get a glimpse of how research papers are structured and written. Not all students in H3 are current or past research students and may not have research/research paper writing experience. This exposure is definitely helpful since some of these students in H3 will go on do research in the future and may even write papers for themselves… (Student 4, google survey; July 12, 2014).

A significant number of students mentioned the rich independent learning which they explored on their own, quoting one student, "…was a very good experience reading and finally figuring out the mechanisms, and is more relatable since it is closer to real life research and examples…" (Student 5, google survey; July 23, 2018). Another student said, "…most of what was in the article wasn't in our notes but I could apply skills learnt especially in proposing mechanisms. It also gave real life applications to what we are learning which was quite refreshing. There were also cool reactions introduced in the article which I enjoyed learning about. Research articles present to us elegant synthesis methods which may not be covered in syllabus and allowed me to better appreciate chemistry…" (Student 6, google survey, July 15, 2015).

From the above anecdote, the epistemic goal was achieved as the students would have to take much greater ownership in their own learning, digging out and compartmentalizing information, and seeking out plausible explanations to what seem to be daunting. In the process of this search and discussion with their peers, they would have to decide on what to take (the perceived 'truth') and what to discard. A lot of decision making was required.

Social Learning Goal

The survey results also showed that the students demonstrated a high degree of independence and practiced collaborative learning when discussing the article. Quoting one student, "We looked at each other's proposed mechanisms and pointed out the flaws in our mechanisms. Afterwards, we tried to draw the mechanisms again. We also brainstormed for ways to draw mechanisms that we were unsure of." (Student 7, google survey, July 7, 2018)

The level of collaboration could go beyond two persons as shown by the following student's feedback:

> Discussed with a CCA friend who is in the same group as me, as well as another friend of a friend. Intense discussion of mechanisms with people who received the same article in the preparation time before viva. It was a fun experience because suddenly you are working together with a bunch of people you do not know previously and discover that they are all interesting people and form new friendships. (Student 8, google survey, July 21, 2015)

The above anecdote aptly summed up how viva actually helped to promote social learning as students who received the same reading would naturally congregate and discuss as everyone's contribution would lead to a more complete appreciation of the reading. In fact, we have also observed that for a certain batch of students, the strongest few students volunteered to read other group's articles. This was done not only for the love of the subject but also to lend a helping hand, when deemed fit. Indeed, it was heartening to see the selfless attitude demonstrated by some of them.

Many of the students who took H3 pharmaceutical chemistry went on to pursue higher education in related fields—medicine, pharmacy, chemistry, etc. They feedbacked that the learning they received from the course helped them immensely in higher education. This could be seen from the feedback given by a former student who is currently pursuing medicine in the university,

> The skills that I have developed from Pharmaceutical Chemistry, which has helped me process information better, and be less apprehensive about *being wrong* and having to learn from outside sources. This has also helped in my undergraduate research, where like most of my time in Pharmaceutical Chemistry, I often feel a sense of being utterly confused when confronted with unfamiliar material. Even then, I have learned to get used to the fact that it is not humanly possible to learn everything there is out there, and that what little I can do, I *should* do. And that builds on my foundation, step by step. (Student 9, email feedback, 23 Oct, 2018)

The summative assessment of Pharmaceutical Chemistry will be the year-end 'A' level examination. Although the proxy to the success of a programme should not only be based on the year-end examination we have made an interesting observation that ever since the revised viva voce was implemented, the percentage distinction of the school went above 60% consistently from 2014. Although there were many factors that might have resulted in the improvement in results, we believe that one of the key contributors was the improved viva voce format as it better prepared the students to face novel situation in the 'A' level examination. The 'A' level examinations from 2014 to 2016 tested more higher order thinking skills and required students to tackle more novel scenarios. Despite the greater amount of preparatory work required from viva voce, the students' survey results and feedback reflected greater joy in learning and most students agreed that the curriculum in HCI focuses more on the pursuit of passion rather than grades.

Limitations

Despite this, we recognized a number of challenges and difficulties in implementing viva voce. One significant challenge lies in the consistency and fairness in assessing the students. This could be circumvented by standardization amongst the assessors (or two assessors testing the same journal article) before, during and after the assessment. Appropriate level of support was also provided to the assessor by allowing them to sit through one viva session as well as giving them a detailed briefing before the actual execution. In terms of logistics, we also needed the assistance of part-time teaching assistants to help us monitor the holding area and preparatory room. Some students also raised issues about feelings of anxiety in the feedback, but many were positive about it and felt that it was a necessity before they moved on to their next stage of learning.

Conclusions and Implications for Practice

Viva voce is a great formative assessment tool and many incidences of rich learning took place through conversations with the assessors. As per all tools, there are limitations but as long as we work around it, the immense benefits gained by the students outweigh them. We will constantly fine-tune the processes and work on more chemistry topics which could potentially include viva voce. Thus far, through our sharing and workshops conducted for the past four years, teacher participants highlighted that they had implemented it in their respective institutions in small scales, including but not restricted to the following areas.

- Teaching of practical skills—probing students further on their understanding of the sequence of procedures, apparatus, use of chemicals and safety.
- Teaching of planning—students to verbalize their thought processes in coming out with the planning of a simple experiment and the assessor will probe deeper.
- For use in school projects presentations—similar to oral defence but in a smaller scale and perhaps less threatening environment.

Viva voce represents one type of tasks which could be crafted using the literature. There are many types of tasks which can assist and value-add to students learning using the literature. We will be writing more about them in due course.

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Gah Hung Lee graduated from the National University of Singapore with a Bachelor of Engineering (Honours) in Engineering Science in 2011. Following that, he spent two years pursuing a Master of Science, working on synthesis of nanomaterials and its application in clean energy. He joined Hwa Chong Institution in 2013 as a lecturer where he is involved in teaching chemistry to students in a variety of programs such as H2 Chemistry and H3 Pharmaceutical Chemistry. He is also the pioneer in developing the teaching materials for the Gifted and Talented Education Programme (Chemistry), where students in this programme were engaged in seminar style learning which Gah Hung taught since its inaugural beginning in 2013.

