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A Decade of Teaching, Researching, and Leading Reform-Based Science Education in Canada, England, and the United States: An Autoethnography

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by

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Abstract

This research investigated the question: What insights can be gained from autoethnographic exploration of my experiences with reform-based science education systems in Canada, England, and the United States? Autoethnographic data was collected from recollections of my experiences teaching, researching, and leading in secondary science education over a decade (2012-2023) in three countries (Canada, England, and the United States), and presented for this research as narrative vignettes. In response to calls to capture the interplay between stakeholders and infrastructure, and to better understand and document the ways in which educational systems enact policy, I used a layered approach to analytic autoethnography to explore my experiences implementing and enacting reform-based science education. Analysis of my narrative vignettes led me to identify similarities and differences from my experiences across national and professional cultures. I discovered that while some context-dependent differences existed, robust enactment of science education across all three experiences was hindered to varying degrees regardless of infrastructural or cultural nuances. From a positioning of inbetween, I was able to capture unique insights into the innerworkings, tensions, and negotiations that took place in the third space between policy and practice from my lived experience. This research aims to increase visibility for internal intermediaries positioned in the inbetween of science education systems and to highlight autoethnography as a reliable science education research method for providing insight into the everyday 'what is' of science education systems in contrast to the 'what should be' as outlined in the aims and goals of government educational policy documents.

Key Words: Science education, reform, inbetween, internal intermediary, enactment, implementation, teaching, research, leadership, cross-cultural, autoethnography

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By uprooting oneself from the world,

a person makes themself present to the world

and makes the world present to them.

Simone de Beauvoir on *The Ethics of Ambiguity*, 1947

Dedicated to all the explorers and inbetweeners.

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Encountering familiar issues in a strange setting is like returning on the second circuit of a Möbius strip and coming to the experience from the opposite side. With yet another turn, what seemed radically different is revealed as part of a common space.

To get outside of the imprisoning framework of assumptions learned within a single tradition, habits of attention and interpretation need to be stretched and pulled and folded back upon themselves, life lived along a Möbius strip.

Bateson (1994, p. 31,43)

CHAPTER ONE: INTRODUCTION TO THE STUDY

Introduction

In this dissertation, I investigate my experiences in Canada, England, and the United States with reform-based science education through autoethnographic means. Reform-based science education in this research is defined as the modern (21st century) vision, aims, and objectives outlined in governmental policy for educational standards which recommend for school science to educate students in the processes, nature, and practices of the natural sciences (in the subjects of physics, biology, and chemistry). The purpose underpinning these recommendations is to equip students, future citizens, with the skills to face and overcome the scientific, technological, and environmental challenges of society in the 21st century (Johnson et al., 2015; National Research Council, 2013; OECD, 2015). This overarching purpose has manifested in educational policy standards, represented as, among other things: developing scientific attitudes (e.g., collaboration, stewardship, inquiry, and mutual respect) with the goal to develop a critical sense of wonder and curiosity in Alberta, Canada (Alberta Education, 2014); to work scientifically with the goal of developing in students an understanding of the nature, processes, and methods of science (UK Department for Education, 2013); and to engage with science and engineering practices with the goal of developing skills for problem solving, thinking critically, and working cooperatively (Arizona Department of Education, 2018). While the aims and recommendations of reform-based science education are detailed in government education policy documents, how those recommendations are interpreted and subsequently enacted in the classroom, are subject to a swath of individual, political, and cultural influences.

It follows that the implementation and enactment of reform-based science education is nuanced and multifaceted. While the student-experienced science classroom is a rather private affair, it is situated within a complex entangled system in which individual, collective, and institutional cultural values, beliefs, skills, and politics are contested and negotiated over daily. Many hands add to the simmering pot of science education, yet it comes down to the teacher, who is tasked with enacting science education behind closed doors.

In this dissertation, I use autoethnography to explore my experiences of enactment and implementation of science education policies in three different countries. To frame my work, I will use this introductory chapter to explicitly outline my research question, approach, and aims. In Chapter Two, I provide a review of the literature on reform-based science education to provide the reader with background to my autoethnography. In Chapter Three, I outline the methods of autoethnography that I used to write Chapter Four, the autoethnographic chapter of this dissertation. In Chapter Five, I discuss my autoethnography in relation to the literature reviewed in Chapter Two. Finally, in Chapter Six, I reflect on several considerations on my research and provide reflections that may help educators, intermediaries, and leaders interested in enacting or supporting the enactment of reform-based science education.

Research question

This autoethnography explores my experiences with implementation and enactment of reform-based science. I had many experiences in reform-based science education over a decade, in three countries and in various teaching, researching, and leadership roles. These experiences were punctuated by episodes that made me question whether individuals and the educational systems that contain them were aligned towards the goals of reform-based science education. I had a feeling that I was constantly working against the grain to achieve the goals set out by policy and wondered what insights might be gained from my experiences. Thus, my research question became: *What insights can be gained from autoethnographic exploration of my* *experiences with reform-based science education systems in Canada, England, and the United States?*

Research Approach

I used a layered analytic approach to autoethnography to explore my experiences of enactment and implementation of reform-based science education. Briefly, autoethnography uses narratives to "describe and systematically analyze (graphy) personal experience (auto) in order to understand cultural experience (ethno)" (Ellis et al., 2011, p. 273). Thus, an autoethnography should provide personal insight into cultural phenomena. In my case, the cultural phenomena include the interactions and actions taking place in the space between implementation and enactment of reform-based science education. Autoethnographic approaches differ and can be placed on a continuum with evocative on one end and analytic on the other (see Chapter Three: *A Brief History of Autoethnography: A Controversial Continuum*). Evocative approaches rely on narratives that grip the reader emotionally, whereas analytic approaches use personal narratives alongside other forms of data (e.g., literature, external documents, etc.), which produces narratives with less emotional impact. More specifically, I used a layered approach to analytic autoethnography. Unlike traditional autoethnography, layered approaches "juxtapose fragments of experience, memories, introspection, research, theory, and other texts" (Adams et al., 2014, p. 85). I therefore use layered narrative vignettes of my experiences as a participant observer teaching, researching, and leading in three countries (Canada, England, United States) over a decade.

I took up a layered approach to autoethnography in the analytic tradition for the purposes of intersecting the "subjectivity of the inner world with the objectivity of the outer world" (Chang, 2008, p. 110) and to "truthfully render the social world under investigation but also transcend that world" to provide insight into broader cultural phenomenon of reform-based science education (Anderson, 2006, p. 388). Though my experiences are not generalizable, I found that my experiences often reflected the experiences of my colleagues and the findings of research studies that have investigated aspects of reform-based science education in more systematic ways.

Purpose of the study

The purpose of this study is to present and analyze my experiences in reform-based science education over a decade in Canada, England, and the United States in an attempt to provide insight into broader cultural phenomenon of reform-based science enactment and implementation. There are three aims driving this research:

Aim 1: Provide insight into the tensions, experiences, and social worlds of stakeholders that implement and enact reform-based science education. Through my vignettes, I hope to provide candid insight of the 'what is' (Hammond & Brandt, 2004) of reform-based science educational systems in the inbetween spaces – the unproductive boundaries (Malin & Brown, 2020) and third spaces between policy and practice (Ball et al., 2012) – to capture interplay between various stakeholders (Fensham, 2009).

Aim 2: Identify the similarities and differences across national and professional cultures for reform-based science education enactment. By analyzing my experiences across educational systems in Canada, England, and the United States, I compare my experiences teaching, researching, and leading across three countries to identify similarities and differences across these systems.

Aim 3: Provide insight into broader cultural phenomenon from personal experience. By analyzing my experiences, I seek to not only truthfully render the social worlds under investigation, but also to offer insight into the broader cultural phenomenon in which my personal experiences are embedded (Anderson, 2006; Chang, 2008).

Context of the Study

In the foreground of this work are my experiences, teaching, researching, and leading in Canada, England, and the United States. I am a white Canadian citizen who was born, raised, and educated in Alberta, Canada. My approach to secondary science education is shaped by my experiences in undergraduate existentialist philosophy, graduate research in cell biology, education research conducted in pre-service teacher education, and ultimately, my own meager childhood secondary science education. Taken together, these experiences have shaped my views and values of science education and motivate the professional work I do—to realize the reform vision of science education.

Over the course of ten years, I have worked in the roles of Junior High Science teacher (Alberta, Canada), Year 7-13 Teacher of Science (Devon, England), Junior High classroom support (Nova Scotia, Canada), R1 University Science Education Outreach Research Coordinator (Arizona, United States), and District K-8 Science Strategist (Arizona, United States). I have engaged in education research in my pre-service teacher education (Alberta, Canada), for an independent sabbatical (Berlin, Germany), and as an inquiry science research coordinator working with a Nobel Laureate for a science outreach center at an R1 university (Arizona, United States). This autoethnographic research investigates these experiences through narrative inquiry.

In the background of these experiences are the secondary science education systems in which I worked and the social and theoretical considerations that surround reform-based science education. My view of science education is reflected in the literature that suggests it has been under a state of revolving 'reform' since the mid-20th century (Ball & Cohen, 1996; Bower, 1996; Furtak & Penuel, 2019; Johnson, 2013; Moreno, 1999; Welch, 1979). Calls for "radical changes to core habits and practices in most schools and systems" (OECD, 2015) echo across the educational landscape in the longstanding history of efforts of scientists, philanthropic foundations, policymakers, and education researchers to support secondary science education systems in achieving this vision (Malin & Brown, 2020). Yet despite these varied efforts to meet the reform vision, my experiences with science education instructional realities largely do not align with the vision (see similar observations by Abrahams & Millar, 2008; Costenson & Lawson, 1986; Fensham, 2009; Hume & Coll, 2010; Sykes & Wilson, 2016).

By foregrounding my experiences, I use autoethnography to explore t inbetween implementation and enactment of reform-based science education across three countries from three occupational perspectives. Through analysis of my autoethnographic narratives, I attempt to provide insights from autoethnographic exploration of my experiences with reform-based science education systems in Canada, England, and the United States.

Researcher Positionality

I believe that there is a world 'out there' and that we investigate this unknowable world through various means (e.g., scientific or social inquiry) to gain an approximate model that can provide explanations of our experiences. This model is constantly revised and in flux for me as an individual but also for all of us collectively as a society. Thus, in a sense I believe that a collective understanding is socially constructed. However, I also believe that as social understanding changes over time, so too does individual understanding. How each individual's perception of the world maps onto the world 'out there' is an unknown. While I believe that it is a virtue to work towards individual and collective understandings that better map to that unknowable world, there are multiple ways to gain insight into the world 'out there'. Each of our stories can be valuable for helping us make sense of and explain our experiences, with the potential to provide insight into the world 'out there'. Here, I use autoethnography to link my narratives of science education to explanations in science education research.

Researcher Assumptions

My research is founded on analyses of my own experiences. These experiences are inevitably steeped in my biases and assumptions, of which I have attempted to remain aware (Bateson, 1994). My assumptions have inevitably been born from my own educational experiences. My perspectives, predispositions, presuppositions, and proclivities have informed my assumptions and beliefs. I have two major biases that I must declare. First, I believe in and support the vision of reform-based science education. My experiences with (natural) scientific research have informed my predispositions relating to science education: that is, science education should reflect the processes, practices, and mindsets of natural scientists. Second, I believe that the vision of science education reform can and should be realized. Driven by my own experiences in science education—as a student, teacher, researcher, and leader—I believe that science education systems should align with and support enactment of reform visions.

Rationale for Research

This research was motivated by the recommendations for future studies by Ball et al. (2012), Fensham (2009), and Hammond and Brandt (2004), among others. I sought to explore what Ball et al., (2012) refer to as the 'third space between policy and practice' to investigate the interplay between stakeholders and observe how schools 'actually deal with' policy (Ball et al., 2012; Fensham, 2009). In doing this, I sought to provide insight into what Hammond and Brandt (2004) term as the 'what is' in contrast to 'what is supposed to be'. It is in this inbetween, or third space, that policy can be transformed into practice. Thus, individuals that occupy this third space, even temporarily, may facilitate more aligned enactments of implemented policy. From these inbetween spaces, varied solutions are possible, but at their center, they do or should share "an emphasis upon somehow spanning these unproductive boundaries for mutual benefit (i.e., better research, better practice, heightened sense of collective responsibility, enhanced infrastructure for educational improvement" (Malin & Brown, 2020 p. 2). The rationale for this research is to provide a voice to this inbetween or third space between policy and practice, which I hope can offer unique ontological and epistemological advantages (Giesen, 2012; Iyer, 2000).

Significance of Research

The significance of this work is three-fold. First, to answer calls to understand and document the ways in which schools 'actually deal' with policy (Ball et al., 2012) and capture the interplay between stakeholders (Fensham, 2009). Second, to increase visibility, support, and demand for internal intermediaries (e.g., knowledge brokers and/or strategists) (Farley-Ripple & Grajeda, 2020; Whitworth et al., 2017). Third, to bring autoethnography as a reliable method to the dominant discourse of traditional science education research culture (Brandt & Carlone, 2012; Hammond & Brandt, 2004). Taken as a whole, this work investigates the interstitial 'third space between practice and policy' (Ball et al., 2012) to document the "everyday situations of social interaction … which are not initially expected to be consequential but can offer important opportunities for the emergence of new practice” (Ollila & Yström, 2020, p. 209). I will take each point in turn.

Answering calls to understand and document the ways in which schools ‘actually deal’ with policy and capture the ‘interplay between stakeholders’

Despite calls to attention to the phenomenon that “the gap between reform vision and the historical/current instructional realities is quite substantial” (Sykes & Wilson, 2016, p.901), the dominant discourse of traditional science education research remains optimistic, largely avoiding the ‘unproductive boundaries’ and ‘third spaces between policy and practice’. Fensham (2009) notes that the politics of science education has remained underexplored, resulting in researchers overestimating the implications of their findings, which largely “ignore the interplay between the stakeholders beyond and in-school who determine the nature of the curriculum for science education and its enacted character.” (p.1076). Further, Ball et al., (2012) note that while “a great deal of attention has been given to evaluating how well policies are implemented… less attention has been paid to understanding and documenting the ways in which schools actually deal with multiple, and sometimes opaque and contradictory demands” (p.142). This sentiment is echoed more recently by Marco-Bujosa et al. (2017) in their discussion that policy analysis and implementation studies do not often or fully document how fragile and unstable the process of policy enactment is.

Increasing visibility and demand for internal intermediaries

Internal intermediaries, like curricular strategists and academic coaches inhabit inbetween spaces between policy and practice. My experiences suggest that these positions can facilitate a more robust enactment of science education policies. This work supports and extends the calls made by Farley-Ripple and Grajeda (2020) and Whitworth et al., (2017) for bringing visibility, support, and demand for internal knowledge brokers who despite being "uniquely situated within their organizations", are "often overlooked" (Farley-Ripple & Grajeda, 2020, p. 81) and overburdened (Whitworth et al., 2017).

Bringing autoethnography into the dominant discourse of science education research

This research seeks to demonstrate the value of autoethnographic research to identify and use insider information to inform outsider actions. Research of ethnographic and anthropological origin, autoethnography included, have yet to be taken up as forms of research endemic to the dominant discourse of science education research (Brandt & Carlone, 2012; Hammond & Brandt, 2004). Using autoethnography, I was able to highlight the everyday tensions I experienced that are overlooked or undiscoverable if a traditional science education research approach was used. In alignment with the tenets of analytic autoethnography, I offer what I hope is an accurate portrayal of the social worlds I experienced to provide insight into broader cultural phenomenon (Anderson, 2006; Chang, 2008).

Summary

In this chapter I explored the foundational elements of my study and outlined the analytic layered approach to autoethnography. I contextualized the study within my personal experiences researching, teaching, and leading in three countries and provided insight into how my researcher perspectives and positionally are informed by my educational autobiography. I conveyed the purpose of this research to accurately portray the tensions of social worlds I experienced and to provide insight into broader cultural phenomenon. Finally, I highlighted the rationale and significance of this work informed by previous research.

CHAPTER TWO: LITERATURE REVIEW

In this chapter, I begin by providing a definition for reform-based science education, which is an amalgamation of recent reforms to science education practice. With this definition in mind, I outline my conceptual framework that guides this research by placing the constituents of science education as actors embedded in a network that includes educational infrastructure. As an entrée to implementation and enactment of reform-based science education policies, I compare three policies that have been implemented in three different districts in three different countries (Alberta, Canada; England, and Arizona, USA). After outlining the benefits and limitations of reform-based science education, I delineate implementation from enactment. Simply, implementation is the adoption of a policy, whereas enactment is how the policy is put into practice. Finally, I review how enactment is affected by different constituents of science education as defined by my conceptual framework (practice, infrastructure, leadership, and intermediaries). I conclude by reflecting on the lack of alignment between national and district/school policies and suggest that until these policies are aligned, progress toward the goals of reform-based science education will continue to be challenging to achieve.

Reform-based Science Education

Defining Reform-based Science Education

What I call reform-based science education has been called by many other names. For the purposes of this research which spans education reform efforts taking place in three countries over a decade, I define reform-based science education to be an amalgamation of many of the more recent reforms to science education practice which includes aspects of what others call science education reform in general (Bower, 1996; Johnson, 2013; Moreno, 1999). Science education reform in the past and present has been referred to by many names and descriptors in education research: standards-based (Lakshmanan et al., 2011), inquiry-based science (Cervetti et al., 2006; Martell, 2020; Riga et al., 2017; Scott et al., 2018), nature of science (Farber, 2003; Taber, 2006), minds-on (Osborne, 2019), science as practice (Furtak & Penuel, 2019), phenomenon-driven (National Research Council, 2013), instructional reform (Ball & Cohen, 1996), school reform (Datnow & Stringfield, 2014), and authentic science education (Bencze & Hodson, 1999), to name a few.

In this research I take reform-based science education to mean the modern (21st century) vision, aims, and objectives of science education government policies. Broadly speaking, this focuses on the study of science through exploring the processes, nature, and practices of science limited to the content of biology, chemistry, and physics. I take this to be expressed through teaching and learning experiences that include, but are not limited to critical discourse, inquiry-based, hands-on, experiential, and problem-based learning. (Furtak & Penuel, 2019; Hodson & Bencze, 1998; Waight & Abd-El-Khalick, 2011; Yarden et al., 2001).

While nuanced differences persist between various authors and initiatives as illustrated above that have at times resulted in tensions between researchers (e.g., Furtak & Penuel, 2019; Osborne, 2019) and with the general public (e.g., Larkin, 2019), for the purposes of this study I focus on the similarities. In contrast to the varied descriptors provided earlier, much of modern policy is synonymous with simply 'science education' (e.g., Alberts, 2009; K. Anderson, 2012; Alberta Education, 2014; Arizona Department of Education, 2018; Fensham, 2009; UK Department for Education, 2013). Thus, for this research, I use the term reform-based science education to include modern science education policy that exhibits the aforementioned descriptors.

Just because I am focusing on the similarities does not suggest that nuanced differences do not exist. In fact, much literature has focused on the differences between various science education teaching and learning strategies (e.g., hands-on, experiential learning, discovery-based learning, problem-based learning, nature of science, science, technology, and science and technology studies, inquiry-based, phenomenon-driven, or science as practice) (Furtak & Penuel, 2019). However, the effects of having so many different options is at least to some extent, counterproductive because it can increase confusion amongst stakeholders, including educators and the public. With different stakeholders using different terminology, the public is left questioning the difference between problem-based, hands-on, and inquiry-based learning (Larkin, 2019), and thus questioning the point of reform at all. Furthermore, much literature has been written advocating for one approach over the other, debating the authenticity of scientific practice in the classroom (e.g., Bencze & Hodson, 1999). To reiterate, for my purposes, I have not focused as much on the differences but instead focus on the similarities between these valuable approaches. The main reasons that I focus on their similarities is because in one way or another, these approaches are trying to fulfil some aspect of the goals of educational policies developed over the last couple decades, which generally speaking, has been to develop scientific literacy of students by building science skills and attitudes beyond the basic content knowledge of each subject. (e.g., Alberta Education, 2014; Arizona Department of Education, 2018; Fensham, 2009; UK Department for Education, 2013).

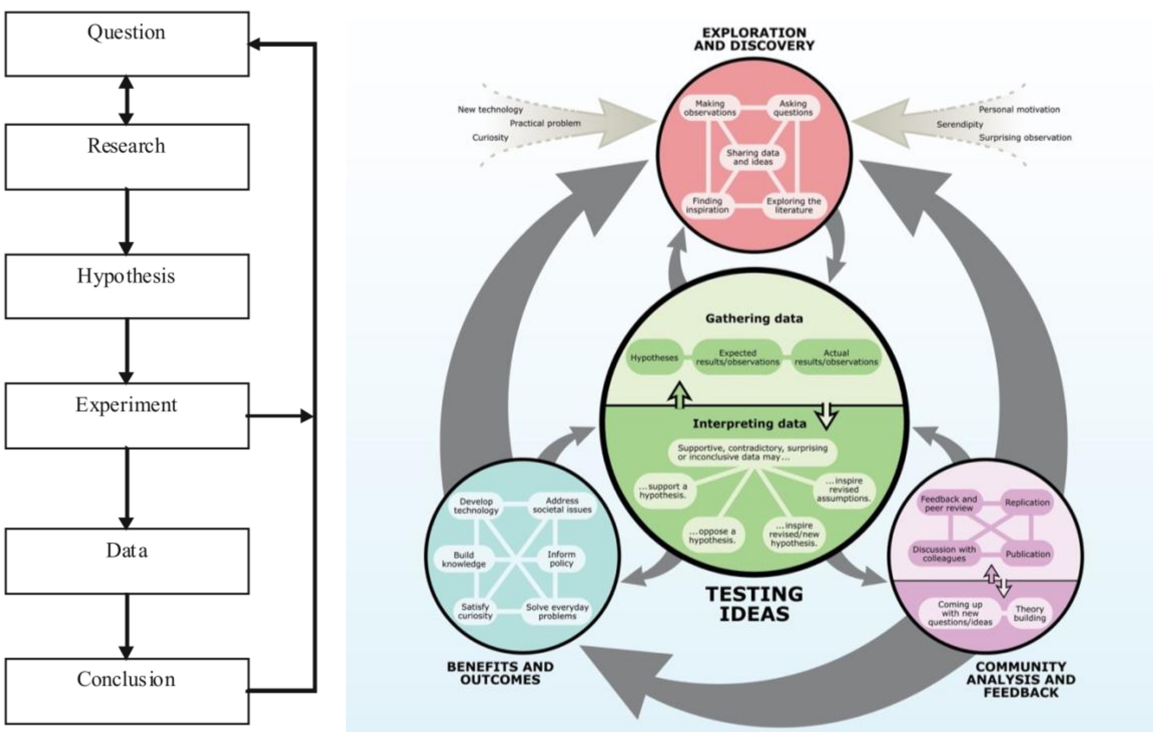
Educational reform is not a new thing. Long before these recent standards came into place, science education has been in a state of revolving reform since the mid-20th century (Ball & Cohen, 1996; Bower, 1996; Furtak et al., 2012; Johnson, 2013; Moreno, 1999; Welch, 1979). Sparked by the First and Second World Wars, perpetuated by the Cold War era, and now charged with developing 21st-century competencies to drive the 4th industrial revolution, science education in the Anglo-Western tradition has sought to increase the scientific literacy and knowledge of their citizens (Schwab, 2017). Specifically, reform-based science education in the 21st century calls for student learning experiences steeped in the processes, nature, and practices of science with the goal of developing scientifically literate citizens adept at critical thinking, collaboration, and evidence-based reasoning (Bencze & Hodson, 1999; Bowen, 2005; Hume & Coll, 2010; Johnson, 2013; Phillips & Norris, 2009; Yarden, et al., 2001).

Reform-based science education is rooted in inquiry-based approaches to learning and encompasses the multiple features of scientific practices, processes, and attitudes (e.g., curiosity, inquiry, investigation, experimentation, critical thinking, evidence-based reasoning, computation, modeling, designing, innovation, communication, discovery, exploration, debate, and negotiation) (Bencze & Hodson, 1999; Furtak et al., 2012; Hume & Coll, 2010; Johnson, 2013; Scott et al., 2018). Reform-based science education attempts to robustly represent the processes and practices of science. Unlike the traditional linear model, a 21st century model represents a vision of science that echoes the foci of reform-based science (compare Figure 2.1 left vs right).

Instead, the 21st century consensus picture of science is nuanced, complex, and dynamic (Figure 2.1 right). Rather than learning a collection of facts and the linear 'scientific method' (Figure 2.1 left), students must instead engage more deeply in their learning results in a more accurate understanding of the processes and practices of science as evidenced in Figure 2.1, right (Hodson & Bencze, 1998; Waight & Abd-El-Khalick, 2011). One of the goals of reform-based science education is to develop student understanding of processes and practices of science, and develop critical thinking skills, evidence-based reasoning, and scientific literacy (Penuel & Furtak, 2019; Yarden et al., 2001). These skills reflect the goals of reform efforts which aim to equip students with the skills to face and overcome the social, scientific, and environmental challenges of the 21st century (Alberta Education, 2014; Johnson et al., 2015; National Research Council, 2013; OECD, 2015). To help frame the way I think about reform-based science education, I will outline my conceptual framework, which will help guide the narrative of this literature review.

Figure 2.1

Linear (left) and 21st century (right) representations of the scientific method



 http://www.understandingscience.org/.

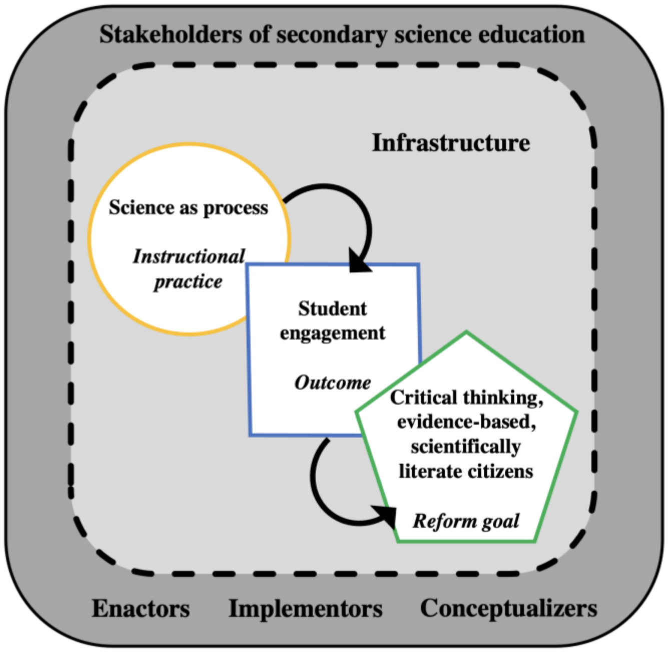
Conceptual Framework for (Reform-Based) Science Education

In my conceptual framework I identify the central elements that directly or indirectly impact the implementation and enactment of reform-based secondary science education. These elements collectively constitute what I refer to in this research as a science education system which includes infrastructure and policies used, created, or enforced by enactors (teachers), implementors (administrators), and conceptualizers (government, education researchers, scientists) (Ball et al., 2012; Fensham, 2009; Penuel, 2019). In Figure 2.2, I illustrate the key elements, constituents, and variables within secondary science education and the presumed relationships between them (Ravitch & Riggan, 2017). The stakeholders of secondary education—enactors, implementors, and conceptualizers (dark grey)—surround, permeate and shape secondary education infrastructure (light grey).

This research is concerned with the interplay between the constituents outlined in the conceptual framework (see Figure 2.2). Instructional practice (yellow circle) is embedded within and is dependent on infrastructure. Instructional practices influence student engagement in scientific practices and attitudes (blue square). How students engage with scientific practice and their attitudes towards it are the outcomes of reform-based science. Through student engagement, the goal of reform-based science can be achieved (green pentagon). Taking science education research and policy into consideration, I believe that the explicit goal of reform-based science education is to develop citizens with skills in critical thinking, evidence-based reasoning, and scientific literacy. I believe that achieving this goal is critical to the foundations of democracy as we continue into the 21st century. This conceptual framework shapes how I think about the work that I do and has shaped my approach to autoethnography.

Figure 2.2

Conceptual framework for the investigation of reform-based science education in this study



As illustrated in Figure 2.2, the following stakeholders of science education influence the student experience of reform-based science: conceptualizers (government, education researchers, scientists), implementors (school administrators, district middle leadership, external intermediaries), and enactors (educators) of science education. Infrastructure is foundational to science education systems. Briefly, I will define each below.

Conceptualizers I take to be the researchers and policy makers. Conceptualizers are individuals of authority that are tasked with creating, developing, and/or enforcing policy compliance. Policy includes instructional, curriculum, and infrastructure-related policy. Individuals include stakeholders such as scientists, government officials, and upper-level district administration such as superintendents (Ball, 2008; Fensham, 2009; Sykes and Wilson, 2016).

Implementors I take to be district-level administrators. Implementors are individuals who are professionally tasked with implementing policy to monitor and support the enactment of science education by teachers. Stakeholders who are implementors includes school administration (principals, vice principals, department heads) and district administrators (superintendents, directors, upper district staff under superintendent such as intermediaries) (Fensham, 2009; Fullan, 2008; Penuel et al., 2007; Sykes and Wilson, 2016; Whitworth et al., 2017).

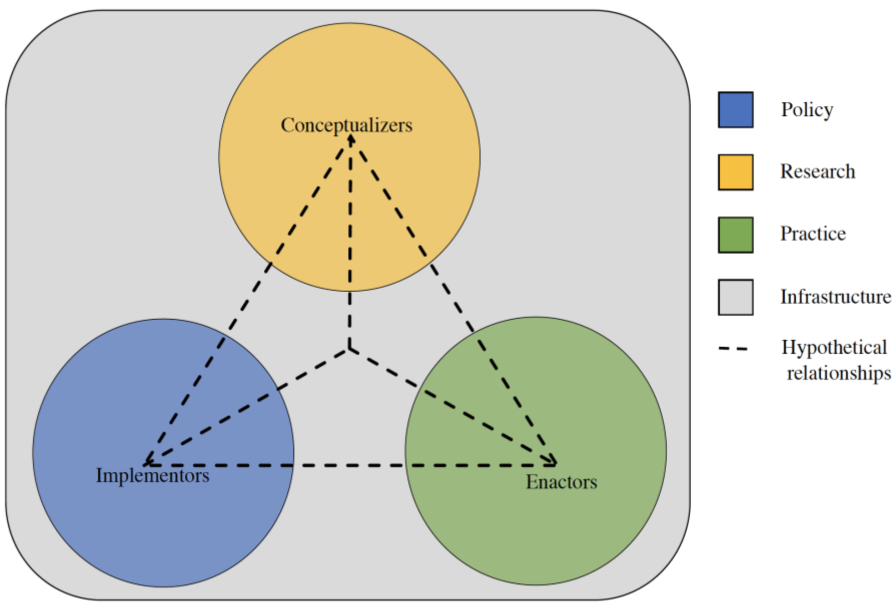
Enactors I take to be ground-level instructional staff, predominantly teachers. Enactors are individuals who are professionally responsible for enacting reform vision by educating students in classrooms in accordance with professional, local, and state policies (C. Anderson et al., 2018; Fensham, 2009; Marco-Bujosa et al., 2017; Pak et al., 2020; Penuel et al., 2007; Sykes & Wilson, 2016). How teachers bring content to life in their classrooms is the process of enacting the intended curriculum (Pak et al., 2020) which is monitored by implementors and created by conceptualizers.

Infrastructure I take to include any artifacts of education including buildings, curricula, policies, resources, etc. I define infrastructure to include any variable that can, directly and indirectly, impact the educator's environment and/or practice. This can include elements that support and sustain educator practice such as access to and availability of teaching resources, work environment barriers/limitations, time availability, structures (authority and incentives), values & beliefs, quality and quantity of professional development, culture of school and/or district. (Fensham, 2009; Penuel, 2019; Powell & Anderson, 2002; Star & Ruhleder, 1996)

To further articulate the relationships between various stakeholders, I developed a relational framework for the hypothetical relationships between stakeholders of the conceptual framework (see Figure 2.3). In many ways the individuals tasked with conceptualizing, implementing, and enacting science education are equally as important as the outcomes produced from their interactions with the environments in which they operate – namely policy, research, and infrastructure. Potential or hypothetical relationships that may exist between stakeholders, either explicitly or implicitly are visualized by a dashed line (Figure 2.3).

Figure 2.3

Relational framework of the stakeholders as constituents of secondary science education



As mentioned above, the three major groups of stakeholders are identified as conceptualizers (producers of research – scientists and education researchers; and users of research – government officials, upper-level district leaders), positioned in the research sphere (shown in yellow); implementors (government officials, upper-level district leaders; school leaders, district leaders), positioned in the policy sphere (shown in blue); and enactors (educators), positioned in the practice sphere (shown in green). Infrastructure (shown in grey) provides the medium of substrates used and products produced by the aforementioned entities. Intermediaries are any entity, individual or conglomerate that inhabits the in between spaces, between conceptualizers, enactors, and implementors.

Reform-based Science Education Policies from Three Systems

Here, I outline the major science education policies from the three relevant countries for the work presented in this study. All three of these policies reflect elements of the aims of reform-based science education discussed earlier. Presently, the 21st-century reform vision for science education calls for the equipping of students with the skills and knowledge to solve what are commonly referred to as the “21st-century challenges” (Johnson et al., 2015). As stated earlier, reform-based science education in the 21st century calls for student learning experiences steeped in the processes, nature, and practices of science driven by the goal of developing scientifically literate citizens adept at critical thinking, collaboration, and evidence-based reasoning. The increased demand for critical thinking, evidence-based, scientifically literate citizens reflects the state of the present socio, economic, and cultural milieu: to increase public understanding of the processes of science, but equally, to equip students with skills to compete in the STEM (science, technology, engineering, mathematics) workforce.

While the reform vision of science education remains moderately consistent across Anglo-Western countries of the Organisation for Economic Co-operation and Development (OECD, 2015), variations on the curricular details of the local educational standards inevitably exist. These variations are captured in different government standards or educational policies. Below I summarize the major aims, themes, and significant elements of each of the three countries (Canada, England, United States) in which my experiences took place (see Table A1 in Appendix).

Science knowledge (content) to be taught in secondary science education is consistent across the three government policies focused on the study of natural sciences limited to: biology, chemistry, and physics in relation to life, physical, earth, and space sciences. Further, the aims or goals of the educational standards share some similarities across government policies: to develop student understanding of the nature and process of science while equipping them with skills and fostering curiosity to ask and answer questions for the purposes of interacting with the world around them to address future science-related issues (Alberta Education, 2014; Arizona Department of Education, 2018; UK Department for Education, 2013). However, differences do exist between the expression of the aims/goals in the themes of the educational standards.

Thematically, each government set of standards varies in its focus. The UK educational policy standards focus on more traditional representations of science education, which, apart from content (knowledge), includes ‘working scientifically’ (i.e., experimental skills for investigations such as measurement, evaluation, and analyses) (UK Department for Education, 2013). In contrast, the Alberta program of studies educational policy outlines three additional themes in addition to knowledge (content): science, technology, and society, skills, and attitudes (Alberta Education, 2014). The Arizona state standards also identify three themes in addition to content (knowledge): science and engineering practices, core ideas for using science, and cross cutting concepts (Arizona Department of Education, 2018). Though the language is somewhat different between the three policies, the sentiment is similar; each is concerned with building science skills and attitudes beyond the basic content knowledge of each subject.

Although all three policies have similar goals, the Albertan and Arizonan government policies are clearer in their program aims and goals that go beyond the basic content. The Albertan Program of Studies states:

> “All students have the opportunity to develop scientific literacy. The goal of scientific literacy is to develop the science-related knowledge, skills and attitudes that students need to solve problems and make decisions, and at the same time help them become lifelong learners — maintaining their sense of wonder about the world around them. Diverse learning experiences within the science program provide students with opportunities to explore, analyze and appreciate the interrelationships among science, technology, society and the environment, and develop understandings that will affect their personal lives, their careers and their futures.” (Alberta Education, 2014, p.1).

The Arizonan standards similarly states: “sustaining natural curiosity and giving it a scientific foundation must be a high priority”, and highlights the importance of engaging students in scientific thinking to strengthen everyday skills used beyond the science classroom (e.g., solving problems creatively, thinking critically, working cooperatively in teams, and valuing lifelong learning) (Arizona Department of Education, 2018). In Table A1 (see Appendix), I provide more detail comparing and contrasting these three systems.

Benefits and Limitations of Reform-based Science Education

Reform-based science education standards have the propensity to encourage teachers to engage with aspects of science in accessible and meaningful ways for themselves and their students. Teaching reform-based science, when done right, has a four-fold value for the learners: first, it contextualizes and engages students in their learning; second, by engaging students through multiple modalities and varied opportunities there is an added benefit of having an excellent behavior management tool; third, it fosters the development of translatable skills (such as critical thinking and evidence-based reasoning); and fourth, it increases motivation and development of scientific identities. Despite their inclusion in educational policy, reform-based science education standards are rarely assessed by standardized assessments. Furthermore, student achievement has been shown to negatively correlate with substantial reform-based education experiences in some studies. The following section will discuss these benefits and limitations in more detail.

Reform-based science education assumes Dewey's philosophy that education is not something done to learners but should be something that learners actively participate in (Dewey, 1938/1997). Reform-based science education that is phenomenon-driven, employs authentic scientific tools and literature, is inquiry-based, offers open-ended problems, and is encouraging of discourse and critical thought is widely recognized as effective pedagogy (Bowen, 2005; Duschl, 2008; Hodson, 2003; Hurd, 1980; Waight & Abd-El-Khalick, 2011; Yarden et al., 2001). Engaging students in robust reform-based science experiences can equip them with skills that are translatable across disciplines and throughout their life: an understanding of the nature, practices, and processes of science and competency in critical thinking and problem-solving skills (Barrows, 1996; Bencze & Hodson, 1999; Hume & Coll, 2010; Scott et al., 2018). Further, centering the student and valuing sense-making in science education can not only increase interest and motivation to learn science, but also contribute to helping students develop science identities (Penuel & Furtak, 2019). I believe that engaging students in the aforementioned learning experiences and skill development will benefit both learners and the society in which they are embedded.

Reform-based science education practices also benefit classroom behavior management (Mergendoller et al., 2006). When students are engaged in their learning and there are structured scaffolds to support learners, disruptive behaviors are reduced (Harris & Rooks, 2010). Reform-based science is inherently student-centered and phenomenon-based, and thus is designed to provide students with agency and choice for engaging in multiple avenues to access, engage in, and demonstrate their learning. An important caveat is that this learning approach requires that teachers strategically implement management strategies (Mergendoller et al., 2006), scaffold support structures (Puntambekar & Hubscher, 2005), and educate students in the practice of self-regulated learning (Schraw et al., 2006). So, with practice and support, I believe that reform-based science education practices can be used by any teacher to help them better manage their classroom while benefiting students, and ultimately society.

Though the benefits of reform-based science on behavior management, student engagement, and development of scientific attitudes are uncontested, there is an ongoing debate on its impact on deeper learning and academic achievement (e.g., Cairns & Areepattamannil, 2019; De Jong et al., 2023; Sweller et al., 2024). This debate raises important questions about the purpose and nature of science education for the individual student and for society. I believe when reform-based science is enacted with high pedagogical content knowledge, that is, skillfully, strategically, with careful consideration, and deep understanding of scientific practices and processes, that reform-based science teaching and learning practices can increase scientific attitudes, beliefs, and identities, alongside academic achievement. How achievable this is however, is another matter, and will be explored throughout this research.