Chapter 19
Learning Trajectory of a Science Undergraduate Working as an Intern in a Research Laboratory: A Science Practice Lens

Cassander Tan and Aik-Ling Tan

Abstract Internship attachments to research laboratories as part of undergraduate science courses offer opportunities for students to be engaged with authentic scientific research. The term "authentic research" refers to the opportunities to work under the supervision of practicing scientists. Such experiences differ vastly from typical laboratory sessions, where undergraduates complete a predetermined set of activities within a duration of between three and six hours every week during the semester. In comparison, students who participate in authentic scientific research work with faculty and research staff engage with the activity over an extended period of time, ranging from months to years. The authentic research experiences aim to expose students to the field of science practice and to gain insights about the nature of science. However, these internships programmes are both labour and resource intensive. Using an in-depth case study, consisting of observations and interviews, of a third-year undergraduate (Tom) majoring in the life sciences, this study re-examines this time-proven mode of learning from the theoretical lens of science epistemic practices. Analysis of Tom's experiences revealed that while Tom was cognizant about the demands of science practices such as the need for rigorous data collection and analysis in the scientific process, he was unprepared for the highly repetitive nature of the experiments he conducted. Additionally, the unpredictable nature of the experimental results as well as the need for attention when experiments were in-progress meant that Tom was unable to make concrete plans outside his laboratory engagements and this resulted in low-grade anxiety.

Introduction

Undergraduate research participation in ongoing science research projects over an extended period in university science research laboratories, also known as laboratory internship attachment, is popular in many science undergraduate programmes

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(Gardner, Forrester, Jeffery, Ferzli, & Shea, 2015; Sadler & McKinney, 2010). Literature reported that undergraduate research experience presents a multitude of benefits that include honing cognitive and practical skills, creating familiarity with scientific theories and standard laboratory procedures, building scientific academic discourse capabilities and exposing participants to genuine scientific research (Lopatto, 2004; Harsh, Maltese & Tai, 2011). In fact, the laboratory internship attachment is recognized as a powerful instructional approach to engage students in authentic science (Barab & Hay, 2001; Charney et al., 2007).

Exposure to authentic science experience refers to the engagement where a student works in a science research laboratory, under the supervision of a practicing research scientist and other members of the laboratory, "doing research that scientists actually carry out" (Chinn & Malhotra, 2002, p. 177). Hence, during laboratory internship attachments, the intern is put in the shoes of the scientist, allowing him to gain insights into how science is conducted on a daily basis. This experience facilitates the development of the intern's perception of what scientists do, which is also known as the scientific practice. The authenticity of learning to be a scientist by being part of the research laboratory includes learning about the conceptual knowledge of science, engaging in the epistemic practices (proposing, communicating, evaluating and legitimizing knowledge) and engaging in the social processes of science knowledge making (Kelly & Licona, 2018).

Stroupe (2015) describes science practice as three overlapping phases, "developing vision of the identity of a scientist and what scientist do", "participating in the daily work of the scientist" and "rehearsing daily routines and receiving feedback" (p. 1035) which consists of four dimensions namely conceptual, social, epistemic and material. Putting the four labels in the context of the laboratory internship attachment, the conceptual dimension encapsulates how the intern uses existing research and theories to explain his findings; the social dimension refers to how he communicates and interacts with the supervising scientist, mentor and other members of the laboratory during discussions; the epistemic dimension relates to the knowledge the intern possesses and lastly, the material dimension involves the use of laboratory equipment and the refinement of protocols and procedures.

Although there has been an extensive research conducted on authentic science research experiences for undergraduates, most focus on the positive impact the research experiences have on the undergraduates (Sadler, Burgin, McKinney, & Ponjuan, 2010). Little is known about the actual learning experiences and processes of the interns. Given that the laboratory internship attachment not only requires a hefty investment of labour and resources, but also a large amount of time by the intern, it is essential to ascertain that the intern has undergone a meaningful learning process through the attachment. Thus, this chapter aims to describe the learning trajectory of a science undergraduate working as an intern in a science research laboratory by illumining his learning experiences and his perception of the scientific practice. In this chapter, after describing the intern's learning experience during the laboratory internship attachment, we would focus on how the intern perceives scientific practices. It is expected that these findings may contribute to the further enhancement of similar laboratory internship attachment programmes.

Methodology

Research Design. To obtain more detailed information about the learning activities that took place in the laboratory, a qualitative and descriptive single-case study design was chosen (Baxter & Jack, 2008). Therefore, in this study, we shadowed one science undergraduate who was participating in the laboratory internship attachment. The focus was on the activities the intern was engaged in and the learning experience he gained from the laboratory internship attachment.

Participant. One participant, with the pseudonym, Tom, was recruited. The aims and the use of the data collected from this research were made known to Tom. Tom understood the purpose of the laboratory observation was primarily to document his learning experiences. Consent was given by Tom at the start of this study. At the time of this study, Tom was a year-three student, majoring in life sciences at one of the large public universities in Singapore. He was a participant of the undergraduate science research programme. This programme involved a component of laboratory internship attachment where participants worked with a faculty member, with the aim to allow participants to experience the challenges faced while pursuing an independent scientific research project. Under this programme, Tom worked with a supervising professor from the university's biochemistry department, a laboratory executive (mentor) and four other members of the research laboratory, including a postdoctoral research fellow, a research assistant and two other undergraduates who are also working on their independent research projects. The research project he worked on sought to characterize previously generated mutant *Candida glabrata* strains based on their antifungal susceptibility and biofilm formation properties. He then compared those properties with the wild-type phenotypes to examine and suggest possible reasons behind antifungal drug susceptibility of *Candida glabrata*.

Data Collection. Sources of data included field notes taken during direct observations of Tom in the laboratory during his internship attachment and interview notes taken during the face-to-face interviews. To understand Tom's perception towards the science practice and his laboratory internship attachment experience, phenomenological interviews were used. The interviews focused on the experience Tom gained and how he made meaning of it. According to Cohen, Manion and Morrison (2013, p. 18), phenomenology refers to "the study of direct experience taken at face value and one which sees behaviour as determined by the phenomena of experience rather than by external, objective, and physically described reality". The structure of the phenomenological interviews comprised open-ended question, allowing Tom to reconstruct his lab experience to better elicit the learning experience that occurred during the internship (Feldman, Divoll, & Rogan-Klyve, 2009). In total, two interviews were conducted—a pre-internship interview was conducted at the beginning of the laboratory internship attachment while a post-internship internship was done at the end after Tom completed his oral presentation and submitted the required deliverables that included a final research paper.

In addition, direct observations (where detailed field notes were taken down) of Tom working in the laboratory during the internship attachment for a period of eight months were carried out. His actions, emotions and conversations with members of the research laboratory (if any) were noted in the field notes. At times, after the observations, based on the field notes taken, questions were asked to follow up and check if Tom truly understood what he was doing in the laboratory.