When considering the correlation between reform-based pedagogy and achievement on standardized assessments, meta-analyses of existing findings suggest that when enacted effectively, these pedagogies facilitate a deeper level of understanding (Barrows, 1996; Furtak et al., 2012; Scott et al., 2018) and increase academic performance (Lott, 1983). However, other studies suggest that reform-based practices are negatively correlated with academic performance, scientific literacy, and a deeper level of understanding (Areepattamannil, 2012; Cairns & Areepattamannil, 2019; OECD, 2016). Against the backdrop of decades of research demonstrating the value for, and importance of, reform-based student-centered pedagogy and classroom experiences highlighted earlier, contentious debates exist. To contextualize this debate on the effect of reform-based science education approaches on academic achievement, it is noteworthy semantic disagreements have also occupied the field as is detailed elsewhere in this chapter (e.g., Furtak & Penuel, 2019; Osborne, 2019; Penuel & Furtak, 2019; Southerland & Settlage, 2019). As identified earlier, there are many facets of reform-based science education regarding pedagogical practices that support the teaching and learning of reform-based science, one of which, is inquiry, and is of particular interest to education researchers.

Large-scale international data analysis that showed a negative correlation between one facet of reform-based science, inquiry-based learning, and achievement on standardized assessments (Cairns & Areepattamannil, 2019; OECD, 2016). These findings have sparked significant debate and raised questions about the purpose and process of science education. Some researchers called into question the reliability of this correlational data given that uniform definitions, expressions, and representations of inquiry are not consistently understood across students and teachers, which was further problematized by the self-reported nature of the student survey results being analyzed (Scott et al., 2018). Other researchers questioned exactly what is meant by inquiry as it can have many applications: teaching of inquiry, teaching about inquiry, or teaching through inquiry (Cairns & Areepattamannil, 2019).

Nevertheless, a debate is ongoing regarding the utility of inquiry-based learning experiences and the what, how, and ultimately, why of reform-based science instruction. After the release of the 2015 PISA results, which showed a negative correlation between inquiry and achievement, the UK education minister called for favoring teacher-led over reform-based instruction (Gibb, 2017). Similarly, in response to the PISA results among other quantitative meta-studies, Zhang et al. (2022) declared an evidence crisis in science education policy citing that science education research and policy has excluded correlational studies that show minimal support for existing science education policy (standards). The authors contest that they do not object to standards-based learning outcomes or the use of investigation activities, yet they argue that conceptual and procedural content should not be taught by exploration-based investigations and that development of other learning goals (such as scientific attitudes) should not be at the cost of learning concepts. While I agree with elements of their arguments (e.g., content is best taught directly rather than through exploration), I believe that Zhang et al. (2022) are not taking into account the relatively low frequency of exploration-based investigations and scientific attitude development activities that take place in science classrooms. Further, in alignment with the arguments of De Jong et al., (2023), the value of combining direct instruction with exploration (inquiry) – based instruction was not considered. De Jong et al. (2023) argue for the merits of both inquiry-based and direct instruction, with a healthy mixture in terms of frequency and quality of both being optimal for development of content knowledge and scientific attitudes along with other reform goals.

I see two prominent issues clouding these debates. The first is concerned with the assumption that researchers made about what goes on (or does not go on) behind closed classroom doors, namely that reform-based instruction over traditional direct instruction is taking place (contrary to other research findings e.g., see Ball et al., 2012; Fensham, 2009; Sykes & Wilson, 2016). The second is concerned with assumptions that student assessments reflect the goals of reform-based science education (when others have argued that they do not and instead focus almost exclusively on content-based standards e.g., Ball et al., 2012; Fensham, 2009; Johnson, 2013). The researchers declaring policy crisis in the face of negative correlations between student achievement and inquiry (Zhang et al., 2022) are perhaps not considering the deeper layers of what reform-based science education asks of educational systems and if reform-based science is being enacted. This is evidenced by Sweller et al. (2024), who go as so far to argue that recent educational research has not focused on the use of direct instruction and thus, it is problematically not explicitly advocated for in government educational policy (standards). Yet, what decades of research shows, is that traditional teaching and learning dominates the science education classroom despite, or in spite of, the aims of reform-based science education that calls for otherwise. In agreement with Johnson (2013) I believe the pressures of standardized assessment accountability has in multiple ways – in practice, research, and policy – resulted in a "perfect storm to derail the ultimate goal of federal policy: educational reform" (p. 712).

In sum, if the evolving aim of science education is to mirror science and to develop scientifically literate critical thinking citizens, then it holds that science education should engage students beyond the *what,* to the many facets of the *how* and *why*. However, moving beyond the basics of content knowledge (the what of science) towards the process (how and why of science) requires educational systems to fully embrace reform-based science education. Implementation efforts of reform-based science can be found throughout the educational landscape as policies, curricula, assessments, resources, and professional development, across all levels of educational systems (e.g., classroom, school, district, state/provincial, national levels). Yet, although various policies for reform-based science have been implemented, studies have suggested that there are significant barriers to their successful enactment (Abrahams & Millar, 2008; Costenson & Lawson, 1986; Fitzgerald et al., 2019; Hume & Coll, 2010; McLeod & Shareski, 2018; Phillips

& Norris, 2009). To better understand these barriers, I will first outline how I understand the differences between implementation and enactment. Following, I will explore variables that impact implementation and enactment of reform-based science education and discuss the role that policy, infrastructure, leadership, and intermediaries play in influencing reform-based science efforts.

Implementation and Enactment of Reform-Based Science Education

Implementation and enactment are neither synonymous nor interchangeable. Despite very important differences, they can be conflated, more often collectively referred to as implementation by researchers, policy makers, leaders, and teachers, alike. To borrow the words of Hammond and Brandt (2004), it is easiest to think of implementation in terms of intent or "what is supposed to be" and enactment as the result or "what is" (p. 16). Enactment was measured by Marco-Bujosa et al., (2017) through observing how close teacher instruction was aligned with the intended outcome of the curriculum (identified as high-enactment and low-enactment). This measure of enactment can also be applied to policy as well – enacted reform-based standards can be identified as how closely instruction mirrors the aims and goals outlined in educational policy. Thus, the intent of a policy and its implementation is distinguished from its enactment. Mirroring this sentiment, Ball et al., (2012) state that "[policy] texts cannot simply be implemented" (p.3) and "enactments are always more than just implementation" (p. 71). Here, I will further define and demarcate implementation and enactment and illustrate how they are interrelated.

Implementation can be defined as the application or adoption of a policy, program, or initiative. Across education research literature, implementation may also be referred to indirectly as policy (Fensham, 2009), abstractions of theory (Ball et al., 2012), or intentions (Ball et al., 2012; Pak et al., 2020) (See Figure 2.4). Implementation endures as text and resides in the spheres of policy, research, and leadership at the government, school district, or school administration level, depending on the policy's nature. Above, I extracted text from government policies and summarized their similarities. These policies are examples of texts that were implemented. Implementation may involve the processes, procedures, expectations, policies, and systems that communicate and disseminate the policy to be adopted or applied, at various levels of authority (Ball et al., 2012; Datnow & Park, 2012; Fensham, 2009; Fullan, 2008). Enactment, by contrast is “always more than just implementation” (Ball et al., 2012, p.71). Across education research, enactment may be indirectly referred to as practice (Fensham, 2009), action (Maguire et al., 2015; Pak et al., 2020), fidelity / alignment (Marco-Bujosa et al., 2017), or experience (Ball et al., 2012) (see Figure 2.4). Thus, enactment can be an ephemeral expression or a sustained action of an implementation effort.

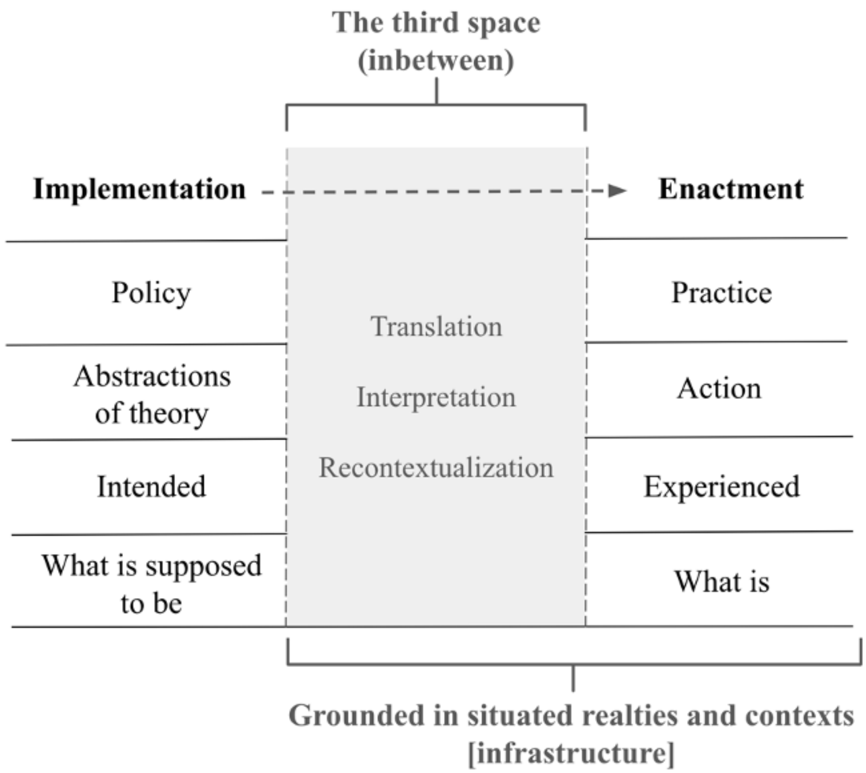
An example of implementation of policy is the publication and dissemination of government educational standards. The educational standards are released by the government, with the expectation that they will be used in the classroom. However, just because a new policy has been disseminated does not mean it will be enacted at all, or enacted in the way it was intended. Thus, “the rich ‘underlife’ and micropolitics of individual schools means that policies will be differently interpreted (or ‘read’), and differently worked into and against current practices, sometimes simultaneously” (Braun et al., 2011, p. 586). In other words, there is more to enactment than mere implementation. This is reflected in policy analysis studies as Marco-Bujosa et al., (2017) argue, enactment is a more fragile and unstable process than is sometimes documented.

Taking a policy from implementation to enactment is a rather complicated and nuanced process (see Figure 2.4). This process is ephemeral in nature and takes place in the "third space between policy and practice" (Ball et al., 2012, p.45), behind closed doors. In other words, the degree to which enactment of a policy, program, or initiative mirrors implementation goals is impacted by the complex interactions of existing variables and contexts of any particular educational system (Ball, 2008; Braun et al., 2011; Majchrzak & Markus, 2013; Sykes & Wilson, 2016).

Given the cacophony of voices, variables, and politics, enactment of a policy is complex and nuanced. It requires stakeholders like teachers and administrators to engage in sense-making not only of the policy itself, but also how that policy fits within their existing cognitive schema and situated contextual realities (Braun et al., 2011; Singh et al., 2013). This entails the stakeholder to engage in the processes of translating, interpreting, and recontextualizing the policy to make sense within their existing professional and epistemological framework (Braun et al., 2011). To enact a policy requires a stakeholder to navigate their existing "contextual dimensions" (Braun et al., 2011, p. 588), situated dimensions (e.g., locale, school histories, intakes and settings), professional dimensions (e.g., values, teacher commitments and experiences, and 'policy management' in schools), material dimensions (e.g. staffing, budget, buildings, technology and infrastructure), and external dimensions (e.g., degree and quality of local authority support, pressures and expectations from broader policy context). Taken together, there are many variables that affect how a policy is enacted, it begs the question as to whether implementation goals are ever realistic or attainable.

Figure 2.4

Implementation, enactment, and the (inbetween) third space



I have made efforts to demonstrate that the relationship between implementation and enactment is complicated and that these complications result from nuanced and manifold interactions between stakeholders as they navigate myriad variables. Just because a policy is being implemented, does not mean that the original implementation goals are achieved. Tensions emerge as stakeholders struggle to make sense of, mediate, and translate policies (implementation) into actionable practice (enactment) amidst interactions and interconnections between diverse actors and the infrastructure of their 'situated realities' (Ball et al., 2012).

Yet, despite its utility for facilitating and fostering sense-making, the 'third space between policy and practice' remains largely understudied. Ball et al., (2012) note that while "a great deal of attention has been given to evaluating how well policies are implemented […] less attention has been paid to understanding and documenting the ways in which schools actually deal with […] policy demands" (p. 142). Moreover, Fensham (2009) identifies how researchers have "maintained a naivete about the politics of science education" and "ignored the interplay between the stakeholders, beyond and in school, who determine the nature of the curriculum for science education and its enacted character" (p. 1078). The concept of the third space, which exists between policy and practice, has resonated with me. Throughout my career, I have acted in spaces that feels in between policy and practice. I have been an interpreter of policy and have enacted policies in my classroom. I also have supported others, in formal and informal leadership roles to do the same. In my efforts with enactment, to the best of my abilities, I have tried to reach the goals laid out by policy. I believe in the work that I have done. But I am faced with the questions: Is it worth the struggle? Can every teacher do it? Was I even successful?

As Ball et al. (2012) suggest, the processes involved in enacting a policy are non-linear and complex, with the bulk of the sense-making processes taking place in this third space, that I so often have felt to have occupied. Here, is where the transition between implementation and enactment takes place. This transition "involves creative processes of interpretation and recontextualisation – that is, the translation of texts into action and the abstractions of policy ideas into contextualised practices" (Ball et al., 2012, p.3). Thus, while implementation is largely limited to leadership, enactment is in the hands of teachers and their direct contacts. The spaces in between can be occupied by many different individuals in many different positions. In the following section, I outline various findings about how reform-based science education practices impact different educational outcomes. The section has been organized into four themes that influence enactment of reform-based science education: Practice, Infrastructure, Leadership, and Intermediaries.

Constituents of Science Education

Practice

How can teaching practice be aligned to reform-based science education goals?

Instructional policy can affect how teachers teach. For this research, I use instructional policy to mean, as defined by Sykes and Wilson (2016), as a "distinctive kind of policy that is intended to exert and direct influence on instructional practice in educational settings, or to offer guidance on the use of new curricular materials" (p. 852). In agreement with Fensham, I believe that effective instructional policy can enable the successful implementation of other policies into practice, only if the policy intrinsically established conditions that enable the enactment of the policy (Fensham, 2009). The difficulty of ensuring the conditions needed for effective instructional practice arises due to the nature of instruction and the 'noisy' landscape in which it is situated (Sykes & Wilson, 2016). Ultimately, I agree with McLeod and Shareski (2018) who argue that if the curricular and instructional policy require teachers to "enable student agency and inquiry, we must enable agency and inquiry for them as well" (p. 23).

Although content cannot be completely separated from practice (Levin, 2008), curriculum documents pay little attention to pedagogical practice. For example, curriculum policies will mention discrete learning goals for students but do not necessarily outline specific pedagogical approaches for teachers (Cohen et al., 2020). Thus, while educational policy dictates the *what* of science education, instructional policies outline the *how*. While curricula and instruction are two sides of the same coin, they are not developed in unison. For example, Fensham (2009) provides an account of how NSF established a centralized curriculum in the 1960s without considering how it would be taken up in the field; "the exciting and expensive development of these new materials for school science thus took place in the absence of any commitment that they would be adopted and used in schools" (Fensham, 2009, p. 1078). Interestingly, a look into the annals of history shows that this trend of funding standards and curriculum development over teacher resources or professional development is not consistent. For example, Welch (1979) found that between 1956 and 1975, over $130,000,000 was "appropriated by the NSF for course improvement projects" whereas $565,000,000 was used to "support various teacher-training activities" (p. 282) focused on the implementation of the new standards. Although more money was spent on curricular development, sustained teacher training requires much more input and dollar comparisons than what is allocated.

Successful enactment of reform-based science policy requires teachers that are engaged in their practice. Teaching practice is affected by teachers' past learning experiences (Bencze & Hodson, 1999), pre-service teacher preparation programs (Kleichmann et al., 2013), and professional development experiences (Penuel et al., 2007). Everyday practice is also heavily influence by structural factors like schedule flexibility (Fitzgerald et al., 2019; Lawson, 2000), competing policy directives (K. Anderson, 2012; Fensham, 2009), the amount of collegial and administrative support (Roehrig & Luft, 2004), student behavior (Lawson, 2000), the quality of instructional resources (Beyer et al., 2009; Powell & Anderson, 2002), and the pressures of standardized assessments (Black, 2001; Fensham & Rennie, 2013; Harlen & Crick, 2003). How schools, districts, and individual teachers use these various factors to facilitate their practice can lead to differences in how reform-based science education goals are met. In the following paragraphs, I will explore how past learning experiences (including pre-service teacher programs), pedagogical content knowledge, and everyday structural factors can influence the goals of reform-based science education.

Teacher educational history impacts individual instructional practices.

If research and policy seek to change instructional practice, it important to start at the beginning with the educational history of teachers. If teachers do not have experience in a particular method of practice, it is more difficult for them to implement this method. I agree with Bencze and Hodson (1999) who argue that it is "absurd to expect teachers to create the necessary experiences for students to develop abilities if they themselves have not had similar experiences" (p. 525). Research shows that teachers have not had exposure to learning experiences that they are expected to create for their own students (Bencze & Hodson, 1999; Coil et al., 2010; Farber, 2003; Taber, 2006). Most teachers' own K-12 and post-secondary experiences involve predominantly traditional, teacher-centered learning (Bencze & Hodson, 1999; Bowen, 2005; Volkmann et al., 2005; Waight & Abd-El-Khalick, 2011). Further, pre-service teacher education is insufficient to address these shortcomings with only one or at best two science-specific pedagogy classes (Akerson et al., 2006; Karras et al., 2015; Kleichmann et al., 2013). Considering the educational histories of teachers it is clear that to enact the goals of reform-based science education requires a different approach since "scientific knowledge cannot be transferred, but must be built up through lived experiences, particularly through participation with others in meaningful activities over time" (Bowen, 2005, p. 109). Through alternative approaches perhaps it is possible to achieve the goals of reform-based science education, including a better understanding of the nature and process of science.

Pedagogical content knowledge impacts individual instructional practices.

While content knowledge (CK), is simply knowledge about the topic being taught, pedagogical content knowledge (PCK) is an understanding of how to best make the subject matter (e.g., science) accessible to students. PCK requires one to have knowledge of student misconceptions and concept-specific teaching approaches and strategies (Shulman, 1986). It has been previous shown that high levels of PCK are essential to support instructional practice that enables successful implementation and management of inquiry and approaches demanded by current science education curriculum and policy (Harris & Rooks, 2010; Hodson & Bencze, 1998; Lawson, 2000; Schraw et al., 2006). Yet despite the necessity of PCK for the effective enactment of reform-based science education, teachers have been consistently found to have low levels of PCK (Abrahams & Millar, 2008; Falk et al., 2008; Farber, 2003; Lederman, 1992; Taber, 2006). For example, to effectively engage students in the process and nature of science, teachers must have PCK beyond the level of teaching concepts and facts. They also must be able to sort through student misconceptions through debate, experimentation, and other minds-on activities.

Everyday classroom realities impact instructional practice.

Even when teachers have been shown to demonstrate high levels of PCK, motivation, abilities, and value for inquiry practices, they struggle with the regular implementation of inquiry approaches to science for a variety of reasons (Fitzgerald et al., 2019; Martell, 2020). For example, Fitzgerald et al., (2019) found that teachers who have identified as "positively inclined" to inquiry pedagogical approaches indicate that barriers to their pedagogical practice include a lack of time, not enough professional development experiences, lack of models and definitions, and a lack of available resources. These findings echo other studies that identified similar barriers (e.g., Costenson & Lawson, 1986). Implementing changes in instructional practice "takes time, requires learning, and must be buffered from distractions, changing priorities, turnover, and other forces" (Sykes & Wilson, 2016, p. 904). If teachers are not given these everyday resources, how then can educators be expected to change their practice?

Infrastructure

What are the infrastructural requirements of reform-based science education?