Data Analysis. The interview notes and field notes were reviewed and coded. Following the chronological order of the data collected, the interview notes collected during the pre-internship interview were first reviewed and analysed by highlighting the main themes. Eventually, the interview notes collected during the pre-internship interview were compared with the interview notes taken during the post-internship interview to see if there were any changes in how Tom perceived science practice. In addition, the notes for both interviews were coded based on the categories derived from similar research studies (for example Cartrette & Melroe-Lehrman, 2012; Hunter, Laursen, & Seymour, 2007) done on undergraduate research experiences.

Similarly, for the field notes collected from direct observations of Tom working in the laboratory, the qualitative data obtained were first coded based on categories derived from previous literature. In addition, the methods from the grounded theory were adapted to develop new codes from the field notes (Saldaña, 2013). The adapted approach of coding began with concurrent initial and process coding in which laboratory activities carried out by Tom were coded for. This was followed with axial coding which is a process of categorizing and relating the earlier codes.

Results and Discussions

The results and discussions are organized into two main sections, addressing the intent of this paper which is to first understand the learning trajectory of the intern, Tom, and map any changes in his perception towards the practice of science after going through the laboratory internship attachment. In general, our findings showed that immersion in authentic science laboratory experience enabled Tom, the intern, to develop a more *realistic* and *accurate* understanding of scientific practices.

The learning trajectory. Drawing data from the field notes taken during the direct observations, Tom was engaged in a range of activities. These activities included observation of demonstration conducted by the research mentor who is also known as the laboratory executive, following instructional procedures given by the laboratory executive, taking down notes, asking questions, clarifying doubts, interacting with other members of the laboratory, washing and cleaning of apparatus and laboratory facilities and doing independent laboratory work. The scope of the laboratory work Tom was observed doing included preparation of culture media, micro-dilution protocol, spotting assay and colony forming unit assay. Other laboratory work that was not noted down during the direct observation but reflected in Tom's final research paper and presentation included a tetrazolium salt[1] (XTT) reduction assay. These protocols and methods of assay involved both basic laboratory techniques such as serial dilution and counting of colony forming unit and the use of typical laboratory equipment such as the incubator, the vortex machine, the centrifugation machine, the microscope and the Bio-Rad imaging machine.

The analysis and coding of the qualitative data obtained from the field notes suggested that Tom went through a progressive learning curve towards independence. Initially, during the first observation session, the laboratory session predominately comprised the following activities, "Observing demonstration conducted by the laboratory executive", "Taking notes in his mini notebook", "Following instructions given by the laboratory executive", "Asking the laboratory executive. questions" and occasional incidence of "Tom working independently". Most of the learning activities observed in the first observation involved much interaction with the laboratory executive, with more than 75% of the two-hour observation involving interaction between the laboratory executive and Tom. Here, the interaction between Tom and laboratory executive comprised their conversations, the laboratory executive's demonstration and instructions. In fact, the first observation recorded the highest frequency of interaction between the laboratory executive and Tom. Subsequent observations saw a marked decrease in the interaction between Tom and laboratory executive with no incidence of interaction between Tom and laboratory executive in the laboratory recorded from the second observation onwards. Instead, from the second observation onwards, Tom was predominately engaged in independent laboratory work, with occasional interaction with laboratory executive and other members of the laboratory. This suggested that the initial phase of the laboratory internship attachment was characterized by scaffolding and modelling in the form of instruction, guidance and demonstration provided by the laboratory executive. This phase of scaffolding and modelling was followed by independent laboratory work.

Another prominent observation made was that while Tom worked independently, he was frequently seen referring to his mini notebook. During the second observation, Tom referred to his notebook every 13 minutes. In comparison, there was no incidence of Tom referring to his mini notebook from the third observation onwards. This showed the unfamiliarity and uncertainty that Tom had with the protocols during the second observation. The frequent references to his notes were needful for Tom to acquire the necessary ease and experience of working with the new protocols. During the second observation, the mini notebook appeared to have taken the place and role of the mentor (laboratory executive). Eventually, as Tom repeatedly carried out the steps in the protocols, he became familiar with them. As such, he stopped referring to the notebook. The progression from actively listening and noting instructions given by the laboratory executive to referencing the notebook, to being familiar with the protocols are evidence of progress made by Tom. Tom was slowly working towards creating a sense of familiarity with the laboratory procedures.

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[1] This is a colorimetric assay for assessing cell metabolic activity. Tetrazoilum dye assays are typically used to measure cytotoxicity, that is loss of viable cells.

As Tom increasingly familiarized himself with the laboratory protocols, it was observed that he carried out the experimental procedures on automatic pilot mode. This meant that he was conducting the experiments more efficiently without much hesitation. Initially, Tom tended to pause very frequently. This is evident from the second observation as he paused once every 26 minutes while working independently. These pauses suggested that Tom was thinking about the next step of the procedures. Comparatively, Tom paused once every 30 minutes and once every 45 minutes during the third observation and fourth observations, respectively. This demonstrated how Tom was so familiar with the procedures of the experiments to the extent that he did not have to pause to think about the next step and could conduct the experiments with great fluency.

Apart from pausing to think about the next steps, the pauses could also be indicative of Tom thinking about the significance behind those protocols, attempting to understand the purpose of the steps in the protocols provided by the laboratory executive. This was supported by the post-interview where Tom mentioned that as the research progressed, he began to modify and adapt the fixed set of protocols provided by the laboratory executive, and as such engaging more in the material aspect of science practice:

> At the start, I would follow the set of protocols given by the L.E. closely. After a while, I began to understand the rationale and purpose of the various steps. This enabled me to refine the steps to save time and resources so that I can conduct the experiments more efficiently. (Tom, interview, December 4, 2017)

Tom progressed from merely following steps (cookbook style) to understanding them and trying to make meaning of each step. Previously, Tom achieved proficiency in technical skills as he could conduct his experiments. Gradually, as he immersed himself in the experiments, he entered the phase where he began to question, made links and gained both instrumental and relational understanding in what he was doing. This holistic understanding of what he was doing in the laboratory further enabled Tom to better appreciate the laboratory work he was immersed in, allowing him to progress to the next phase.

Moving forwards, Tom entered the next stage where he started to discuss the experiments with his supervising professor and the laboratory executive. Although discussions of the experiment results and procedures were not recorded during the field observations in the laboratory, Tom mentioned in the post-interview that discussions with his supervising professor and L.E. were carried out every month:

> Prof would hold a discussion every month to look at the results, track my progress and see how we could continue. (Tom, interview, December 4, 2017)

During the discussions, he evaluated and critiqued his experimental data, highlighted possible experimental flaws, proposed viable explanation to his data as seen from the post-interview:

> During the discussion, I would try to provide some possible reasons for the results obtained by speculating.” – (Tom, interview, December 4, 2017)

Here, Tom was exposed to the social dimension of the scientific practice where he was actively engaged in the negotiation, debate and argument of scientific theories and knowledge. From there, he learnt how scientists reason and the process involved in the creation of scientific knowledge. This is supported by Ford (2015), who maintained that critique plays an integral role in the creation of scientific knowledge and this process of interpersonal construction and critique helps to shape one's intrapersonal reasoning process. Similarly, while Tom attempted to provide plausible reasoning based on speculation, he added that those explanations contained flaws. Therefore, his supervising professor would provide him with prompts and guiding questions, scaffolding and modelling the reasoning process.

Following the discussion phase, Tom made further progress as he entered the phase where he consolidated his work and presented them to the supervising professor and other laboratory members. The informal presentation included the sharing of results he achieved, the progress of his research and relevant background information about the experiments. At the end of his presentation, the supervising professor conducted a brief question and answer session. Again, Tom was engaged in the social dimension of the scientific practice.

Finally, with the completion of the experiments and the pointers Tom received from the discussion and informal presentation, Tom started writing the final report and preparing the final presentation where he consolidated the methodology he used and data he collected and analysed, translating them into words and a brief verbal presentation to share his newly discovered knowledge.

Perceptions towards scientific practice

Tom's initial impression of scientific practice was compared with his perception towards the practice of science after going through the laboratory internship attachment. The comparison showed that Tom had a better appreciation of the scientific practice.

Authentic science experiments consist of multiple repetitive processes

Specifically, Tom had a first-hand experience of the repetitive laboratory work. Even though Tom had already expected laboratory work to be repetitive as seen from the pre-internship interview: "I think a typical day in the laboratory would involve a lot of repetitive processes." (Tom, 30/09/2016), it still took Tom quite some time to get accustomed to having to keep repeating and re-doing similar steps as mentioned in the post-internship interview: "The repetitive nature of laboratory work was so physically and mentally draining that I had eventually become numb to it." (Tom, 12/04/2017).

In addition, during the direct observation, there was a high prevalence of sighs heard. This suggested that Tom may be feeling a tinge of exasperation, exhaustion or frustration as he let out those sighs while conducting the experiments. In fact, as seen from the post-internship interview: "At times, I would feel that the whole weeks' worth of work has gone down the drain as I have to redo them all over again." (Tom, interview, December 4, 2017).

During the laboratory internship attachment, Tom had encountered many challenges such as failed experiments, anomalies in results and refined protocols that did not work well for the experiments. As a result, Tom had to repeat the whole set of experiments. This tedious process led Tom to lament the following during the post-internship interview: "Terrible, the whole process is terrible!" (Tom, Interview, December 4, 2017).

On a hindsight, through this process, Tom found himself acquiring greater perseverance and tolerance. With tenacity and patience, he managed to deal with failure, figured out the reasons behind those failures, moved on and overcame those obstacles. This made him realize that working in the laboratory requires perseverance, patience and tolerance that he initially did not perceive to be important qualities that scientists should possess. This finding was supported by Hunter, Laursen and Seymour (2007) who similarly reported that a successful scientist requires attributes such as perseverance, regardless of whether those traits are natural or acquired. Hunter, Laursen and Seymour (2007) further described the understanding of the repetitive process in science research where one "must be able to take frustration in stride" as "a gain hard won from experience" (p. 51). This truly entails the rigour in authentic science.

This laboratory internship has allowed Tom to better appreciate the rigour of science. The repetitive characteristic of authentic science is typically absent in mainstream school science and most undergraduate science modules. Students doing science in mainstream schools or at the undergraduate level did not have the opportunity to experience this aspect of science. The experiments conducted by students during science lessons in the mainstream schools often allow students to obtain results and conclusion within an hour of curriculum time. In addition, in schools, teachers tend to reveal the answers or conclusions to the students at the end of the lesson. This might have eventually led to students having an impression that in science, one would be able to obtain a conclusion after sitting through an hour of lesson since they had never seen or experienced the arduous processes involved in doing authentic science. As a result, the repetitive nature of science, and ultimately the tedious process of doing science might have long been forgotten by students.

Unpredictability is an Integral Part of Authentic Science

Another prominent aspect of scientific practices that Tom experienced was the unpredictable nature of authentic science, which was illuminated in the post-internship interview: "Laboratory work is unpredictable. I could only plan for the next session based on what I have completed on that day itself." (Tom, interview, December 4, 2017).

Tom could only plan his experiment a day in advance as he would not know the direction of the research until he found out the outcome of his current set of experiments. The linear sequential nature of the experiments that Tom was involved with is described as a progression of work meaning "the results from one experiment will determine the overall direction, depending upon whether the predicted outcome was observed" (Cartrette & Melroe-Lehrman, 2012, p. 1094). Here, the unpredictability of science contributed to the uncertainty of the research progress.

This characteristic of authentic science differed vastly from mainstream school science. During science practical lessons in the mainstream schools and other undergraduate science modules, students are required to only conduct one experiment within a stipulated, specified duration. Moreover, the experiments conducted were usually seen as isolated entities, in other words, the results of one experiment had no relation or impact on the other experiments. In fact, the results of those experiments conducted during science practical lessons were well known. This meant that the students were aware of the expected outcomes. In the event when the outcomes went awry, the teacher, teaching assistant or the professor would be the problem solver who would troubleshoot, propose possible experimental errors and rectify them (Cartrette & Melroe-Lehrman, 2012). This painted the impression of science being a body of hardened, pre-established, known and absolute facts (Barab & Hay, 2001). Such a distorted view of science is further exacerbated by the way science is taught in mainstream schools where students believed that they would be able to obtain the so-called model answers within a short period of time.

Unlike mainstream school science, the laboratory internship attachment that Tom was engaged in was filled with many unknowns. Even though some outcomes could be predicted, very often Tom would have to deal with unexpected results as exemplified in the post-internship interview: "Sometimes, the results obtained were not what I expected." (Tom, interview, December 4, 2017). When Tom met with those unexpected results, in other words, results that were inconsistent with his predictions, he troubleshot, conducted multiple trials and errors, looked for possible sources of errors or readings that could possibly support and explain the unexpected results. Through this process, he uncovered the reasons behind the unexpected outcomes and then repeated the experiments to verify the conclusions he drawn from the unexpected results.