Like Star & Ruhleder, I take infrastructure to be a "fundamentally relational concept" that "emerges for people in practice, connected to activities and structures" (Star & Ruhleder, 1996, p. 113). Thus, infrastructure encompasses several tangible and non-tangible components including materials, policies, experiences, and structures. Within their definition of infrastructure, Penuel (2019) includes: standards, curriculum, assessments, professional development, instructional techniques, school and district-level policies, school schedules, instructional supports, school routines, and performance evaluations. In addition, I would include science-specific components such as materials, equipment, laboratory space, technical support, including technicians (Beyer et al., 2009; Powell & Anderson, 2002).

Without the appropriate infrastructure, reform-based science educational practices cannot be effectively performed. Infrastructure that is rich, dynamic, multifaceted, organized, and robust provides the necessary conditions for a healthy environment supportive of new initiatives and policies (Fensham, 2009). Appropriate infrastructure can cultivate growth-oriented and trusting learning environments that can contribute to sustainability and scalability of initiatives (Friesen et al., 2016). Infrastructure can also create the conditions needed to support educators in making innovations for organizing learning activities (Penuel, 2019), and help them direct and focus the interpretations of curriculum (Hume & Coll, 2010, p. 45). Finally, infrastructure is important to guide the successful implementation of policy into enactment through practice (Fensham, 2009). What I believe to be the important point here is that infrastructure is an inevitable component of all educational systems that, when appropriately aligned, can help to achieve policy goals. In the next few paragraphs, I will outline a subset of infrastructure components and how they have been (or not) aligned to reform-based science education and its goals.

Curriculum aligned with reform-based science education requires extra support for enactment.

Curriculum policy dictates the *what* of science education. A reform-based science education curriculum will favor engagement in scientific practice and the nature of science over the rote memorization of facts. Developing educational curriculum policy is intensely political and is the subject of much debate (Levin, 2008). Mindful that policy is written in relation to the "best of all possible schools" (Ball et al., 2012, p.3), there is a danger that reform-based science education curricula are not usable by ordinary teachers (Levin, 2008, p. 13). Thus, an oversight of curriculum reform is that typically only the expert and highly effective educators are invited to the table (Ball et al., 2012; Levin, 2008). Even so, a few high quality curricula have been developed in the past decade that could be adopted by schools with the funds to purchase these materials (e.g., Amplify Education, 2019b; Harris et al., 2022; Nilsen et al., 2020). Unfortunately, if curricular adoptions are not aligned with additional school or district level policies and infrastructure, then the overarching reform-based science education goals are not met.

For example, Marco-Bujosa et al. (2017) investigate how teacher-educative materials (i.e., materials used by teachers to learn the goals and lessons in a curriculum) are used by different teachers to facilitate curricular enactment. In this investigation, a curriculum was piloted for three months in a couple schools (five teachers total) and teacher self-efficacy of enactment as well as researcher-assessed enactment were evaluated. The authors found that different teachers used the curriculum for student learning but used the teacher-educative materials provided differently. They concluded that teachers may need more dedicated time to review and engage with the teacher materials to better enact the curriculum in the classroom. In my experience, more professional development centered around curricular enactment would be beneficial. This study found that teachers tend to use teacher learning materials in very individual ways. If teachers use these materials in such different ways, it means it is very difficult if not impossible to design universal educative materials that will result in a more uniform enactment of curricular policy. Thus, although the same materials were provided to teachers, their ability to enact the curriculum was quite different suggesting that other school- or district-wide policies should additionally be deployed to facilitate curricular enactment.

Instructional techniques and evaluation of effective instruction.

How teachers teach affect student outcomes. Traditional teacher-centered teaching methods can be contrasted with student-centered approaches. Reform-based science education advocates for more student-centered approaches as these are thought to facilitate a greater understanding of the processes and practice of science. These approaches have been called by many names, including 'inquiry-based' among others (e.g., Furtak & Penuel, 2019; Osborne, 2019). Furtak et al. (2012) provides a meta-analysis of previously published (1996-2006) inquiry-based science education studies. They show that inquiry-based teaching methods have a positive effect on student learning (at least based on studies that used pre-post surveys and two-group design). Another major finding from this investigation is that teacher-led inquiry had a substantially larger effect size than student-led inquiry activities. Their findings largely focus on the general benefits of inquiry-based methods for teaching science. Why do these studies seem to contradict data from organizations like PISA?

The contradictions between standardized assessment achievements like those reported by PISA (e.g., Cairns & Areepattamannil, 2019; OECD, 2016) and the studies like those reported by Furtak et al. (2012), likely differ because they are measuring different things. Standardized assessments focus mostly on content whereas inquiry-based teaching methods focus on teaching students about the process and nature of science through experience. Inquiry-based approaches and student-centered teaching are much more time consuming than traditional methods resulting in content being cut from the curriculum. For example, some student-centered techniques include constructing knowledge through phenomenon-driven exploration, student-student discourse through debates, designing experiments, and modeling concepts. Each of these activities takes away class time from students learning and memorizing content. Thus, there seems to be a trade-off between engaging in scientific process and learning scientific terminology by rote (De Jong et al., 2023). Because most standardized assessments focus on content rather than the process or nature of science (Fensham, 2009; Johnson, 2013), the benefits of reform-based science education are not easily measured. In fact, district and school pressures are often not aligned with the goals of national reform-based science education (Ball et al., 2012; Fensham, 2009). However, through various policy changes and external supports, district and state/national goals could be more aligned.

Professional development.

One way to influence teaching practice to better enact reform-based science education goals is through professional development. However, just providing professional development is not enough. Roehrig (2023) performed a meta-analysis of 150 papers (spanning 2012-2022) that investigated the effects of professional development on science teaching. They found that there is no one way to do professional development as any one approach didn't have much effect.

Instead, it was only when five or more activities were combined that effects on student outcomes were noticeable. Other studies across disciplines have indicated that coherence across professional development sessions is also important (e.g., Firestone et al., 2005). Thus, if you want to influence teacher practice, the goals must be clear, the interventions must be persistent, and just like when teaching students, it needs to be done in a variety of different ways. Without consistent training, positive learning experiences, and teacher buy-in, teachers will continue to teach in the way they are most comfortable.

For example, Lakshmanan et al. (2011) performed a three-year investigation with 70 teachers demonstrating that a combination of yearly professional development, monthly professional learning community meetings, and persistent observational evaluations, reform-based teacher efficacy can be markedly improved. Thus, through extensive intervention, teacher behavior can be impacted. However, other reports like Johnson (2013) suggest that even the best research-informed professional development strategies will fall short if scaled up in environments where "educational turbulence" exists that prevents high-quality science instruction within a standards-aligned curriculum (Johnson, 2013). In this paper, the author considers high-quality science instruction to be that which assesses student abilities to apply, analyze, synthesize, and evaluate knowledge across disciplines. Though high-quality instruction exists, they lament that critical thinking, problem-solving, communication, and collaboration are rarely assessed. Thus, professional development is only effective if it is aligned broadly with organizational goals as well as student assessments.

And once again we are faced with a dilemma. Reform-based science education requires not only policy and curriculum change, but also a fundamental shift in how science is taught, which requires extensive professional development. Ensuring professional development impacts teacher practice requires major changes in teacher professional development and teaching practice, which requires major input from leadership.

Leadership

How can leadership influence the success of reform-based science education efforts?

Research and policy inform practice, but only through aligned leadership can policy implementation be robustly enacted. Leadership plays a central role in creating and securing the conditions for the "emergence of the as-yet unimagined" (Davis & Sumara, 2008). It is school and district leaders that are responsible for bringing to light the visions of a particular policy or directive. They must create the work environment to effect change. No universal leadership style will work for any individual or any school, but I believe that some combination of transformational leadership (Hallinger, 2003; Leithwood & Sun, 2012), student-centered leadership (Robinson et al., 2008), distributed leadership (Louis et al., 2010; Spillane, 2005), and instructional leadership (Blase & Blase, 2000; Hallinger, 2005) can be beneficial for supporting implementation and enactment of reform-based science. My work has focused on transformational leadership and instructional leadership, which will be briefly expanded upon.

Reform-based science education leadership benefits from leaders that inspire workers to achieve beyond what they thought possible. Because enactment of reform-based science education requires teachers to change and adapt their work habits, inspiring transformational leaders are required. Transformational leadership strategies include shared leadership, empowerment, intellectual stimulation, rewards, and the modeling of values and priorities (Hallinger, 2003). Further, Leithwood and Sun (2012) advocated that these leadership practices increase both the commitment and effort of organizational members towards the achievement of organizational goals. Transformational leaders have the power to foster cultural change, or as Nietzsche refers to as ‘consecrating the spirit’ (Nietzsche, 1872/2016), of reform-based science education in teachers and effect change.

To effect change in teachers, leaders need to be active in and around classrooms to provide direct instructional leadership. Instructional leadership coordinates curriculum, supervises and evaluates instruction, monitors students, protects teacher instructional time, and provides incentives for learners and teachers by modeling values and priorities (Blase & Blase, 2000). It employs more of an individualized control strategy for leading alignment in that it sets “clear, time-based, academically focused goals to get the organization moving in the desired direction through coordinated and organized instruction” (Hallinger, 2003, p. 347). Thus, to provide clear goals for teachers, leadership must provide instructional support to achieve the downstream student-centered goals of reform-based science education.

Leadership requires micro-level policies to be aligned with macro-level goals.

Unfortunately, national policies and goals for reform-based science education are often in direct conflict with school and district level policies (Ball et al., 2012; Majchrzak & Markus, 2013). These tensions can only be mitigated by a complete overhaul of how leaders lead. For example, a study by Johnson (2013) investigated the impacts of high-quality professional development on teacher quality over a three-year period. Their investigation highlighted a number of issues that teachers reported as limiting their progress such as mandated accountability, funding limitations, mandated curriculum and instruction, personnel, scheduling issues, learning environment quality, and lack of community engagement. Most of these issues are problems with school or district level policies and environments, which can only be mitigated by school and district leaders. Thus, even with many hours of professional development and other programs that greatly increased teacher quality, major limitations to robust enactment persisted.

Leadership can facilitate better alignment between enactment and intent of implementation.

As I have described above, the intent of an implemented policy does not always align with the realities of classroom enactment. I believe that robust enactment requires leadership involvement in the day-to-day workings of classroom interactions. Pak et al. (2020) investigated how teacher practice aligned with policy standards across four districts using interviews from all district positions. Although this investigation was not directly related to science education, it determined how leadership can impact enactment of curriculum reform. In particular, this investigation differentiated leadership challenges between technical challenges of implementation from the adaptive challenges of enactment (Pak et al., 2020). Technical challenges would include determining curricular alignment, or said another way, the determination of the curriculum, how it aligns with policy goals, and what resources to use. Conversely, adaptive leadership challenges include learning how to get teachers to use curriculum materials effectively. This, to my mind, is an enactment problem because adaptive leadership challenges require leaders and stakeholders to collaboratively experiment with new procedures, norms, or beliefs to address problems of practice with unknown solutions. Unfortunately, because a significant proportion of educational reform literature deals with technical problems instead of adaptive problems very little reports can be consulted to help determine the leadership needs of reform-based science education. More often than not, it seems, that the goals of reform-based science education fall outside the sphere of school leadership and instead into the hands of a few ambitious teachers that turn to intermediaries to help enact reform-based goals.

Intermediaries

Many reform-based science education goals are supported by intermediaries.

Lending the definition of Honig (2004), intermediaries are organizations and/or individuals that "operate between policymakers and implementers to affect changes in roles and practices for both parties" (p. 66). For the purposes of my research, I categorize the following as intermediaries, based on Honig's definition: philanthropic foundations, science outreach centers, and knowledge brokers. (Ball, 2008; Center on Budget and Policy Priorities, 2015; Grantmakers for Education, 2019; Malin et al., 2020; McWhorter et al., 2020; Scott et al., 2018). The role that intermediaries play in implementing and supporting the enactment of reform-based science is explored in the following section. Returning to the conceptual framework of the study (Figure 2.2) and the relational framework of stakeholders (Figure 2.3), intermediaries are integral elements, but largely act behind the scenes and are hidden as they work in between stakeholders of science education systems. In the following section I will outline categories of intermediaries based on whether they are internal or external to educational organizations, or whether they are one-way or two-way communicators of knowledge.

Increasingly, intermediaries are entering the educational landscape in response to the reality that "district central offices and schools have faced demands that far exceed their traditional capacity for action" (Honig, 2004, p. 66). The ubiquitous prevalence of intermediaries coupled with the needs of the educational systems they serve, well-positioned intermediaries have the potential to substantially influence and shape the content and delivery of education and education policy (Ball, 2008; Scott et al., 2018). Yet, however well-intentioned and well-positioned intermediaries might be, they have come to be defined as a "motley collection of organizations" (Honig, 2004, p. 66) that at times produce "crowded, complex, and varied efforts" (Malin et al., 2020, p. 14). This is evidenced by the immense landscape of current resources and artifacts of previously funded projects that are at the disposal of educators to use (or not) (see Table A2 in Appendix). I will next describe the three kinds of intermediaries: philanthropic foundations, outreach programs, and knowledge brokers.

One-way vs. two-way communication with intermediaries: towards robust enactment.

Intermediaries engage with schools or districts either in one-way or two-way communication. One-way communication occurs when knowledge is communicated from intermediary to educators, without much communication in the reverse direction. One-way communication is more prevalent as evidenced by the various philanthropic organizations and outreach that develop programs to enhance teaching and learning opportunities for educators and their students by bridging the gap that is left unserved by state funding (Center on Budget and Policy Priorities, 2015; Fitzgerald et al., 2019; Grantmakers for Education, 2019). Through their gifts, philanthropic foundations can nucleate and galvanize novel partnerships between educators, the scientific community, community agencies, and social programs. Resultantly, these partnerships can provide opportunities for students and educators to engage with science more deeply and meaningfully through experiences and activities that would not otherwise be feasible (Fensham, 2009; Grantmakers for Education, 2019). Science education outreach programs can be independent not-for-profit entities (e.g., Let's Talk Science), university-affiliated (e.g., Center for Mathematics, Science, Technology, and Engineering; Pathfinder Center; Biosciences Outreach), scientific societies (e.g., Royal Society for Chemistry, Society for

General Microbiology), or a vestige of a science research grant (e.g., broader impacts, social engagement, community outreach). Funding for these programs can come from independent donors, general university funds, scientific grants, or philanthropic grants. Further, scientists are being charged with increasing responsibilities to incorporate science outreach, support, funding, etc. to the local community and beyond – both as a requirement for 'service' to support tenure bids, but also in scientific grants (e.g., see National Science Foundation's "Broader Impacts"). Regardless of origin, science education outreach intermediaries seek to fill the gap that is left between the needs of school systems and government-provided resources for meaningful and authentic science experiences (Honig, 2004). Importantly, both philanthropic and outreach programs develop extra-curricular supplements to what is being delivered in classrooms and their communication is one-way.

Knowledge brokers are a kind of intermediary that function differently than the previous intermediaries discussed. Perhaps the most important distinction is that knowledge brokers generally employ two-way communication. Two-way communication enables educators to communicate their needs and challenges such that intermediaries can better support educator needs (Malin et al., 2020). Two-way communication can be used to strategically bring the priorities, beliefs, and capacities of stakeholders in educational systems into closer alignment (Malin & Brown, 2020; McWhorter et al., 2020) while remaining focused on measures that are practically applicable and coherent with professional realities of educators (Malin et al., 2020).

The act of knowledge brokering takes place "in-between people, departments, processes, or organizations" (Cooper et al., 2020, p. 90) and involves processes of translation, coordination, and alignment between perspectives (Meyer, 2010). Using these key features, knowledge brokers can be distinguished from other intermediaries by applying the framework of Ward (2017), to evaluate and categorize the processes and outcomes of the organization or individual (Cooper, 2014; Malin et al., 2018). For example, because stakeholders speak multiple institutional languages and are both motivated and bounded by priorities and beliefs unique to their context, they take on the role, of what Ball (2008) refers to as nodal actors in networks, to assume a "whole system perspective to explore the relationships (or lack thereof) between diverse stakeholders at different areas of the system" (Cooper et al., 2020, p. 92). This enables the creation of spaces for all stakeholders to honestly assess "individual and organizational readiness and commitment to work together in new ways" (McWhorter et al., 2020, p. 52) in order to bridge gaps, synergize ideas and catalyze efforts to support the needs of educators and schools. The individualized approach of knowledge brokers makes them, in my opinion, excellent entities that can support and maintain change in educational systems.

While philanthropic organizations and outreach programs are by definition external to school systems, knowledge brokers can be internal or external intermediaries. Internal intermediaries are employed directly by schools or districts, not by other organizations and are "uniquely situated within their organizations" (Farley-Ripple & Grajeda, 2020, p. 81) to build capacity of educators tasked with implementing (leaders) and enacting (teachers) reform-based science (Abbott et al., 2023; Whitworth et al., 2017). Internal intermediaries, like instructional coaches or disciplinary strategists, however, are often overlooked (Farley-Ripple & Grajeda, 2020) and overburdened (Whitworth et al., 2017). When equipped appropriately, internal intermediaries can support more robust enactments that can better align with implementation goals.

The narrow reach of external intermediaries limits their longstanding effects while internal intermediaries are limited by their lack of institutional power.

Although reform-based science education goals are supported by intermediaries, their impact is not assessed by standardized assessments and therefore not recorded in any standardized or robust way. For example, Laursen et al. (2007) engaged in outreach with K-12 science classrooms whereby they led inquiry-based, hands-on science activities. They reported that activities led to teacher-perceptions of enhanced interest and engagement in science, and a better understanding of science and its relevance for students. However, there was no discussion on whether after the intervention, students agreed with the teacher-reported observations and further, if these experiences were sustained beyond the intervention.

Furthermore, not every classroom or student has the opportunity to engage in outreach activities. While there might be enough interest from scientists to engage in more outreach activities, significant barriers such as lack of time and funding, limit scientist involvement in outreach (Woitowich et al., 2022). Similarly, teachers struggle to find the time, effort, or connections to engage with and incorporate outreach into their schedules (Friedman, 2012). The burden of both delivering and participating in outreach is therefore likely shouldered by a minority of individuals. Thus, outreach is inaccessible for many classrooms. Without outreach, teachers must meet reform-based science education goals using other means.

If reform-based science education policies are to be taken seriously, measures to achieve their goals must be put in place. Although engaging in outreach can reach some of the goals of reform-based science education, there are too few outreach opportunities and not enough time available. Thus, although intermediaries could represent a means for more effective enactment of reform-based science education goals, traditional educational structures continue to limit their effectiveness.

Inbetween

The first of my three research aims was to explore the inbetween, or said another way, the boundaries (Malin & Brown, 2020) and third spaces between policy and practice (Ball et al., 2012) of science education, to capture the interplay between stakeholders (Fensham, 2009) and provide candid insight into the 'what is' (Hammond & Brandt, 2004) of science education systems (see page 4). The context in which this research was situated, the third space, or, inbetween, was outlined in *Chapter One*: *Introduction*, emerged as a common theme throughout the data presented in *Chapter Four: Results*, and subsequently explored in in *Chapter Five: Discussion*.

In the previous section, *Intermediaries* (p. 45-49), the burgeoning field of intermediaries and knowledge brokers, along with their role in facilitating interactions and knowledge translation in the spaces in-between educational stakeholders was explored. But what does 'in-between' mean in regards to space and time, and where can it be found? For my research, I define inbetween (referred elsewhere as in-between) as existing in both time and space as a phenomenon that emerges between policy and practice; teachers and administrators; district and schools; implementation and enactment. Inspired by the grammatical creativity of Giesen (2012), I intentionally use the word inbetween (as opposed to in-between) throughout my dissertation in an effort to advocate for awareness and acknowledgement of a non-institutionalized and relatively lesser studied space and phenomenon.

The ambiguous, amorphic, and ephemeral realm of the inbetween is a phenomenon more commonly explored by artists and authors (e.g., *inbetweenness* by Igloliorte (2018) and *Stages on Life's Way* by Kierkegaard (1845/1991) while having much less visibility within the dominant discourse of academia (Brighenti, 2013; Giesen, 2012). The field of cultural sociology has seen some contributions to the named phenomenon of inbetween (in-between). Three discrete works by scholars who have brought visibility to this phenomenon are presented below as examples pertinent to my research. I highlight how inbetweenness can be applied to an open 'space' (or an interstice) but also applied to a positioning within that space (taking up work in that space either with intentionality or by accident). For my research, I employ both of these concepts of inbetween: there is a space inbetween implementation and enactment, and one can position oneself in that inbetween. In the following, I will explicate the phenomenon of inbetween as both space and positioning within that space as it pertains to implementation and enactment of reform-based science education. Below I briefly explore select features of inbetween studied elsewhere as they apply to my research: invisible unclassifiable remainders (Bateson, 1994; Giesen, 2012); interstitial phenomena (Brighenti, 2013); and the emergent, recursive, translative, and multiplex nature of inbetween spaces (Ollila and Yström, 2020).

Inbetween constitutes the invisible unclassifiable remainders

In the book chapter, *Inbetweenness and Ambivalence*, Giesen (2012) explores various phenomenon of inbetweenness through examples such as trash, victims, monsters, and heroes. They define inbetween as an "extraordinary space in between the opposites" that "transcends the successful ordering and splitting of the world into neat binaries" (Giesen, 2012, p. 788). This "unclassifiable remainder", Giesen (2012) argues, is "essential for the construction of culture" (p. 788) and "drives the process of social communication" (p.789). Yet despite the utility, it is "disregarded, invisibilized, and silenced in the order that is generated by classification" (p. 793). This sentiment echoes that of Bateson (1994) who contends that "the webs of perception and meaning that human beings construct tend toward integration. What does not fit is likely to remain invisible, unnamed, unattended to" (p.57). I interpret both Bateson and Giesen as using inbetweenness as an evasion of binaries and classification in the cultural sociological sense. Similarly, in my research, the unclassifiable remainder is that which transcends the demarcation of implementation and enactment, or boundaries between stakeholders. As I outline elsewhere in this research and as shared by other scholars, the inbetween of science education remains largely unstudied.

Inbetween is an interstitial phenomenon

The 'interstice' or 'in-between' of urban space, such as vacant lots, wastelands, and planned urban community spaces, is explored through Brighenti's introduction to their edited book, *Urban Interstices: The Aesthetics and the Politics of the In-between*. In-between for Brighenti, is "not simply a physical space, but very much a phenomenon 'on the ground', a 'happening', a 'combination' or an 'encounter' (2013, p. xviii). Thus, they contend interstices "can be found or produced at any place and time" (p.xviii) to create possibility through "fluid spatiality by encounters in loose space (p.xix). Similarly in my research, I experienced inbetween as encounters or interactions between stakeholders and infrastructure that occupy dimensions of both time and space. Brighenti contrasts inbetween spaces with those that are more institutionalized, stating the latter is "endowed with a stronger identity, and therefore more recognizable or typical" (2013, p. xvi). Further, they explain the impact of this contrast: "issues of visibility and invisibility are always ambiguously played out in between the denial of recognition and the possibility of resistance" (p. xix). As a teacher, researcher, and leader I experienced the 'denial of recognition' and the 'possibility of resistance' in and around science education systems – both from outside and within institutionalized spaces. In my research, I respond to previous calls (e.g., Ball et al., 2012; Fensham, 2009; Hammond & Brandt, 2004) to explore how this tension manifests in the interstitial spaces between policy and practice, namely, how institutionalized policies and stakeholder responses to policies are negotiated (and subsequently accepted, denied, or resisted) in private and complexly dynamic spaces.

Inbetween spaces are emergent, recursive, translative, and multiplex

In-between spaces of open laboratories are discussed in the book chapter of Ollila and Yström (2020), *Open Laboratories as "In-between Spaces".* Through this lens they define an in-between space as a "space in-between actants (including both individuals and objects) with its own character and value. It is a space which is "both-and" as well as "neither- nor". It is a space of transformation, embracing disorder and ambiguity with the potential of destruction as well as becoming." (p.205). Further, Ollila and Yström describe how collaborating and working in an "in-between space is to let go of fixed ideas of 'how things should be' and 'how things should work' " (Ollila & Yström, 2020, p.211). Following, their work identifies four features of 'in-between space' in that it must be: in becoming, recursive, translative, and multiplex.

Throughout my research, I refer to and revisit the nature of these inbetween spaces in relation to the positioning of constituents (e.g., internal intermediaries) and the dynamic actions taking place in the inbetween spaces of science education. The four features of "in-between space" described by (Ollila & Yström, 2020) that are relevant to understanding the nature of these spaces in science education for the purposes of my research are:

- Emergent in that they are 'in becoming' through continuous evolution resulting from interaction and learning (p.207).
- Recursive as "the space is what shapes action and interaction, it is also reshaped by actions and interactions" (p. 208).

- Translative, offering opportunities for translation and where "hidden agency can become present" (p.209).
- Multiplex in that the inbetween spaces embrace and are constituted by multiplicity where individuals are able to "keep their multiple identities separate but knowing when to use them" (p. 205).

Throughout my research, I explore the concept of inbetween and inbetweenness in science education. I borrow from, and build on, interrelated concepts from cultural sociology (Giesen, 2012), urban sociology (Brighenti, 2013), educational policy (Ball et al., 2012), anthropology (Bateson, 1994), and behavioral science and design (Ollila & Yström, 2020). In this dissertation I use inbetween to refer to the spaces left unoccupied by the systemic structures of traditional science education systems but that can be occupied by choice or modifications that lead to new structures within existing systems. Thus, I define inbetween as a phenomenon that takes place in both space and time between stakeholders, infrastructure, practice, and policy – or what previously has been referred to as the third space by Ball et al., (2012) and unproductive boundaries by Malin and Brown (2020).

I also use inbetween to refer to a positioning as a concept or stance. Inbetween is amorphic and shifts dynamically in response to the changing needs, gaps, and interactions of science education constituents. To lend the words of Brighenti, in-between is "not simply a physical space, but very much a phenomenon 'on the ground', a 'happening', a 'combination' or an 'encounter' (2013, p. xviii). Thus, I believe that the interstitial spaces of inbetween offers possibility through dynamicity by fostering interactions and responding to the "interplay between stakeholders" (Fensham, 2009, p.1028). By positioning oneself in the inbetween, access to "hidden agency" (Ollila & Yström, 2020) may be able to contribute knowledge by revealing how “schools actually deal with policy” (Ball, 2012, p.142), or said another way, the “ ‘what is’ in contrast to ‘what is supposed to be’ ” (Hammond & Brandt, 2004, p.16) of science education systems.

Summary

Within Chapter Two, I provided a definition for reform-based science education and placed it within my conceptual framework of science education. I demarcated the various constituents of science education and outlined how reform-based science education policies might be enacted differently due to a variety of factors. By articulating the necessity of policy-aligned practice and infrastructure, I argued that through ample infrastructure, effective leadership, and with the help of internal intermediaries, robust enactment that leads towards the goals of reform-based science education can be better achieved. To conclude, I wish to return to the question of how systems assess successes and failures of enacting reform-based science education.

The implemented reform-based science education policies clearly value embedding 21st century science practices into the classroom. However, instructional policies, curriculum, infrastructure, teaching practices, and student assessments are often not explicitly aligned to these reform policies. If the goals of reform-based science are to be met, infrastructure, instructional policies, and teaching and assessment approaches must be modified to align to these goals. If these changes are not made, how can one assess the successes and failures of the implemented policies if the enactment is failed? In the following chapter, I outline my approaches to autoethnography to investigate what insights can be gained from my experiences in enacting reform-based science education policies.

CHAPTER THREE: METHODOLOGY AND METHOD

In this chapter, I outline the autoethnographic methodology and method used to probe and address the research question of this study: *What insights can be gained from autoethnographic exploration of my experiences with reform-based science education systems in Canada, England, and the United States?* The data of this study was collected through autoethnographic means from my personal experiences in and around education research, teaching, and leadership over ten years (2012-2023) from three countries (Canada, England, the United States). This chapter explains how I used a layered approach to autoethnography in the analytic tradition (Anderson, 2006; Chang, 2008) to analyze narrative, internal, and external data to investigate the phenomena of this study, my experiences with reform-based science enactment (what happens in the classroom) and implementation (what policy states should happen in the classroom).

Autoethnography is a method that "seeks to describe and systematically analyze (graphy) personal experience (auto) in order to understand cultural experience (ethno)" (Ellis et al., 2011, p. 273). Autoethnographic methods exist on a spectrum with evocative autoethnography on one end and analytic ethnography on the other (Sherick & Pennington, 2017). In this chapter, I position my research method within this continuum and explore the controversies surrounding analytical approaches to autoethnography. Further, I provide a rationale for how and why I used this method to address my research aims by engaging with the literature. Following this, the framework I used for layered autoethnographic data collection, analysis, interpretation, and management in this study is presented, with each framework element explored thereafter. Finally, ethical considerations and the trustworthiness, limitations, and delimitations for this research are identified.

Research Context

Research Setting

This research is situated in an organic collection of cross-cultural personal experiences collected over a span of ten years (2012-2023). Data for this study was collected from my recollection of experiences implementing and enacting reform-based science as a teacher, researcher, and leader, in four discrete locations: Western Canada (Alberta), South West of England (Devon), Eastern Canada (Nova Scotia), and the Desert Southwest of the United States (Arizona). Preliminary data (my experiences) were collected as a participant observer from places otherwise inaccessible to traditional research methods that include, but are not limited to: classroom closets and cupboards, pubs/bars, behind closed classroom doors, staff rooms/teacher lounges, offices, and school hallways.

Research Participant

The primary research participant for this autoethnographic study, is me, Alicia Baier Wideman. Data collected for this autoethnography included memories and artifacts from my personal experiences implementing and enacting reform-based science education over the past ten years (2012-2023), conversations and communications (written and verbal), official documents, and academic literature. Unavoidably, my personal narratives have included others. I have removed identifiers and descriptors, my memories of their stories and/or experiences with them have been shared in my research.

I am a white Canadian citizen born and raised in a heteronormative and traditional Catholic family in a small city in Alberta, Canada. As a child I was always interested in exploring, but was largely disinterested in much of my traditional (e.g., rote memorization, teacher-centered) educational experiences. I was a natural explorer of the outdoors and was happy to be left alone to peruse an encyclopedia or to be shown new things like a microscope at my mom's work. In my Bachelor's of Science, I embraced interdisciplinary inquiry at my liberal arts institution through experiential learning in outdoor education and engaging in individual research projects in philosophy, ecology, and cell biology. In my Master's of Science research, I developed a novel research project to study signal transduction pathways to determine the role of GTPases in regulating mast cell exocytosis (Baier et al., 2014). In my Bachelor's of Education, I conducted two elective independent research courses reviewing literature on inquiry-based/reform-based science education. In my Doctor of Education research, I grappled with various education research methods. As a teacher I strove to provide student-centered, hands-on, minds-on, discourse-rich, and authentic science experiences to my students. As a university research coordinator and school district science strategist, I investigated science education professional development and capacity building (Baier Wideman & Hale, 2020 and Abbott et al., 2023, respectively).

My experiences in and around secondary science education include:

- Two years of teaching university biology labs in Alberta, Canada.
- Six months of teaching Grade 7-9 Science in Alberta, Canada.
- Three years of teaching Year 7-13 Science in Devon, England.
- One and a half years of teaching Grade 7-12 l students in Nova Scotia, Canada.
- Five years of researching and leading in Arizona, United States: One year at an R-1 university science outreach center and four years at a K-8 school district.

Woven throughout these experiences in and around science education, are my interactions with education research methods, university outreach centers, and efforts to enact research-based pedagogy. In sum, these educational experiences listed above are the lived experiences from which the autoethnographic narratives were drawn.

Autoethnography as Method

In this section I introduce autoethnography and outline the continuum of traditions from evocative to analytic. I also explore the controversies around layered and analytical approaches to autoethnography, my chosen method. The purpose of providing a brief history into the controversial continuum of autoethnography is two-fold. First, to convince the reader that what I am doing, is indeed, autoethnography. Second, to position my layered analytic approach to autoethnography along the continuum to provide a rationale for how and why I used this method to address my research aims. Following, I provide a methodological framework to describe how I used strategies from Chang's layered autoethnographic approach for data collection, analysis, interpretation, and management. Concluding this section are the ethical considerations taken and the trustworthiness, limitations, and delimitations of this research.

A Brief History of Autoethnography: A Controversial Continuum

The following section provides a brief history of autoethnography from its conception in the 1960s/70s to present day. I detail the debates and controversies surrounding the spectrum of approaches to autoethnography, focusing on analytic approaches to autoethnography. The purpose of this section is to clarify the breadth of approaches to autoethnography that exist and to situate the analytic layered approach to autoethnography I used within this continuum, in response to tensions I have experienced pursuing less traditional forms of autoethnography on the analytic end of the spectrum.

Autoethnography is a relatively young method in the social sciences, the roots of which can be traced back to anthropological and ethnographic traditions situated in self-observant research (Hayano, 1979). While the 1960s and the 1970s witnessed examples of social scientists experimenting with self-observation in ethnographic and anthropological study, autoethnography was first used in 1966 by Firth, and later demarcated and described in 1979 by cultural anthropologist, Hayano from a realist ethnographic stance. In this seminal work, Hayano was concerned with opening a dialogue about "auto-ethnography" – in regard to "how anthropologists conduct and write ethnographies of their 'own people'; the problems of methodology and theory associated with this approach; and whether anthropology can profit from these exercises" (Hayano, 1979, p. 99). These three tenets are very much still considered, explored, and debated amongst those interested in participant-observation of their 'own people', as evidenced by the development and expansion of the field of autoethnography encompassing a variety of approaches ranging from evocative (e.g., Ellis & Bochner, 2000) to analytical (e.g., Anderson, 2006) and everything in between (e.g., see Sherick and Pennington (2017) for a brief overview of twenty-two types of autoethnography).

Since its conception in the 1970s, autoethnography has developed and grown into a rather diverse field that has not only expanded research horizons within the field of autoethnography itself, but also within existing traditional social science disciplines. This expansion has brought on resistance and criticism from fields outside autoethnography for being "either too artful and not scientific, or too scientific and not sufficiently artful" (Ellis et al., 2011). Regardless of the external criticism, the incidence of autoethnographic research has substantially increased within traditional social science disciplines of education, sociology, and anthropology (Chang, 2022). However, this increase in incidence of breadth of applications in various fields has not been without controversy and resistance to newcomers to autoethnography attempting it in their own academic fields (for example, in ethnography see Anderson (2006), in education, see Eisenbach (2016), and in science education see Bazzul and Siry (2019); Brandt and Carlone (2012); Hammond and Brandt (2004); Riggs Stapleton (2019)). This resistance, or gatekeeping bias, can be made visible when applying the search criteria by Medina-Jerez (2018) to search for "autoethnographic research" or "autoethnography" from a few journals of science education research with higher impact factors (e.g., Science Education, International Journal of Science Education, Research in Science Education, Studies in Science Education, Journal of Science Education and Technology). I obtained a "0 results found" error message in my attempts to identify preliminary research trends of autoethnographic nature in high profile science education journals.

With at least twenty-two types of autoethnography it is unsurprising that there exists a history of fevered disagreement and debate about what does and does not constitute autoethnography. Following the work of Hayano (1979) that originated in the anthropological sphere of realist ethnography, autoethnography took a turn from more analytical to evocative traditions with the emergence of the prominent works of Ellis, Bochner, Adams, and Holman Jones (e.g., see reviews of these works found in Ellis et al., 2011; Ellis and Bochner, 2000; Holman Jones et al., 2013) which evidently shifted the dominant discourse of what has become canonical autoethnography (Anderson, 2006).

The (re-)emergence of analytical approaches to autoethnography (e.g., Anderson, 2006; Chang, 2008) brought about a considerable amount of conflict and disagreement within the field from autoethnographers of the evocative tradition (e.g., Charmaz, 2006; Denzin, 2006; Ellis & Bochner, 2006; Ellis, 2009). The conflict is largely centered around the disagreement of individuals who represent opposite sides of the autoethnographic continuum, with canonical (evocative) autoethnography on one end and analytic autoethnography on the other. The focus of this conflict is the divergence of 'analytical' from 'evocative' autoethnography: the latter of which solely relies on personal evocative narrative data, and the former which shifts to also include external data from others (e.g., observation, informal interviews, official documents, and artifacts). This has led to a polarization between the two camps. Burnier (2006) articulates the tensions and resulting dangers of demarcating these approaches as binaries that may lead to reinscribing the gendered feminine/masculine dichotomies of "heart/mind, emotional/rational, literary-poetic/analytical, personal/scholarly, descriptive/theoretical" (p. 416) within autoethnography. This tension can be felt through scholarly debate between the two 'camps'.

This debate is well captured in a 2006 issue of the *Journal of Contemporary Ethnography*, which focused on Anderson's introduction of analytic autoethnography, and the response from the members of the autoethnography community. In this issue, Denzin (2006) shows the challenges of using one term to represent many interpretations by illuminating the differences in definitions by researchers in the field. Charmaz (2006) speaks to the power of names when defining and delineating the what, how, and why of autoethnography. These are important considerations in light of the efforts of Anderson (2006) to expand the field of what constitutes autoethnography. Anderson (2006) attempts to break into the realm of autoethnographic research using methods that do not solely rely on evocative personal narratives, arguing that "evocative or emotional autoethnography may have unintended consequences of eclipsing other visions of what autoethnography can be and of obscuring the ways in which it may fit productively in other traditions of social inquiry" (p.374).

Anderson defines the term, analytic autoethnography, to describe research in which the researcher is: “a full member in the research group or setting, visible as such a member in published texts, and committed to developing theoretical understandings of broader social phenomenon” (p.375). In contrast, Ellis et al., (2011), define autoethnography as an “approach to research and writing that seeks to describe and systematically analyze (graphy) personal experience (auto) in order to understand cultural experience (ethno)” (p.273). Further, Ellis et al., (2011) state that autoethnographies should be “thick descriptions of personal and interpersonal experience” (p.277) in which vulnerability is embraced to produce evocative narratives of these experiences. The prominent differences distinguishing the evocative and the analytical camps is the inclusion of other sources than just the self in narratives and the generalizability of findings to contribute to theory about broader social phenomenon characteristic of analytical approaches to autoethnography. Ultimately, this tension is best encapsulated by the following; “the definitive feature of analytic autoethnography is this value-added quality of not only truthfully rendering the social world under investigation but also transcending that world” to provide insight into broader cultural phenomenon (Anderson, 2006, p.388).

The alterations proposed by analytic approaches to autoethnography were not welcomed by the evocative camp. Denzin (2006) claimed that Anderson’s analytic ethnography is a case of “déjà vu” that stirs up old tensions with the ‘Chicago School’, claiming that analytic and ‘traditional’ evocative ethnography are as similar as “apples to oranges” (p.420). Ellis and Bochner (2006) suggested their review of Anderson’s work is an “autopsy”. They stated that what Anderson does “isn’t autoethnography” (p. 432), that at the very best, is “aloof autoethnography” (p. 436), ending their response questioning themselves “Why does (Anderson) want to call this autoethnography? It’s just another genre of realist ethnography” (p.432).

Further, Burnier (2006) shares their fear that analytic autoethnography is "too much an attempt to contain, limit, and silence the personal, or the self, in the research context" (p.417). The defensiveness against the analytic tradition is understandable, considering the concerns of the researchers belonging to the evocative tradition of autoethnography for they have "waited for many years for the scholarly space to be opened for the personal" (p.417). Burnier (2006) articulates fears that perhaps others refuse to utter: that "analytic autoethnography will, with the full weight of traditional social scientific qualitative inquiry behind it, eventually eclipse evocative autoethnography" (p. 417). Yet, in response to these criticisms, Anderson (2006b) contends that space must be made for other variants of autoethnographic practices to allow for a "broader potential range of cognitive, emotional, and behavioral orientations within the social phenomenon a researcher is seeking to understand" (p.456).