Tom also saw these unexpected outcomes and the various unknowns encountered in the internship as novel discoveries, which were of essence to the scientific community, leading him to respond with the following: "After all, it is novelty that drives research." (Tom, interview, December 4, 2017). The uncertainty in authentic science is a quest to search for answers despite not knowing what was awaiting the researcher. This clearly demonstrated how Tom came to appreciate one of the practices of science, the unpredictability which played an integral role in authentic science research.

Conclusions and Implications for Practice

Our results have demonstrated that the learning trajectory of the intern, Tom, started off with scaffolding and modelling by the research mentor that allowed Tom to work independently. This related largely to the epistemic and material aspects of science practices as described by Stroupe (2015). While working independently, he gradually created a sense of familiarity with the laboratory protocols to the extent that he could conduct the experiments fluently. During this process, he began to understand the rationale and purpose of the protocols as he attempted to refine and discuss them in relation to the results he obtained with his supervising professor and research mentor. The shift from engagement with the material and epistemic aspects of science to more social and conceptual aspects, as manifested by his discussion of the results with the supervising professions and research mentor reflects Tom's growth in understanding the work of scientists more holistically. While going through this learning trajectory as an intern, Tom came to better appreciate the practices of science, particularly, the repetitive and unpredictable nature of authentic science experiments, which were currently still absent in mainstream school science and other undergraduate science modules. The repetitive and unpredictable nature of science as experienced by Tom is not trivial but is part of the "rehearsing daily routines and receiving feedback" (Stroupe, p. 1035) practice. Future studies which can take this aspect into consideration and explore ways to incorporate the essence of authentic science experiments that was found in an internship laboratory attachment into school science can be conducted. Despite that, this research has monitored and tracked the learning trajectory of a science undergraduate participating in a laboratory internship attachment in relation to not only the learning activities, skills and knowledge gained but also with respect to the intern's perceptions towards the scientific practice.

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Chapter 20
The Role of Empowerment Evaluation in the Professional Development of Science Teachers in the Enactment of an Inquiry-Based Pedagogy

Umesh Ramnarain

Abstract This chapter explores the role of empowerment evaluation in supporting practicing high school science teachers shift their practice towards an inquiry-based pedagogy. Science teachers have struggled to implement inquiry-based learning that forms the cornerstone of national curriculum reforms in South Africa. In-service professional development efforts by the ministry of education have failed due to them being out of tune with intrinsic factors (teacher capacity, teacher beliefs) and extrinsic factors (resources, class size, assessment requirements) that impact upon the context in which teaching and learning take place. Empowerment evaluation is an approach whereby individuals can achieve self-determination in their practice and this chapter discusses its potential by drawing upon studies conducted by the author in the South African school science landscape.

Introduction

Over an extended period of time, a common curriculum goal in school science education worldwide has been to encourage teachers to use scientific inquiry in their instruction as a means to advance learners' understanding of scientific concepts, the processes of scientific investigation and the nature of science (National Research Council, 2012; Rocard, et al., 2007). This is certainly the case in South Africa where the national Curriculum and Assessment Policy Statement (Department of Basic Education, 2011) promulgates a learner-centred, inquiry-based science curriculum, that is expected to transform classroom practices of teachers and the students' learning environment. Scientific inquiry refers to the various ways of studying the natural world, asking questions, proposing ideas, collecting evidence to justify assertions and explanations and communicating results (Hofstein & Lunetta, 2004). Underlying this pedagogy is the assumption that science education is not merely about knowledge-acquisition, but understanding how scientific knowledge is generated,

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evaluating knowledge claims and conducting scientific investigation. In this manner, science education is more than inculcating ‘what we know’ but it should also give learners a sense of ‘how we know’ and ‘why we believe what we know over alternatives’ (Duschl & Duncan, 2009).

According to Crawford (2014), an inquiry-based pedagogy is ‘a complex and sophisticated way of teaching that demands significant professional development’ (p. 292). Huge investments have been made in professional development programs to support teachers in inquiry-based teaching, although there is still a paucity of evidence to support its effectiveness (Crawford, 2014; Ramnarain, 2016). In South Africa, teachers have bemoaned the lack of substantive support from the Department of Education on inquiry-based teaching (Ramnarain, 2016). Inquiry-oriented teaching places high demands upon teachers’ conceptual literacy because it plays a pivotal role in facilitating student learning during inquiry-oriented teaching. According to Bybee (1997), conceptual literacy entails understanding the structure of the discipline and the procedures for developing new knowledge and techniques. Individuals who are conceptually literate understand that scientific inquiry includes asking questions, designing scientific investigations, using appropriate tools and techniques, developing explanations and models using evidence and explanation, recognizing alternative explanations and communicating scientific procedures and explanations. Pedagogically, ‘the art of skilful questioning appears to be crucial to achieving the balance between giving students suitable guidance and leaving sufficient scope for then to think independently’ Mines (1995, p. 14). This can only be achieved if teachers’ conceptual literacy is sound.

However, in South Africa, despite the need to support teachers in addressing significant school science curriculum reform (Department of Basic Education, 2011), in-service teacher training on the revised science curriculum consisted mostly of one-shot workshops in which the new policies and terminology were explained, with very little offered in terms of how to address teacher conceptual literary to enable them to facilitate scientific inquiry. Such professional development efforts have been heavily criticized and are regarded as being brief, fragmented, incoherent encounters that are de-contextualized and isolated from real classroom situations (Feiman-Nemser, 2003; Villegas-Reimers, 2003).

Empowerment Evaluation

This chapter engages the reader on the role of an empowerment evaluation approach as an alternative form of professional development in supporting practicing high school science teachers to broaden their perspectives on scientific literacy, and shift their practices towards an inquiry-based pedagogy. Empowerment evaluation is a term first coined by David Fetterman during his presidential address for the American Evaluation Association in 1993. Since that time, this approach has altered the landscape of evaluation and has spread to a wide range of settings in many countries. It is an approach whereby individuals can achieve self-determination in their practice.