This debate between the polarized ends of the autoethnographic spectrum did not fade, remaining raw as ever when Chang came out with their book, *Autoethnography as Method*, which explicated a method for a 'layered approach' to autoethnography, in 2008. Chang offers a systematic approach to autoethnography that employs multiple data sources, from both internal and external sources to explore the intersection of "the subjectivity of the inner world with the objectivity of the outer world" as participant observer (Chang, 2008, p. 110). The purpose of using external data in addition to personal narratives, Chang states is to "confirm, complement, or reject introspectively generated data" (2008, p. 104). This approach is coherent with the desire to offer insight into the larger cultural phenomenon of which the autoethnographer is studying. Aware of the heated autoethnography debate that surfaced in 2006, Chang clarifies their interpretation of what they consider autoethnography to be and how to go about doing that type of autoethnography: "The autoethnography I promote in this book combines cultural analysis and interpretation with narrative details. It follows the anthropological and social scientific inquiry approach rather than descriptive or performative storytelling. That is, I expect the stories of autoethnographers to be reflected upon, analyzed, and interpreted within their broader sociocultural context" (2008, p. 46). The ultimate goal of autoethnography for Chang, akin to Anderson, is "cultural understanding underlying autobiographical experiences" (2008, p.49) to "expand understanding of social phenomenon" (Chang, 2013, p. 108).

Although Chang's layered approach to autoethnography was moderate compared to Anderson's analytic autoethnography, Ellis (2009) remained concerned by it. First, while Ellis identifies that Chang "emphasizes cultural understanding a major task of autoethnography" (p. 360), they accuse this approach as one that "privileges theoretical understanding of broader social phenomenon over the concrete understanding and theorizing that can be evoked from personal storytelling" (Ellis, 2009, p. 360). Following from this, Ellis admits that "I cannot find the heart and soul of autoethnography in this book. From my perspective, you can't have autoethnography without heart and soul." (p.362). Echoing the words of Burnier (2006), Ellis states that "I don't want autoethnography to be tamed and ritualized in the way that Chang is suggesting… I need the researcher to be impassioned and embodied, vulnerable and intimate, and the stories to be evocative, dramatic, engaging, with concrete layered details, and when the topic calls for it, even heart-breaking." (p. 363). Ellis concludes their review of Chang's book by acknowledging that "this book has made me ponder the past, present, and future of autoethnography. It has made me think of the politics of inclusion and exclusion, and the power of naming things" (p.363). Yet, what Ellis fails to realize, is that they have flexed their own power and politics over naming things – the very thing they accused others of doing.

The criticism Anderson faced in 2006 for their work on analytic autoethnography mirrors the criticism Chang faced in 2008 for their work on a layered approach to autoethnography. In both cases, Ellis speaks with authority using terms that suggest 'exclusion' and their desire to 'hold the power of naming things' – criticisms that Ellis (2009) directed at Chang, but are also applicable to Anderson's 2006 work. Ellis' statement; "It has made me think of the politics of inclusion and exclusion, and the power of naming things" (2009, p.363) underpins the very nature of what Ellis is proposing, that the field of autoethnography exclude Chang's layered approach to autoethnography and Anderson's analytic autoethnography as method because they are not evocative enough, do not solely rely on narrative, and offer insight into broader social phenomenon. This sentiment is also echoed in Anderson's response to the criticisms they faced, arguing that Ellis and Bochner have claimed "sovereign ownership" over the term autoethnography by "redefining the term to apply exclusively to work that conforms to their criteria for evocative autoethnography" (Anderson, 2006, p. 455).

As it currently stands, the overt tension has diminished to a point where it appears the two camps have come together through a hemming in of compromise, that indeed, there is room for both traditions within the field of autoethnography and that both can exist without the exclusion of the other (Anderson & Glass-Coffin, 2013; Chang, 2013; Holman Jones et al., 2013). Holman Jones, Adams, and Ellis offer an olive branch to the analytical end of the spectrum in the introduction they wrote for the 2013 Handbook of Autoethnography in which they state that the work autoethnographers do "ranges from including personal experience within an otherwise traditional social scientific analysis (Anderson, 2006; Chang, 2008) to the presentation of aesthetic projects – poetry, prose, films, dance, photographic essays, and performances – as autoethnographic research" (p. 22). Likewise, Anderson and Glass-Coffin

(2013) offer an attempt to define autoethnography that is “panoramic rather than partisan” (p.58), wherein they acknowledge that “autoethnographic inquiry is shaped not just by scholarly traditions, but also by life and career trajectories of individual scholars” (p.58). To that end, Anderson shares that they have come to be “convinced that the modes and key features of autoethnographic inquiry are similar no matter where along the spectrum, from ‘evocative’ to ‘analytic’, one stands” (p. 64).

Despite what appears to be calm waters (e.g., Anderson & Glass-Coffin (2013) and Holman Jones et al. (2013)), Stahlke Wall (2016) has stirred the pot once more, owing to their concern about the enduring tensions from the “swirling polemics” and the “polarized methodological debates” (p.18) that continue to permeate the everyday politics and processes of peer-reviewed journals. Stahlke Wall (2016) acknowledges that “there are numerous definitions of autoethnography and, although they arise from scholars on all points of the continuum of evocative-to-analytic autoethnography, they all refer in some way to a systematic approach using ethnographic strategies, the linking of personal experience to social, cultural, and political issues, and a critique of certain discourses within a cultural context with a vision and hope for change.” (p. 5). However, speaking to their experience as a reviewer of peer reviewed articles, Stahlke Wall (2016) shares their concern regarding “the lack of analysis that I see both in the manuscripts I review and in published papers that are described as autoethnographies” (p.5).

Stahlke Wall (2016) proposes a ‘moderate autoethnography’ for the purpose of “draw[ing] attention to the middle ground, to encourage would-be autoethnographers to consider a balanced perspective that lies between the warring factions of evocative and analytic approaches to this method, one that captures the meanings and events of one life in an ethical way but also in a way that moves collective thinking forward—a moderate autoethnography.” (p.

7). Further, they contend that this moderate approach to autoethnography would allow for and encourage "innovation, imagination, and the representation of a range of voices in qualitative inquiry while also sustaining confidence in the quality, rigor, and usefulness of academic research" (p.2). I experienced similar tensions pursuing less traditional forms of autoethnography on the analytic end of the spectrum, having been told directly that what I was doing is not autoethnography—this section was written to further clarify the multitude of approaches and situate this research within that spectrum. While the publicized overt debates have appeared to have subsided, the politics behind the scenes, inevitably remain ever present.

Ultimately the 'moderate approach to autoethnography' promoted by Stahlke Wall (2016) advocates "for an ethical and self-focused but analytical approach to autoethnography" (p.7) that uses "'the power of one' to explore and critically analyze the complexity of social events or topics for the purpose of transformation and social justice" (p.8). In moving towards this moderate autoethnography, Stahlke Wall believes that it would "combine the power of the personal perspective with the value of analysis and theory, so that sociological understanding is advanced in ways it might never have otherwise been" (p. 8). These goals resonate with me and have influenced my approach.

Rationale for Using an Analytic Layered Approach to Autoethnography

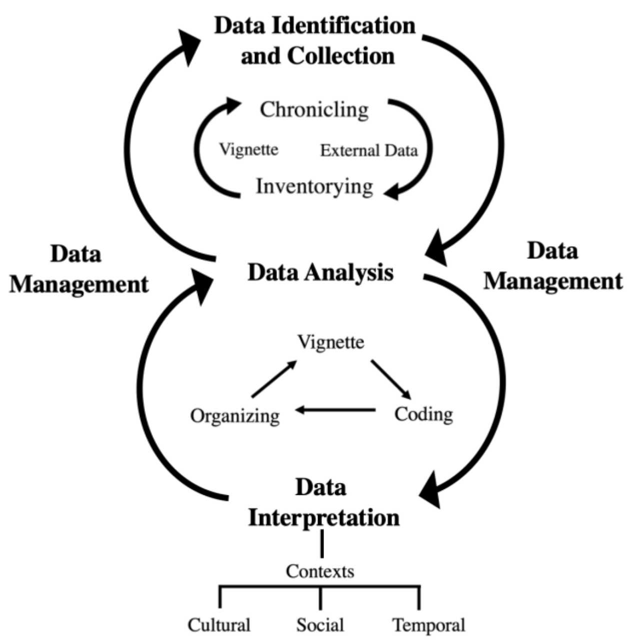
My research is best fitted to an analytic layered approach for several reasons. First, because my work is centered around the implementation and enactment interface of reform-based science education I wanted to include external data to 'zoom out' to situate my personal experiences and internal data within the "broader context in which these personal experiences occurred (Chang, 2008, p. 113). Though autoethnography is best known for its evocative approach, it was the analytical approaches of Anderson (2006) and Chang (2008) that drew me into this field. The *how* and *why* of Chang's and Anderson's approaches created controversy but also piqued my interest. For me, Chang and Anderson add layers that move beyond evocative ethnography so that I can also include external data (e.g., conversations/informal interviews with others, official documents, textual artifacts) to "breathe the spirit of ethnography into autoethnography with the emphasis on cultural interpretation" (Chang, 2008, p. 113) in order to provide insight into the broader sociocultural context and social phenomenon surrounding personal experience (Anderson, 2006; Chang, 2008). This feature was essential for achieving my research aims: to provide insight into to social worlds of science education stakeholders (Aim 1), identify similarities and differences across cultures (Aim 2), and provide insight into broader cultural phenomenon from personal experience (Aim 3).

Methodological Framework for Autoethnographic Data Collection, Analysis, and Interpretation

Autoethnography is both process and product (Ellis et al., 2011) and is far from linear. Autoethnographic data collection, management, and analysis interact concurrently and in a cyclical fashion (Chang, 2008). Considering this dynamicity of autoethnographic data, Chang (2008) suggested leaning into data management as a link that both organizes and brings intentionality to data collection and data analysis, advising that data are managed as they are collected. Informed by the work of Chang (2008), I developed the following framework to illustrate the process that I used to engage in my autoethnographic data collection, analysis, interpretation, and management for this study (see Figure 3.1). The central processes are shown in bold type font and are iterative in nature, indicated by arrows. The majority of preliminary data was acquired through chronicling and inventorying, which subsequently underwent iterations of analysis, interpretation, and management before becoming finalized data in the form of narrative vignettes. This iterative process occurred throughout my research and supported me in effectively organizing and managing my autoethnographic data. Data was made readily identifiable and accessible to ensure that subsequent iterations were steered effectively toward my research question by helping to visualize any deficiencies, redundancies, and irrelevancies in my data (Chang, 2008). The details and processes of this framework will be explored briefly in the subsequent sections. Descriptive accounts will be provided in Chapter Four.

Figure 3.1

Framework for autoethnographic data collection, analysis, interpretation, and management.

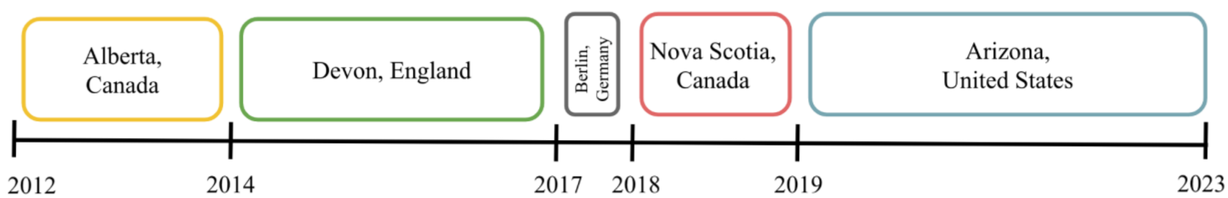


Data Identification and Collection Methods

An analytic layered approach to autoethnography was employed in this study to collect both self and external data to (1) Focus the author's experience alongside data, abstract analysis, relevant literature; (2) Use vignettes, reflexivity, and introspection to invoke readers to enter the "emergent experience" of doing and writing research; and (3) Propose to understand some aspect of self or of a life as it intersects with a cultural context (Ellis, et al., 2011). Because autoethnography is "both process and product" (Ellis et al., 2011, p. 273), the process of identifying the experiences to be included in the study and the demarcation of boundaries between them is the first step in the autoethnographic process. Thus, to begin with preliminary data collection, I created a chronological timeline spanning over ten years (2012-2023) (see Figure 3.2).

Figure 3.2

Spatiotemporal autobiographical chronological timeline



I made internal boundaries within this timeline denoting when I lived in different places. Within each boundary, I inventoried events that positioned myself in relation to my experiences in science education (Chang, 2008). This included self-data and external data that was collected through a general-to-specific approach to "excavate personal experiences related to the topic" (Chang, 2008, p. 62) (see Table 3.1 for list of internal and external data collected). Data identification and collection methods are further narrated in Chapter Four.

Table 3.1

Data collected for autoethnography

Internal Data	**External Data**
- Memories - Mementos and journal entries - Vignette	- Official documentation - Informal discussions with others - Textual and pictorial artifacts - Scholarly literature

Data Analysis, Interpretation, and Management

Chronicling and Inventorying

I used two approaches to guide the identification and extraction of self data and external data (see Table 3.1). First, I used chronicling to identify timelines of border-crossing events and serve to demarcate spatial and temporal details associated with my experiences related to science education (Chang, 2008). The timeline created through chronicling served as a loose framework upon which I identified memories and associated external data that aligned with the timeline events. Second, I used inventorying for each timeline as a sort of nucleation site to generate clusters of memories based on temporal, spatial, and/or circumstantial events identified on the timeline (Chang, 2008).

As the "building block of autoethnography", personal memory was my preliminary source of data as it enabled the "past to give a context to the present self, opening a door to the richness of the past" (Chang, 2008, p. 71). Because what is recalled from the past and "extracted through memory can be written down as textual data", my memories were recounted through narrative vignettes to form the basis of my autoethnographic data (Chang, 2008, p. 72). An important consideration in reconstructing details from memory is that it is a “challenging task” that questions the reliability of the outcome (Chang, 2008, p. 72). To address this challenge, I incorporated external data, artifacts, and academic literature to help reconstruct memories and increase trustworthiness (Anderson, 2006; Chang, 2008) (see Table 3.1). Chronicling and inventorying methods are further narrated in Chapter Four.

Analysis and Interpretation

To address the complexity of my data, I engaged in multiple iterations of coding, organizing, and analyzing the data to give a “logical structure to a mass of collected data” (Chang, 2008, p. 116). Employing the strategy of 'compare cases’ was useful to identify similarities and differences between separate data, while ‘contextualization’ enabled me to shift my attention to the cultural data that lay beyond my personal data (Chang, 2008). This not only helped me to identify the essential features of the data but also to visualize the interrelationships between data to cluster data into broader themes that spanned cultural boundaries of nations and science education constituents. These strategies were critical to supporting my research aims as they allowed me to “breathe the spirit of ethnography into autoethnography with the emphasis on cultural interpretation” (Chang, 2008, p.113). Using these strategies, I reduced a preliminary dataset of 90 memory ‘bits’ to 40 potential narratives. From these 40 preliminary narratives, I organized data into 10 initial thematic descriptor codes. Coding methods and preliminary data codes are further described in Chapter Four (see section *Coding* and Table 4.1). I expanded on my preliminary narratives, which eventually became the 40 narrative vignettes that compose the data of this study. Through iterative analysis and interpretation, the 40 self-narrative vignettes were grouped within three central themes, which compose the thematically organized parts of

Chapter Four: (Part I: Tending the Garden; Part II: Mind the Gap; Part III: It's a Matter of Perspective).

Vignette Data

The primary autoethnographic data of this study were significant life moments relevant to the phenomenon of this study, my experiences implementing and enacting reform-based science, that were "recalled from the past and extracted through memory… written down as textual data" (Chang, 2008, p. 72). In accordance with the typologies identified by Ellis and Bochner (2000), the self-narrative vignettes of this study include "texts by complete-member researchers" who "explore groups of which they already are members or in which … they have become full members with complete identification and acceptance" in addition to "personal narratives written about some aspect of their experience in daily life" (p. 740). Each of the 40 self-narrative vignettes varies in length and style, and is organized thematically, rather than chronologically to reflect my diverse experiences. To shift away from binaries, I excluded gendered pronouns in the vignettes.

Data Presentation

Given the inherently personal nature of autoethnography, autoethnographers encourage those undertaking autoethnography to find an expression that speaks to the author (Anderson, 2006; Chang, 2008; Spry, 2001). For some, that expression manifests as an autoethnography through art (Coleman, 2022), poetry (Maurino, 2016), dance (Vionnet, 2022), fiction (Grant, 2010), photography (Suominen, 2006), film (Lotfalian, 2013), and theater (Saldaña, 2008). For others it is analytic text that is descriptive-realistic (Anderson, 2006; Chang, 2008). Like Anderson and Chang, I found myself drawn to autoethnography through an approach that leans more towards the analytic tradition than the evocative or performative traditions. This very difference in process and product between evocative/performative and analytical autoethnographies has caused tension in the field of autoethnography (discussed in the earlier section *A Brief History of Autoethnography, a Controversial Continuum*) and, as recent history has shown, for my own autoethnographic research trajectory as well. While others have chosen poetry, art, dance, or photography as mediums to express their autoethnographic research, I, inspired by the work of (Kierkegaard, 1846/1998), have chosen to express my autoethnographic research using the literary device of presenting my data as a ‘study within a study’.

Considering the deeply personal nature of autoethnography in comparison to other social science methods, autoethnographic inquiry is unavoidably “shaped not just by scholarly traditions, but also by life and career trajectories of individual scholars” (Anderson & Glass-Coffin, 2013, p. 58). Thus, it follows that autoethnographic expressions of research is what Spry (2001) calls a “convergence of the ‘autobiographic impulse’ and the ‘ethnographic moment’ " (p. 706). Admittedly, while Spry is speaking about performative approaches to autoethnography (e.g., art, theater, poetry, etc.), their words deeply resonate with me and the approach I took. My desire to write my autoethnographic research as an academic paper, or a study within a study, is exactly that, an ‘autobiographic impulse’ in an ‘ethnographic moment’ that reflects my previous life and career trajectories. In the same way as someone whose life and career trajectories are grounded in dance, poetry, or photography that have chosen to express their autoethnographic research through these mediums, I too have chosen a medium through which to express my autoethnographic research that reflects my life and career trajectories. It just happens that the life history and autoethnographic expression for me, reflects expressions found in natural science research.

Further encouraged by the advice of Chang (2008) to be creative with developing my own writing style, I have chosen to present my autoethnography, as a study within a study, using the narrative style of an academic paper in the natural sciences. Following an introduction with seven suppositions, I provide detailed methods, followed by results and discussion. The suppositions were generated to help guide the reader through the various narratives and towards the conclusions that I made about my own experiences. To be explicitly clear, in no way is the expression of my autoethnographic findings experimental in the sense that they reflect or are constituted as an experiment in the physical, chemical, or biological sciences.

Trustworthiness

Credibility

I sought to provide accurate portrayals of my experiences of the ‘everyday’, ‘in the field’, and ‘on the front lines’ of science education systems. I hope that I have “evoke(d) in readers a feeling that the experience described is lifelike, believable, and possible” (Ellis et al., 2011, p.282), and even true. Discussions around ‘credibility’ is contentious in autoethnographic circles, the tensions of which can be felt in the dialogues contained in the journal publications discussed above. Verisimilitude is the term preferred by Ellis et al., (2011) to describe their interpretation of research validity. In alignment with Ellis et al., (2011), this was a quality I sought to achieve through my research, that is, to describe accurate renderings of the events I experienced so as to provide the appearance that they were real. However, I also sought credibility, an important feature of my analytic layered autoethnographic research, that is, what I have written is plausible and trustworthy. Like Anderson, I sought to “truthfully render the social world under investigation” (2006, p.388) by using a layered approach including external data to “confirm, complement, or reject introspectively generated data” (Chang, 2008, p.104).

To keep focused on credibility and verisimilitude, in recollecting memories, I sought to remain aware of how, and to what extent, the impact that the present self had on past experiences and memories. Considering that “to conjure up the past for oneself is not as difficult as to conjure away the present for the sake of recollection”, I made efforts to “use memory against recollection” to engage in the reflective relationships between the two using a layered approach to autoethnography so that my recollection did not become “something different in the moment of preparation” (Kierkegaard, 1845/1991, p. 13).

The credibility of my study is important to me because I want to demonstrate that autoethnography is a credible approach for science education research. There are few autoethnographic-based research studies in science education research. A few non-peer-reviewed master’s and doctoral dissertations exist (Awasthi, 2023; Vega, 2021), but very few peer reviewed autoethnographies in science education exist including one ‘special issue’ found in *Cultural Studies of Science Education* titled “Critical Voices in Science Education Research” (Bazzul & Siry, 2019). However, in examining each article in this special issue, I found that none of the work presented in this special edition related to the analytic layered autoethnographic approach I used, or my research topic of implementation and enactment of reform-based science education. After my defense, I found one example of an autoethnography of one person’s experience teaching ‘nature of science’ in a fifth-grade classroom in Turkey for fifteen weeks Aksöz et al., (2023). However, this research does not address secondary education and it is limited to fifteen weeks. Thus, I believe that my approach is novel to the science education implementation and enactment research field. Indeed, I was unable to find any autoethnographic research related to my research interests and none in any top-ranking science education journals. Whether this is due to “the ‘gatekeeping’ effect of academic journals… or other factors influencing the rarity" of such studies, is to be seen (Brandt & Carlone, 2012, p.146). I hope that I can contribute to the science education research community by way of autoethnographic research.

Limitations

My dissertation has two central limitations: my role as participant-observer and the scope of the study bound by my autobiographical experiences. First, the autoethnographic self-data for this study, vignette, was collected and analyzed by the researcher, who also served as the key participant in this study, both of which were myself. As discussed earlier in Chapter Three (see Trustworthiness section) and in Chapter Two (see Intermediary section), this was both a limitation and a strength. Data I collected and analyzed in this research was inherently embedded with biases from myself, the researcher. Thus, while efforts were made to transparently declare biases and create systematic measures to interact with recollections and data collection, the data remains unavoidably subjective. Any insights and conclusions provided in Chapters Five and Six, are limited to my own experiences, however, it is the hope that the experiences of others may resonate with my findings, and if so, may they consider the insights provided.

Second, it follows that the scope of this study was limited to the parameters of this study that are spatiotemporally bounded by the events, situations, relationships, and conversations that I experienced and/or engaged with relating to secondary science education in Eastern and Western Canada, the Southwest of England, and the Desert Southwest of the United States between 2012-2023. Experiences over the course of this time period include those which are both extemporaneous and intentional in nature. Both limitations considered, my observations of experiences in science education as a participant observer were ultimately limited to the lenses through which I experienced and subsequently recollected and remembered these events. The scale of my observations are limited to the sphere of my direct and indirect interactions in addition to my positioning within each context, and in no way represents every single classroom, school, or district of each of the countries in which I worked, but that is also true of any science education research study.

While it is my hope that my 'insider' insight, may contribute to understanding of broader social phenomenon in and around science education, ultimately, the strength and legitimacy of my narratives and analysis are subject to the degree to which they resonate with readers and corroborate their own experiences within the cultures of science education constituents and science education systems. In Chapter Five: Discussion and Chapter Six: Conclusions, I offer theoretical considerations of social phenomenon, based on my experiences. However, these considerations are in no way conclusive, rather, they offer opportunities to be considered by future work and call on the reader to do so. One salient element of autoethnography is that is provides critical analysis of cultures and cultural phenomenon in which the author's autobiographical experiences are embedded (Anderson, 2006; Chang, 2008; Ellis et al., 2011). The concluding chapters are my efforts to do just that.

Ethical Considerations

Ethics Approval

While it was impossible to acquire ethics approval prior to the unfolding of the experiences under study, ethics approval was obtained to conduct the vignette data collection, analysis, and interpretation written about the past experiences from the Institutional Review Board (IRB) through the University of Calgary study under Ethics ID: REB21-1453. Data collection of self-reflective vignettes, memos, and notes from past interactions in the form of emails or other artifacts followed systematic approaches and were aligned with the ethical requirements outlined in REB21-1453. To protect the identity of others directly or indirectly associated with the events recollected for this study to the greatest extent possible, identifying descriptors and names of people and places were excluded from the text (Chang, 2008; Ellis, 2007).

Potential Risk or Benefit to Self

In preparing to undertake this autoethnographic study, I was tasked with considering the personal and social risks before entering into this "hazardous realm of research" (Eisenbach, 2016, p. 609). As the study unfolded, deepened, and evolved, it was essential that I remained vigilant to monitor tensions and hazards that emerged. There were two central risks to self that I monitored and navigated throughout the research process: the first related to revisiting past trauma and the second regarding professional identity.

Throughout the research process I both prepared and assessed myself for the potential risks and benefits that might have emerged from uncovering, investigating, and analyzing data that resulted from revisiting the voluntary and involuntary removal of my cultural familiarities as I navigated my autoethnographic data. I had to revisit and relive the turmoil that was brought on over a decade of working and living in four discrete cultures by constantly "starting from the beginning", the feelings of having an unsuccessful "zigzag" career, the "loss of status", and the frustrations of being a "groping infant in learning" (Bateson, 1994, p.82) resulting from the choices of my partner (and ultimately, myself), whose research moved us to new places and cultures.

In revisiting my autoethnographic data, I was continuously reminded of "the internal change that new learning required, and the loss of status that goes with being a beginner once again" (Bateson, 1994, p.71). As Bateson (1994) articulates so eloquently; "It is not easy to use the crises of one's own life as the stimuli for new ethnographic insights, yet we all arrive as strangers at the moments of crisis in our lives, having to improvise responses from previous learning. This must be labor; this is bereavement" (p.27). Since my autoethnographic contemplation was an "excruciation only because it is also a joy" (de Beauvoir, 1947/2018, p.11), this labor did result in a therapeutic benefit, proving to be a significant and necessary part of the healing process (Ellis et al., 2011; McMillan & Ramirez, 2016; Spinazola, 2018).

What may be confusing to the reader, is that admittedly, the writing style (scientific) and narrative devices (study within a study) I employed in Chapter Four does not reflect the vulnerability and trauma I re-experienced recounting these experiences, but rather reflects what evocative autoethnographers typically consider cold or 'masculine' writing (Burnier, 2006; Ellis & Bochner, 2006; Ellis, 2009; Sherick & Pennington, 2017). However, my partner, therapist, and anyone at my dissertation can attest, that the process of having to speak to my work at my dissertation or throughout post-dissertation edits, was an overwhelmingly emotional and vulnerable experience for me. After my dissertation defense, which required major revisions, I had to take stress leave from work, go on anti-depressant and anti-anxiety medication, and eventually quit my job. The material in this dissertation is deeply personal and rooted in raw emotion, although that might not come through in the way it reads. Writing, defending, and revising this dissertation twice, I had to relive again and again, my greatest fears and nightmares of being unseen, unheard, unaccepted, and misunderstood. I broke my mind and I broke myself to write this work, and I have rebroke myself to finish it. Completing this dissertation was a necessary step in healing for me to move on from the trauma, frustrations, anger, disappointment, and sadness I experienced in my cross-cultural personal and professional life trajectories, of which include implementing and enacting reform-based science education reform.

The second risk has the potential to impact my personal, professional, and academic identity, a risk that was ever present throughout, but also one that outlives the research process. During the writing, defense, and revision process, like Forber-Pratt (2015), I too struggled with challenges on how to find my voice as an author, negotiating university expectations for dissertations, and addressing validity concerns for autoethnography. However, the prevalence of this risk after publication will only become more apparent since I will "continue to live in the work of relationships" in which my research was embedded, long after the research was completed (Ellis et al., 2011, p. 282). I found myself faced with the very same questions which Eisenbach (2016) raised for themselves: "How might others come to view my experiences and myself? How might their interpretations affect the way in which I am perceived in the world of education" (p. 608). These questions have echoed in my heart, gut, and mind – as concerns that might potentially impact my educational professional and research worlds, not to mention my personal identity amongst my natural science and education researcher acquaintances.

In sum, engaging in this work and facing these risks was a necessary process for me to realize that "a zigzag, seen from another angle, may be a rising spiral, so that readjustments are a record not of failure, but of growth" (Bateson, 1994, p.83). Further, Nepo (2019) reminds me that "this lifelong process of weaving what enters us with what rises within us is the necessary art by which we lift the veils between us and keep the world together" (p.1). This autoethnography helped me to do just that.

Relational Ethics

Since autoethnography "lies at the intersection of discourses and experiences of Self and Other, Insider and Outsider, Native and Colonialist" (Anderson & Glass-Coffin, 2013, p. 73); others are inherently implicated in my research. As the author of this autoethnographic research, my identity is unavoidably disclosed. Resultantly, because my study is situated within my experiences of specific contexts in and around science education systems, I will "inevitably share the stories of others" (Wall, 2008). Thus, it was essential that I continually attended to the reality that "other participants are always present in self-narratives, either as active participants in the story or as associates in the background" (Chang, 2008, p. 68).

Relational ethics thus were considered in this research, framed by the question Ellis (2007) asks "What are our ethical responsibilities toward intimate others who are implicated in our stories we write about ourselves?" (p. 5). My narratives include information about others who were directly or indirectly involved in my cultural experiences of science education. Thus, my experiences, the experiences others informally shared with me, and the experiences I shared together with others are the substance of my research, and subsequently detailed and analyzed. It was important that I endeavored to "value mutual respect and dignity" (Ellis, 2007, p. 4) as I wrote about my experiences with others, implicated directly or indirectly in science educational cultural phenomenon. To do this, where and when possible, I endeavored to follow the recommendations by Ellis (2007) to "anticipate and feel (the) consequences", "ask questions and talk about (the) research with others", "include multiple voices and multiple interpretations", and "inform people and get their consent" (p. 23). Admittedly, these recommendations were not always feasible, owing to the fact that I was no longer in contact with individuals and/or that the accuracy or message of the story would be diluted or compromised (Ellis, 2007).

Throughout the autoethnographic research process, I strove to “leave the communities, participants, and (myself) better off at the end of the research than they were at the beginning” (Ellis, 2007, p. 25). In most cases, the ‘others’ referred to or presented in my narratives are, or were at one point, my peers, leaders, friends, colleagues, students, and participants whom I respect and value. Indeed, many of my narrative vignettes explore neutral observations (e.g., microscopes in dusty, unopened boxes) or emotional frustrations (e.g., annoyances shared by a chemistry teacher about their colleagues) with science education and in no way do I intend for those tasked with enacting (teachers) and implementing (administrators) reform-based science education to shoulder the blame, but rather, I aim to demonstrate that it is the system in which we work, is problematic. In both the past and present— these individuals whom are implicated directly or indirectly in my narratives have been, and continue to be, “a source of identity and partners in my survival” as they are always in my peripheral vision (Bateson, 1994, p.75). Yet, despite my best intentions, Ellis reminds me that “In the best of all worlds, all of those involved in our studies will feel better. But, sometimes they won’t; you won’t” (p.25). The latter possibility inevitably is a risk one runs when attempting to provide a critical lens that illuminates otherwise inaccessible or difficult to see elements of everyday cultural phenomenon.

Given the unavoidable implications of ‘the other’ in my research, significant efforts were taken to ensure a code of confidentiality was present at all steps of my inquiry (Wall, 2008) by omitting descriptors, identifiers, and names of individuals, schools, and locations so as to protect the privacy of the individuals that are either active participants or background associates (Chang, 2008; Ellis, 2007). It was imperative that I remained cognizant that my stories were not “made in a vacuum, and others are always visible or invisible participants in my story” (Chang, 2008, p. 69), and vigilant to protect the identities and stories of those participants.

Summary

In this chapter I critically engaged the literature to outline the controversial continuum of autoethnography, situating the analytic layered approach to autoethnography I used in this study, within this continuum. I described how I, the researcher and my past life experiences and disciplinary groundings informed my selection of an analytical layered approach to autoethnography. I outlined the methodological framework I used to conduct the layered analytic approach to autoethnography in both graphic and written form to illustrate the iterative process of autoethnographic data collection, organization, management, analysis, and interpretation conducted in this study. Trustworthiness for this study was explored in relation to the credibility and relatability of the study in alignment with analytical and layered approaches to autoethnography. Finally, ethical considerations relating to self and 'the other' were framed within the ethics approval obtained for this study.

Arriving in a new place, you start from an acknowledgment of strangeness, a disciplined use of discomfort and surprise. Later, as observations accumulate, the awareness of contrast dwindles and must be replaced with a growing understanding of how observations fit together within a system unique to the other culture. Having made as much use as possible of the sense that everything is totally alien, you begin to experience, through increasing familiarity, the way in which everything makes sense within a new logic… The final description should deal with the other culture in its own terms. Yet it is contrast that makes learning possible.

Bateson (1994, p.27)

CHAPTER FOUR: RESULTS

An Autoethnography of Reform-Based Science Education

Abstract

In this chapter, I frame my autoethnographic data as an academic study. Taking inspiration from my disciplinary grounding in the natural sciences and shaped by my love of the Kierkegaardian pseudonymous works, I found an expressive style that fits my narrative. In the following, I explain why and how I used this literary device. I outline the nature of my autoethnography and identify the seven suppositions that I used as heuristics to frame my research. I describe my layered analytic approach to autoethnography, providing details of how preliminary data was coded and organized into a set of over forty narrative vignettes, which upon analysis were subsequently categorized into three overarching themes. In the results and discussion section, I present these three collections of narrative vignettes with short conclusion sections in which I discuss my findings with respect to my heuristic suppositions.

Introduction

Over a decade ago, I started a journey in science education which now culminates in this dissertation. Just as I was once drawn to scientific research to probe molecular phenomena of the cellular world, I found myself drawn again to research, but this time, to the social sciences to investigate phenomena from my own lived experiences in science education. I have written this autoethnography and my experience reflects what Spry, (2001) calls a “convergence of the ‘autobiographic impulse’ and the ‘ethnographic moment’ " (p. 706).

Many different creative expressions of autoethnographic data have been used to quell the ‘autobiographic impulse’ including performances of poetry, dance, theater, or art (Spry, 2001).

Though evocative prose (Ellis et al., 2011) is perhaps the most common, a spectrum of styles exist (Holman Jones et al., 2013; Sherick & Pennington, 2017). Analytic autoethnography offers an alternative to these more artistic forms and better reflects my disciplinary groundings (Anderson, 2006; Anderson & Glass-Coffin, 2013; Chang, 2008; Chang, 2013). However, my data did not lend itself entirely to an analytic style and I have chosen to creatively frame my autoethnography—not as dance, poetry, or art, but rather—as an academic paper. Inspired by the narrative style of Søren Kierkegaard, I wrote a 'study within a study' (Kierkegaard, 1846/1998). To do this, I framed my autoethnography as an academic paper, complete with introduction, detailed methods, and results and discussion sections. In what follows, I present seven suppositions to serve as guiding heuristics for navigating the themes that emerge from the following vignettes.

Seven Suppositions About Reform-based Science Education

Throughout my career in education, I was continuously impressed, inspired even, by the aims and goals of educational standards produced by the governments in the countries in which I taught (see Appendix, Table A1). For example, early in my teaching career, I encountered the Alberta Education Science Program of Studies which championed that: "All students have the opportunity to develop scientific literacy… to help them become lifelong learners — maintaining their sense of wonder about the world around them" (Alberta Education, 2014, p. 1). Later, in England, I became acquainted with the national standards, which identified that "students will develop an understanding of the nature, processes, and methods of science through different type of scientific enquiries" (UK Department for Education, 2013). And finally, in Arizona, United States, I engaged with the state standards that underscored the importance of "sustaining natural curiosity" through engaging students in scientific thinking to strengthen skills that people use every day such as solving problems creatively, thinking critically, working cooperatively in teams, and valuing lifelong learning (Arizona Department of Education, 2018). Considered in step with the science education literature I had explored throughout my career, my belief in these various policies led me to consider the following suppositions that I will return to at the end of each section of vignettes:

- Supposition 1: Research-informed recommendations and science outreach resources for inquiry-based science can help achieve the goals of reform-based science.
- Supposition 2: Science technicians and experimental materials can help achieve the goals of reform-based science.
- Supposition 3: High-quality, reform-based standards-aligned curriculum can help achieve the goals of reform-based science.
- Supposition 4: Implementation of reform-based science classroom infrastructure can achieve the goals of reform-based science.
- Supposition 5: Intermediaries can build capacity for reform-based instruction of teachers.
- Supposition 6: Leadership frameworks, models, and theories can build system-wide capacity to achieve reform-based science aims.
- Supposition 7: Autoethnography is a valuable method for exploring enactment of reform-based science education.

If the reader chooses, the vignettes could be skipped entirely as the summaries of each part provide a synthesis of my experiences related to the contents of each supposition. As a disclaimer, it should be noted that all these suppositions were generated after the data and are simply used as guideposts. In general, my experiences and reflections are largely consistent with the literature reviewed in Chapter 2, although national-level policies are aligned with reform-based goals, these policies are not easily aligned to existing school and district policies. My narratives showcase the professional and personal tensions that these misalignments produce.

Materials and Methods

This section will identify the materials and methods used throughout stages of my autoethnographic research. Various memory-inducing artifacts linked to my experiences in science education were used to activate recollection, including pictures, music, and other mementos (Bateson, 1994). In addition to these personal artifacts, various external data were used including government educational policy documents such as programs of study or educational standards (e.g., Government of Alberta, 2009; DoEECD, 2019; UK Department for Education, 2013; Arizona Science Standards, 2018), official documentation (e.g., teaching certificates, work visas, grant applications, teaching material), informal conversations (e.g., with current and past colleagues, friends, and family), and other documents like email communications and primary literature. Internal data included my personal memories, my annotations and marginalia of papers or books, as well as other journal entries or notes spanning the last decade. Encouraged by the advice of Bateson (1994), as often as possible, I physically relocated myself to remote locations in nature or revisited past places of residence to reflect on and write about past experiences. In removing myself from the minutiae of everyday life, I could access deeper parts of memory with greater clarity, which proved to be useful to access more nuanced or overlooked memories (Bateson, 1994).

To organize and categorize my thoughts and memories as well as all forms of internal and external data, the following items were used for data storage, organization, and coding:

colored sticky notes, sharpies, colored pens and markers, notebooks, a storage tote, colored folders, poster board, and an office space. Finally, a very patient partner in sustaining years of a disorganized and inaccessible office was imperative to facilitating this process. In the sections that follow, I outline my framework for doing autoethnography. I then describe in detail my methodological approach for coding and analyzing my data.

Autoethnographic Data Collection, Analysis, and Interpretation

Informed by the work of Chang (2008), I developed the following framework to illustrate the process I used for my autoethnographic data collection, analysis, interpretation, and management (see Figure 3.1). The majority of preliminary data was acquired through chronicling and inventorying, which subsequently underwent iterations of analysis, interpretation, and management before becoming finalized data in the form of narrative vignettes. This iterative process occurred throughout my research and supported me in effectively organizing and managing my autoethnographic data. Data was made readily identifiable and accessible to ensure that subsequent iterations were steered effectively toward my research question by helping to visualize any deficiencies, redundancies, and irrelevancies in my data (Chang, 2008).