Empowerment evaluation is the use of evaluation concepts, techniques, and findings to foster improvement and self-determination (Fetterman, 2001, p. 3). It focuses on helping people help themselves and improve through self-evaluation and reflection in a non-threatening environment that is conducive for reflection and experimentation. Empowerment evaluators serve as coaches or facilitators in providing guidance and direction as needed. Critical friendship characterizes the mentoring relationship between the teacher (evaluee) and the coach (evaluator). Fetterman (1999) describes it as a 'stepped approach' (p. 16). Empowerment evaluation commences with 'taking stock' with an assessment of current practice. This is followed by 'setting goals' where the evaluee agrees upon goals to achieve. In 'developing strategies', the evaluee and evaluator agree on how credible data will be provided. Thereafter, they document progress', evaluate and improve. Accordingly, empowerment evaluation is 'the use of evaluation concepts, techniques, and findings to foster improvement and self-determination' (p. 3), and, its primary purpose in this regard is to 'help people help themselves' (Fetterman, 1996, p. 5). Important facets of this evaluation thus include facilitation, advocacy, illumination, and liberation (Fetterman, 1996). Advocacy entails helping evaluees use credible data to present their case in an evaluation of their curricula. Illumination is an eye-opening and enlightening experience that brings about new insights or understanding about an issue or practice. Liberation follows illumination, and is the act of freeing oneself from pre-existing roles and constraints, contributing to self-determination.

The chapter reports on studies done in South Africa that attest to the value of empowerment evaluation as a viable and sustained form of science teacher professional development in inquiry-based pedagogy. I present two cases this approach has been empirically investigated.

CASE 1: Supporting a Life Sciences Teacher in Understanding the Importance of the Curriculum Design Principles Related to His Lessons

The reform in the Life Sciences curriculum towards an inquiry-based curriculum meant a reconceptualization of scientific literacy from a curriculum dominated by content specification to one where the goals of scientific literacy are more broadly defined. Post-apartheid, science curricula documents define scientific literacy broadly in terms of process skills, conceptual knowledge and relationships between science, society and the environment. However, research that has been conducted in South Africa has shown that science teachers due to deficiencies in their competences (Ramnarain & Ramaila, 2012) are unable to reflect this broad and multi-faceted perspective on scientific literacy in their teaching.

In a study conducted by the author and a fellow researcher (Ramnarain & Modiba, 2013), an empowerment evaluation approach was used to enable a Life Sciences teacher to reflect upon and refine his curriculum design principles in promoting the scientific literacy of learners through inquiry-based learning. Our research was guided by the following question: How can empowerment evaluation influence a teacher's beliefs and pedagogy of science teaching within the context of inquiry-based curriculum reform?

A case study design was used (Merriam, 1998) together with qualitative ethnographic methods (Miles & Huberman, 1994) in this investigation. We conducted 16 classroom observations of grade 10 Life Sciences lessons over a period of eight months. Observations took place fortnightly, and each lesson was followed by stimulated recall discussions where both researchers acted as critical friends to the teacher within the framework of empowerment evaluation.

The stimulated recall discussions prompted the teacher to reflect upon the lesson taught, and provided the researchers with the opportunity of seeing the classroom practices through the teachers' eyes. The discussions centred on the following aspects: the objectives of the lesson, adequacy of background information, assumptions on which the lessons were based, investigative questions, plan/design of the lessons, activities during the lessons, what was used to evaluate the lessons and how this was done and why, how misconceptions were identified during the lessons and what was done to correct them and why. These discussions were underlined by the key facets of empowerment evaluation already described. By probing the teacher on his planning of the lesson and his action taken during the lesson, we sensitized him to the curriculum design principles that were enacted. Through this approach, the teacher was now able to recognize these principles as tools that could be drawn upon in his self-assessment. The facet of 'facilitation' was promoted by us through the guidance in the form of prompting questions posed to the teacher to enable him to reflect on his practice in relation to the advancement of the intended scientific literacy of his students. With regard to 'advocacy', we presented to the teacher the data that we had collected and then through stimulated recall, the teacher was able to unpack how curriculum design principles were being translated into practice. In trying to identify instances of 'illumination', we looked collaboratively for new insights in planning and shifts in the practice of the teacher towards an approach that better promoted the scientific literacy of learners. For example, in his planning of a lesson on breathing and lung capacity, we questioned the teacher on his objectives for the lesson, and how these objectives supported curriculum design principles such as the nature and structure of the subject, the relationship between science, society and technology and needs of the learner. Further to this, he was asked to consider how these educational purposes were going to be addressed through the educational experiences that were being planned. When asked to reflect upon the curriculum design principles he drew upon when planning the lesson, the teacher stated that his intention was to support the organization and sequencing of learner ideas to enable a deeper understanding. Key to this approach was the notion of learners assuming ownership over their learning. He explained that 'I believe learners need to be supported in being in charge of the manner in which they learn. I cannot impose concepts in them. They must experience and co-construct ideas'. In the stimulated recall discussion, we probed the teacher on how these design principles were unfolding in his practice. He referred to the manner in which the class discussions unfolded. He believed in opening up the learning space to the entire class so that learners' ideas could be explored. This is reflected in the excerpt: 'I encourage learners to express their ideas and then for others in class to evaluate it for whether it is scientifically correct or not'. We then played excerpts of the video-recorded lesson to him that conflicted with his interpretation of the lesson. The teacher acknowledged that the classroom interactions were mainly between the teacher and learner, and seldom between learners. So, in practice, the lesson was predominantly teacher-centred. In the next lesson, we observed that the teacher made a concerted effort to implement in the lesson his belief that learners should assume more autonomy in the formation of science concepts. It became evident from our interactions with the teacher that the key facets of empowerment evaluation were being realized.

Over the series of lessons, we observed that the experience of learners at doing practical work became more enriching and representative of the nature of science. They were given more opportunities in designing their own investigations by formulating their own investigative questions, choosing their own materials and deciding on a procedure to be followed. The lessons showed evidence of an inquiry-based pedagogy such as learner autonomy, argumentation and the facilitative role played by the teacher. These characteristics showed up in a lesson on fungi where the teacher posed the question 'Does bread produce the grey-black structures that we see when it gets stale?' In this lesson, the learners worked in groups to plan an investigation. The role of the teacher was mainly facilitative, as he supported the learners through the use of prompting questions. The teacher checked the plans, and once he approved them, the learners conducted the investigation in the following lesson. In this regard, there was a definite shift in the role of the teacher from one who was a 'sage on a stage' (Billings, 2001, p. 2) to one who assumed a more supportive role in scaffolding learners' progress during the investigation. In terms of the facets of empowerment evaluation, this shift in practice towards a more learner-centred pedagogy in the development of procedural scientific literacy may be considered as an example of 'liberation' that the teacher underwent. The teacher became increasingly confident in his own capacity, gradually entrusting more autonomy to learners so that they could explore their own ideas. For example, he invoked their existing knowledge and experiences by inviting them to make predictions on scientific investigations in a pre-lab discussion. The teacher indicated to us that he would plan future lessons whereby learners would be given the opportunity to design investigations based on questions formulated by themselves a particular topic, thus enabling them to engage themselves deeper in scientific thinking. As remarked by the teacher, he was able to achieve this transformation in his practice because of the opportunity we created for him to reflect on the curriculum design principles that were applied in the lesson and then in light of this, think forward on how the design principles may be revised so that learners may achieve scientific literacy.

CASE 2: Shifting a Grade 9 Natural Sciences Teacher Towards an Inquiry-Based Pedagogy

This research was undertaken by the author and a fellow researcher (Ramnarain & Makhubalo, 2018) also followed a case study design, and examined a grade 9 Natural Sciences teacher's lessons focusing specifically on how the curriculum imperatives and principles for practical work are being translated in practice. Drawing on data obtained by using ethnographic tools, I describe and discuss an empowerment evaluation approach that enabled this teacher (i) to reflect upon his understanding of the curriculum design principles for practical work he draws on when planning and teaching science lessons and (ii) to refine and improve how he translates these design principles in advancing an inquiry-based pedagogy.

The research was guided by the following research question: How can an empowerment evaluation approach influence and shift the practice of a Natural Sciences teacher towards an inquiry-based pedagogy? The goal was to empower the teacher in the introduction of an inquiry-based pedagogy informed by the 4Ex2 instruction model, which combines key components of inquiry instruction (Engage, Explore, Explain, Extend) with formative assessment and reflective practice integrated into each of the inquiry components. Data were collected through classroom observations and stimulated recall informal discussions.

The researchers applied the Electronic Quality of Inquiry Protocol (EQUIP) as a classroom observation tool when conducting six classroom observations. Using EQUIP, the teacher was assessed on 19 indicators associated with inquiry spreading over four constructs: Instruction (5 items); Curriculum (4 items); Discourse (5 items) and Assessment (5 items). After scoring the teacher on each indicator, a composite score was generated and this could range from 1–4 (Level 1 = pre-inquiry, Level 2 = developing inquiry, Level 3 = proficient inquiry and Level 4 = exemplary inquiry). All lessons were video-recorded and later scored independently by the researchers.

We commenced with 'taking stock' by engaging with the teacher on a discussion on his current practice, and how this practice was not in sync with the learning outcomes he envisaged for his learners. Lesson 1 was on minerals and mining, which falls under the theme Planet Earth and Beyond in grade 9 Natural Sciences. This lesson was scored low on all four categories of EQUIP, namely instructional factors, discourse factors, assessment factors and curriculum factors. The lesson was heavily dominated by teacher talk that was directed at the dissemination of information, with little interaction with learners. The questions were mainly close-ended and discouraged students from articulating their ideas. The communication was controlled and directed by the teacher and followed a didactic pattern. For example, the teacher spent much time describing the types of minerals that were mined in South Africa and the use of these. It was also evident that the learners were given notes on this topic prior to the lesson. When questioned on this, the teachers stated that this was to ensure that learners did not miss anything of importance. The lesson was classified as pre-inquiry, and this placed the teacher as a novice in inquiry teaching and learning.

Thereafter, we agreed on the 'goals' to be achieved and 'developed strategies' in achieving this. We 'documented progress' through lesson observations and interviews.

In the stimulated recall discussion that followed the first lesson, the teacher recognized the need to shift his practice towards an inquiry-based pedagogy. A goal was collaboratively set with the teacher for him to transition to the next level of inquiry, according to EQUIP, namely 'Developing inquiry'.

In the next stage of empowerment evaluation, for 'developing strategies', we discussed the instruments used to 'document progress'. The scoring in the EQUIP observation protocol was explained, and correspondingly the levels of inquiry from pre-inquiry to developing inquiry to proficient inquiry to exemplary inquiry were discussed. The role of the stimulated recall interview was also communicated.

In lesson 2, the teacher introduced indicators by demonstrating the use of litmus paper and bromothymol blue in testing for acids and bases. The learners were asked to take note of the colour of the indicators in the acids and bases. The colours on these indicators in basic and acidic solutions were demonstrated. Using EQUIP, the lesson was scored as 'developing inquiry.' A stimulated recall discussion after this lesson enabled the teacher to reflect on what learning goals had been achieved, and how the acquired knowledge could be applied. The teacher recognized the need for learners to do become more actively engaged, and planned for the next lesson an investigation based on the use of indicators

In lesson 3, learners were given a sample of substances, and asked to classify them into acids and bases using the indicators. The teacher had changed the classroom arrangement and organized learners randomly in groups of six learners The learners were prompted to write a practical report on their investigation. The report was structured as follows: hypothesis; identifying variables, results, interpretation of results and the conclusion. The role of the teacher shifted from one who demonstrated to evidence of some facilitation. In this lesson, the learners were cast from a passive to a more active role. There was also a change in the order of instruction. Whereas in the baseline lesson and the second lesson, the teacher explained concepts, in this lesson, the learners first did an investigation and this was followed by a discussion of their results. This enabled concepts to be developed inductively. The scoring of the lesson according to EQUIP showed that the lesson was at the level of 'proficient inquiry.' In lessons 4–6, the teacher implemented an inquiry-based pedagogy. These lessons were scored at the level of 'proficient inquiry' and were reflected through indicators such as the students were engaged in investigative activities that helped develop conceptual understanding, the teacher asked questions that challenged students to explain, reason and/or justify and the teacher often followed-up responses with engaging probes that required the student to justify reasoning or evidence.

This study demonstrated the effectiveness of an empowerment evaluation approach in shifting a teacher's pedagogical practice from a traditional teacher-centred approach to inquiry-based approach.

Discussion

The findings of the two studies reported in this chapter reflect the potential of the empowerment approach in supporting in-service teachers through mentoring. It offers a viable and sustained form of professional development that is likely to empower teachers in assessing, planning, implementing and evaluating what they do. This success can be attributed to a stepped approach that is associated with empowerment evaluation (Fetterman, 1999). Another factor that explains this success is the deep reflection done by the teacher arising from the stimulated recall discussions. Over time, both teachers realized limitations within their existing practices, and this leads to self-initiated and self-determined changes in teaching.

Empowerment evaluation approach has an outstanding feature of being flexible and suitable for any context (Charoenchai et al., 2015). The two studies reported here have shown the potential of this approach in the South African educational landscape where teachers have struggled to cope with very significant curriculum reform over a relatively short period of time. In South Africa, there is an enormous range in the knowledge and skills of the teachers due to the legacy of the previously segregated education system along racial lines, and not all teachers operate at a level where they can readily embrace and reflect curriculum change in their classrooms. According to Rogan and Grayson, 'innovation is most likely to succeed when it proceeds just ahead of existing practice' (p. 334). In essence, this suggests that a shift in the practice of a teacher should occur in manageable steps. The case studies reported in this chapter have provided ample evidence in underscoring the role played by empowerment evaluation in supporting teachers to adopt a stepped approach towards an innovate inquiry-based pedagogy. The findings emanating from these South African studies invite further research in other countries.

Inquiry-based science teaching demands a set of teaching practices that are different from typical didactic science instruction. Over the years, conceptions of inquiry have changed, as research has consistently demonstrated that what is enacted in classrooms is mostly inconsistent with visions of inquiry, past and present (Anderson, 2007; Crawford, 2014). This incongruence has long been recognized and researched and was often explained as a challenge that teachers experience in making a shift from a teacher-directed, content-oriented approach to teaching, to a learner-centred approach (Entwistle & Walker, 2002). This shift may create conflict between existing practices, beliefs and perceptions as teachers acquire new experiences and information through their existing knowledge structures (Mansour, 2008). Traditional professional development efforts to transition this shift towards an inquiry-based pedagogy have proved to be largely ineffective, due to them being top-down, not recognizing teacher beliefs, and being decontextualized from the school realities of the teacher (Loucks-Horsley et al., 1998). This chapter that explored an empowerment evaluation approach characterized by critical friendship, facilitation, coaching and monitoring provided a new insight into addressing a familiar problem, namely teachers enacting classroom practice that is out of sync with curriculum reform. The empowerment approach is a result of the author's efforts at 're-looking' and indeed 're-searching' a worldwide problem where teachers are inadequately prepared to enact an inquiry-based pedagogy.

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Correction to: Conceptualizing Multiplicities of Scientific Literacy from Five Theoretical Perspectives

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

Correction to:
Chapter 1 in: T. W. Teo et al. (eds.), *Science Education in the 21st Century*, https://doi.org/10.1007/978-981-15-5155-0_1

In the original version of the book, in the following correction has been incorporated: The chapter author's "Sophia (Sun Kyung) Jeong" first and last name have been corrected. The correction chapter and book have been updated with the change.

The updated version of this chapter can be found at
https://doi.org/10.1007/978-981-15-5155-0_1

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Epilogue

Re-searching Science Education: Seeking Better Solutions Using Different Lenses

The chapters in this book represent the collective wisdom of science education practitioners and researchers in their search and re-search for solutions to “old” or persistent problems in order to improve science education. Across the book chapters, the authors have articulated how different lenses were utilised to re-examine familiar science education problems of interest to their local context. The problem spaces taken up by these educators and researchers span three broad areas indicated by the book sections: science curriculum and teaching, science learners and learning, as well as science teachers and teacher education. Collectively, the lenses have shed light on components within education systems (e.g. curriculum, learners and teachers) and the interactions among them (e.g. teaching and learning).

Tackling problems in science education is no mean feat as education systems are large and complex. Traditional scientific approaches to understanding real life, complex systems often involve the reductionist approach, which assumes the properties of the whole can be understood and predicted by the aggregation of components in a system. Thus, the behaviour of the whole system is presumably known by knowing the characteristics of individual components and the rules governing their behaviour. However, complexity science—the scientific studies of complex systems—which has gained prominence in the twenty-first century, suggests the reductionist approach cannot account for behaviours and properties demonstrated only at the systems level. Complex systems demonstrate the phenomenon of emergence, that is, the “properties of a complex system as a whole are very different, and often unexpected, from properties of their individual components” (De Domenico et al., 2019). One of the most cited examples of emergence phenomenon of a complex system is the “V” formation of migrating birds in flight. Individual birds are not aware of or assigned a position within the formation. Yet, the formation emerges as the flock of bird is in flight. Studying the behaviour of individual birds in the system (e.g. how individual

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birds fly) would not have predicted the "V" formation, which only emerges at the systems level.

Recognising the education system as a complex system, some researchers have adopted the lens of complexity science to make sense of the phenomenon of learning (Jacobson, Kapur, & Reimann, 2016). The extent to which this alternative lens can lead to a better understanding of and solutions for education systems remains to be seen. Nevertheless, readers are invited to review the book chapters and consider which sub-system of a whole education system each chapter focused on, what components and interactions were studied and what was found out about them, as well as which of the researched phenomena might be considered emergent and what was found out about them. Readers interested in contributing to the research agendas articulated in the book chapters would also want to consider questions such as which additional aspects of the system need to be studied and how they can best be studied, which aspects need to be strengthened and how they can be strengthened and how do we know how well the system is doing and whether it is sustainable.

Pushing further the lens of complex systems and considering the relevance of science education to STEM education, which also gained prominence since the beginning of the twenty-first century, leads to more questions and considerations for science education practitioners and researchers. We invite readers to ponder some questions from the following perspectives. From the systems modelling perspective, there is a need to consider how science education systems are situated in relation to STEM education systems. Related questions include: To what extents are the systems interconnected? Is science education a sub-system of the broader STEM education system or are they distinct systems with different goals or reasons for existence? How do relationships between science education and STEM education systems look like within a local school or tertiary institution, at the school district, the state, national level and international level? From the research advancement perspective, there is a need to consider how research in science education can contribute towards research efforts in STEM education, and vice versa. Relevant questions include: What methods and findings from science education can inform and improve STEM education research and practice? How might findings from STEM education inform the future direction for science education? Answers to the research advancement perspective questions might be dependent on answers to the systems modelling perspective questions.

As this book concludes with more questions for science education researchers and practitioners to consider, it highlights the need for further work to improve science education as we progress into the third decade of the twenty-first century. It is hoped that with the insights gained from different lenses presented in the book chapters, readers will be inspired to seek better solutions to problems in their local education contexts and contribute towards improving science education.

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