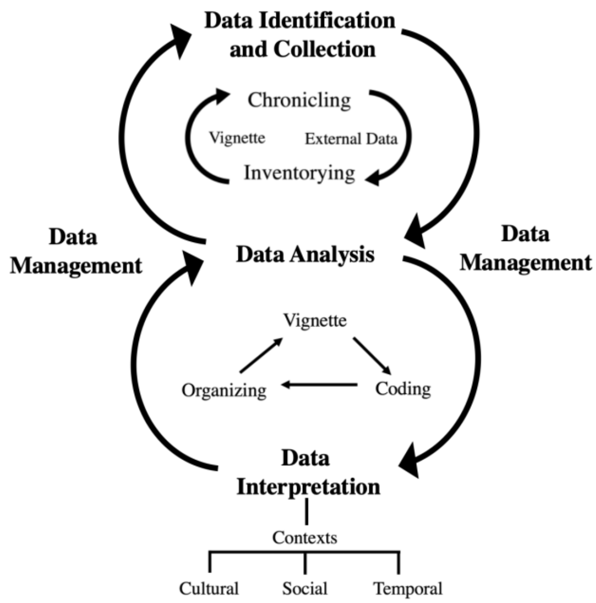


Figure 3.1: Framework for autoethnographic data collection, analysis, interpretation, and management
The central processes are shown in bold type font and are iterative in nature, indicated by arrows.

Data Identification and Collection

A layered approach to autoethnography was employed in this study to collect both self and external data to juxtapose memories from personal experience of the inner world with artifacts of the outer world (Adams et al., 2014; Anderson, 2006; Chang, 2008). Because autoethnography is "both process and product" (Ellis et al., 2011, p. 273), the process of identifying the experiences to be included in the study and the demarcation of boundaries between them was the first step in the autoethnographic process that I undertook, creating a chronological timeline over ten years (2012-2023) (see Figure 3.2). I used twoo approaches to guide the identification and extraction of both self-data and external data from this timeline (see Table 3.1). First, I used chronicling, a strategy identified by Chang (2008) to "give sequential order to bits of information you collect from memory" (p.72), to identify timelines of border-crossing events and serve to demarcate spatial and temporal details associated with my experiences related to science education. The timeline created through chronicling served as a loose framework upon which I identified memories and associated external data that aligned with the timeline events. Second, I used inventorying as an activity that provided a structure to collect, evaluate, and organize the "memory bits" from my autobiographical timeline (Chang, 2008, p.76). I engaged in the activity of inventorying for each segment of the timeline as a sort of nucleation site to generate clusters of memories based on temporal, spatial, and/or circumstantial events identified on the timeline.

Personal memory, the "building block of autoethnography", was my preliminary source of data as it enabled the "past to give a context to the present self, opening a door to the richness of the past" (Chang, 2008, p. 71). Since reconstructing reliable details from memory is a challenging task, I used a layered approach to autoethnography to address this challenge. By incorporating supporting external data such as artifacts, official documentation, informal conversations, and academic literature, I sought to increase the likelihood that memories were reconstructed appropriately by corroborating them against external data in an effort to increase trustworthiness that the narratives accurately portrayed my experiences and the social worlds in which they occurred (Anderson, 2006; Chang, 2008). As identified in the *Limitations* section of Chapter Three, the data is bounded by my personal experiences and recollections of those experiences. Regardless of my efforts to ensure that memories of events and the cultures surrounding them were constructed as accurately as possible, they are by their very nature, inherently fallible. The data collected for this study is summarized below and will be expanded upon in the following section (see Table 3.1).

Internal Data

Self-reflective data was collected and analyzed through the lens of Kierkegaard's definition of, and the distinction between, remembering and recollection. In the preface of an essay titled *In Vino Veritas* in the 1845 pseudonymous work, *Stages on Life's Way,* Kierkegaard, states that, "To recollect [*erindre*] is by no means the same as to remember [*huske*]. For example, one can remember very well every single detail of an event without thereby recollecting it. Remembering is only a vanishing condition. Through memory, the experience presents itself to receive the consecration of recollection." (1845/1991, p. 9). For this study, remembrance was used to recount facts in what Kierkegaard terms a sterile manner, whereas recollection was used to focus on the essence of the idea and evoke mood.

Recollection enabled me to bring texture to my vignettes by engaging in an impressionist approach to autoethnography by preliminarily including temporal, sensory, and physical accounts in addition to narratives of space and place in my writing (Adams et al., 2014). Further, the narrative style employed by Bateson (1994) to provide textured accounts of the spatiotemporal contexts within which their experiences were couched, was used as a mentor text in how the data vignettes were written. In earlier forms of my vignette writing the textured narratives of the spaces and places surrounding my experiences in science education were lengthy, however in the final form, they were shortened substantially or removed entirely, only sometimes appearing at the beginning or end of a vignette to briefly situate the reader withing the larger sociocultural context in which the memory was embedded.

External Data

External data in the form of official documentation, informal conversations with others, academic literature, and artifacts (i.e., textual, pictorial, auditorial) were used to stimulate memory, provide evidence of thematic and boundary-crossing timeline events, and add context and richness to these events where appropriate. Further, external data was used to “confirm, complement, or reject introspectively generated data” (Chang, 2008, p. 104). The use of external data proved to be useful in this sense as I referenced past emails and/or comments on written work to exclude a few pieces of preliminary data as my remembrance of what was said was incorrect. In other cases, external data such as official documentation or academic literature was used to support self-reflective internal data. Examples of external data used in this study include items such as various official paperwork relating to obtaining teaching certifications and work visas in addition to textual artifacts such as newspaper articles, past university papers, annotations on academic articles, email communications (with various colleagues, mentors, and family), and personal videos and/or photographs.

Preliminary Data Collection, Analysis, Interpretation, and Management

Chronicling and Inventorying

I used chronicling to create a ‘database’ of memory data by demarcating chronological and spatiotemporal events, which I subsequently filled in through the process of inventorying memories associated with each segment of time (Chang, 2008). By creating an autobiographical chronological timeline (2012-2023) I ensured a sequential order to the fragments of information collected from memory. The spatiotemporal timeline is represented below (see Figure 3.2). Five significant periods demarcated by unique cultural and geographical circumstances were identified: Alberta, Canada (2012-2014); Devon, England, UK (2014-2017); Berlin, Germany (2017-2018); Nova Scotia, Canada (2018-2019); and Arizona, United States (2019-2023). Although my vignettes are largely focused only on the times spent in Alberta, UK, and Arizona, some data also came from my time in Berlin and Nova Scotia. Therefore, even though I have demarcated five significant periods, I often refer only to the three contexts in which I had longer-term more permanent employment (Alberta, UK, and Arizona).

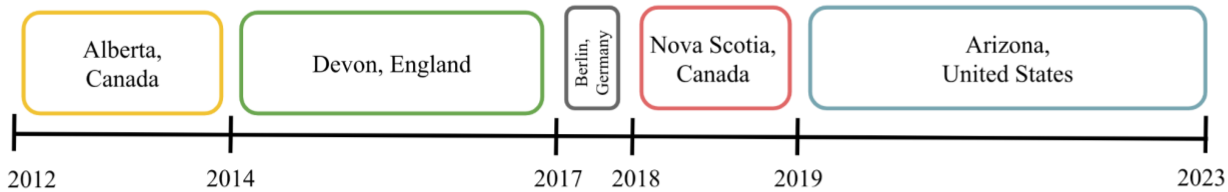


Figure 3.2: Spatiotemporal autobiographical chronological timeline
The width of each colored box provides a visual representation of time spent working in and around science education for each of the locations in which I lived. The length of the bar correlates to standard units of time. For scale reference, six months of time is represented by the grey bar representing time spent in Berlin, Germany.

For each time period, I created an inventory of significant life events, of both a personal nature and those relating to science education. Importantly, inventories included significant moments representing "border-crossing experiences" – transformative and transitory situations, experiences, and states in which "unfamiliar cultural characteristics of others" challenged and caused me to "adject (one's own) cultural standards of thinking, perceiving, evaluating, and behaving" (Goodenough, 1981, p. 62, as cited in Chang, 2008).

As I worked through the spatiotemporal order, it was common for memories unrelated to the time and location for which I was writing to appear, illustrating the cyclical nature of data identification, collection, and analysis. Any memories that emerged outside of the timeframe for which I was writing, were collected, but organized initially according to the correct timeline. The first iteration of the data identification process occurred in an organic fashion. As I processed my memory inventory, I conducted what I call 'quick writes' to capture the essence of the memory in brief notes that were either handwritten or typed and contained no more than 300 words, "memory bits" as Chang (2008) refers to them. Over 90 pieces of preliminary memory data were collected over two years. I then narrowed and transformed the 90 pieces of "raw data" into something understandable and meaningful in relation to my research question. While initially it was valuable to organize my data autobiographically and chronologically, it became apparent that this lived data was far too complex to be treated in a linear fashion (Pinar, 1975). Circuitous iterations of data analysis, interpretation, and management helped me draw connections, identify themes, and organize the data that transcended spatial and temporal timelines into something understandable.

Coding

My data was complex owing to the cross-cutting and hierarchical themes over multiple sites, populations, and cultures and spans a decade of experiences teaching, researching, and leading in science education (Bloomberg & Volpe, 2019). To address this complexity, I engaged in multiple iterations of coding, organizing, and analyzing the data to give it a logical structure (Chang, 2008). This helped me to identify essential features and interrelationships to cluster memories into broader themes, the process of which is described in the following section.

First, I used emergent coding to let the data 'speak to me' (Chang, 2008) and allow for themes to emerge organically from the data (Stemler, 2001). Thus, how I felt about different experiences may have helped to organize vignettes with different content, but similar personal meaning. Second, I engaged in two rounds of deductive coding (Stemler, 2001), in which each memory data was coded with a predefined set of codes from my research phenomenon (e.g., teaching, leading, and/or researching) and my conceptual framework (e.g., infrastructure, intermediaries, policy, practice, educators, leaders). Third, I coded preliminary vignette data using additional descriptors that were not pre-defined, but rather, emerged as themes throughout the data upon analysis (e.g., change, reform, culture, learning, professional learning, politics, tension, beliefs, values, teacher self-efficacy, funding, outreach, barriers, technician, pedagogical content knowledge, teacher education, professionalism, unions, resources, change management, and cross-cultural differences). Over 90 pieces of data were summarized and organized on a spreadsheet. Each memory was given a title and brief description and applicable codes noted.

The coded preliminary memory data in this format allowed me to visualize and identify initial themes and what data could be excluded. Heeding the advice of Bloomberg and Volpe (2019), I cut several pieces of data from my analysis: “just because something is noticeable does not mean that it is meaningful or noteworthy in terms of the study and analysis” (p.238). I then reviewed each memory for relevance and accuracy. For example, to determine relevancy, I asked myself whether this memory is part of my experiences of science education? To evaluate accuracy, I asked myself “did these events really happen in this way?”. Because “autoethnographic data collection does not have to be a solitary activity” (Chang, 2013, p. 114), I corroborated my memories, by consulting my partner, friends, past and present colleagues, written artifacts and external documents.

I made efforts to exclude data that were not productive, such as data that expressed overt emotion or was accusational, unsubstantiated, unfounded, or irrelevant to the research question. For example, in at least two instances, I realized that I had misremembered a few written and verbal comments, and thereby perpetuated a false memory. Upon reflection, analysis of notations on data of external documents and conversations with others, I found that these false memories were based on an emotional misrepresentation. I therefore removed this memory from the data set.

An iterative process led to the reduction of preliminary memories from 90 to 50 pieces. To further address the complexity of the data and identify patterns that “cut through the data” (Bloomberg & Volpe, 2019, p. 237), each memory was recorded onto a separate sticky note such that I could more easily organize my memories into more concrete themes. This allowed me to "hover over the entire data and context" and connect my data to sociocultural contexts to "find cultural meaning beyond the data" (Chang, 2008, p. 127).

In the end, I identified 10 themes (see Table 4.1). These themes would help to provide a logical and cohesive flow throughout my vignette writing. Preliminary data were analyzed for association with the 10 thematic codes. If data did not have an association with any codes, then it was removed from the data set, bringing the final memory data total to around 40 pieces. Themes presented in Table 4.1 transcended space, time, and the various roles I took up, suggesting that even preliminarily, there were cross-cultural similarities. Similarities between geographical and educational cultures can be briefly visualized by the notation in Table 4.1 next to the themes connected to my experiences. I used the connections I found between my data and the descriptor codes listed in Table 4.1 to inform the insights and considerations of this study presented in Chapter Five and Chapter Six.

Preliminary Thematic Descriptor Codes	Number of Preliminary Data Associated with Code	Geographic Culture*	Education Culture*
Tensions going from science to science education	7	C UK US	Teaching Researching Leading
Tensions going from science to science education research	8	C US	Researching
Leading from inbetween	12	UK US	Teaching Leading
Follow up to follow through	3	C UK US	Teaching Researching Leading
Multiple meanings	8	C UK US	Teaching Researching Leading
It's an outside job	5	C UK US	Teaching Researching Leading
Money for things, not for people	3	C US	Teaching Leading
Implementation does not equal enactment	4	C UK US	Teaching Leading
In defense of ambiguity	4	C UK US	Teaching Leading
Some things change, some things stay the same	14	C UK US	Teaching Leading Research

Table 4.1: Preliminary Thematic Descriptor Codes Associated with Preliminary Data
*The geographic cultures (C = Canada (Alberta, Nova Scotia), UK = United Kingdom (Devon), US = United States (Arizona)) and education cultures (teaching, researching, and leading) of which I personally was a participant observer, were listed where relevant to each code.

Vignette Data Collection, Analysis, Interpretation, and Management

The primary autoethnographic data of this study are significant life moments relevant to the research question of this study "recalled from the past and extracted through memory […] written down as textual data" (Chang, 2008, p. 72). The final format of textual data in this study is a collection of 40 self-narrative vignettes, grouped into three Parts: Part I: Tending the Garden; Part II: Mind the Gap; Part III: It's a Matter of Perspective. The process of curating and grouping vignette sketches allowed me to construct a thematic vignette that I was able to present as research findings (Bloomberg & Volpe, 2019). Each of the 40 vignettes varied in length and style, and organized thematically, rather than chronologically. Gendered pronouns are removed from the vignettes and cultural-specific spellings or common phrases were included when relevant.

Results and Discussion

Introduction to the Data

Writing my autoethnography, I explored my lived experience 'in the field' as a teacher, leader, intermediary, and researcher in and around secondary science education, to compare these experiences to the 'what should be' of reform-based science educational systems, as outlined by government educational policy (e.g. educational standards) and promoted by science education research. As a participant within each geographic and educational culture, I collected memories of the everyday goings-on, tensions, frustrations, and politics of educational systems in three countries. These memories are my data, herein represented as narrative vignettes. My observations come from experiences with B.Ed. students, secondary science students, teachers, administrators, science education researchers, outreach intermediaries, philanthropic foundations, and scientists. Some of my memories are about my experiences in science classroom closets, science outreach centers, professional development sessions, educational resource storage rooms, and science classrooms. While other, more informal memories are about my experiences that took place in non-conventional private spaces and places—pubs, bars, school hallways, teacher lounges, and behind closed office doors. Conversations that take place in these latter spaces and places are often kept hidden from the prying eyes and ears of evaluators, researchers, and administrators, and thus not privy to the reach of traditional science education research. What is said and observed in these spaces can provide unique insight into the 'what is' of everyday experiences in schools, as opposed to 'what is supposed to be' of educational policy (Hammond & Brandt, 2004). Through this research I sought to open the "black box of daily life in schools and classrooms" and provide insight into "hidden agendas, which illustrate why traditional interventions to improve schools are difficult to achieve" (Hammond & Brandt, 2004, p.16).

While I do believe that my experiences are similar to the experiences of others, I cannot know this for certain. I can only present my experiences as I remember them and hope that they resonate with others. Many research papers in science education mirror many of my individual experiences. However, no science education research can span the length, positionings, or geographical distribution of my experiences, and for this reason, I am excited to share my findings. Yet, I am acutely aware that autoethnographies do not yet hold the same weight compared to canonical qualitative and quantitative studies (Brandt & Carlone, 2012; Hammond & Brandt, 2004). The most I can hope for is that the stories I tell ring true for others and that these stories offer unique insight into the interactions, challenges and tensions that are lived and felt by stakeholders tasked with implementing and enacting reform-based science.

In my own way, I have been playful with my writing approach and move between narrative and academic styles, moving through time and space following thematic, rather than chronological necessity. Vignettes have been grouped into three parts (Part I: Tending the Garden; Part II: Mind the Gap; Part III: It's A Matter of Perspective). Where there are subthemes, they are denoted by a break (—).

Finally, I would like to remind the reader of the aims of this research. First, to provide insight into the tensions, experiences, and social worlds of stakeholders that implement and enact reform-based science education (Aim 1). Second, to identify the similarities and differences across national and professional cultures for reform-based science education enactment (Aim 2). Third, to provide insight into broader cultural phenomenon from personal experience with implementing and enacting reform-based science education (Aim 3). Mindful of these aims, I invite the reader to enjoy the journey while getting "some feel for the storyline including the major and minor stories that are told within the data" (Chang, p. 237).

I should like to be the landscape which I am contemplating, I should like this sky, this quiet water to think themselves within me, that it might be I whom they express in flesh and bone, and I remain at a distance. But it is also by this distance that the sky and water exist for me. My contemplation is an excruciation only because it is also a joy. I cannot appropriate the snow field where I slide. It remains foreign, forbidden, but I take delight in this very effort toward an impossible possession. I experience it as a triumph, not defeat.

de Beauvoir (1947, p. 7)

Part I: Tending the Garden

Every climate, space, place, and season brings unique challenges to the gardening frontier. What works in one region might fail in another. What grew well one year might fail the next in the very same location. Such are the ways of gardening - there are many variables that impact the success or failure of a particular crop in any given year or season—even in the same location. Change the location and you have unending permutations and combinations of reasons for failure. Regardless of the number of variables at play, no matter how much effort is put in, or not - two things always remain consistent - some plants will grow and some plants will die. So too is this the way of educational systems, regardless of the effort you put in - some things will work and some things will fail.

Learning to live and work in different educational systems is very much like learning to garden in different climates. Over the past decade, I have seen my share of trials and tribulations in both horticulture and education. Just as I created four gardens from scratch in four distinct geographical locations, I also tended classrooms in various roles in these different places: Central Alberta, Southwest England, Coastal Nova Scotia, and the desert Southwest of Arizona.

Preparing the substrate of the classroom culture is equally backbreaking and time-consuming as working the soil. This preparation is essential to classroom success but does not necessarily guarantee it. Much as a gardener must do so in a new ecosystem, teachers must navigate and establish themselves in a new educational ecosystem with established routines, expectations, policies, acronyms, spoken (and unspoken) rules of engagement, cultural norms (at the classroom, school, and state/provincial level), and of course, the student participants themselves. Even after great preparation, both the gardener and the educator must navigate the complex interactions between all factors that impact garden and classroom success. What works one year, may not work in the next. There are so many hidden and surprising factors. In Alberta, my whole crop of carrots froze in the ground in early September. In England, the snails devastated my carrot seedlings. In Nova Scotia, my carrots were bored through by beetles. And in Arizona, the desert heat produced carrots so hairy with cores so wide they were inedible.

These gardening analogies demonstrate that what might be successful in one place or season can be met with failure the next season or elsewhere. If you only garden in one place, you can develop deep and nuanced knowledge of how to navigate the local ecosystem; however, this knowledge is not necessarily transferable. In my experiences, I found that each place offered new challenges to overcome, but also, new knowledge and opportunities to leverage. What I learned in one place was sometimes transferable (e.g., general pedagogy for student engagement strategies, content of science education standards) although often not (e.g., language, outreach resources and connections, instructional materials, school procedures and policies unique to each school). Each context proved to be unique, with novel variables to consider when enacting reform-based science, and yet, in a general sense, they were largely the same, for "sameness and difference are a matter of context and point of view" (Bateson, 1994, p. 89).

What these parallel experiences in horticulture and education have shown me is that no matter where or what you do and no matter how hard you try, you will invariably experience resistance, disappointment, frustration, and failure. Yet, you too will also experience new success by going where no teacher or gardener around you has gone before, adding new tools and knowledge to your pedagogical, epistemological, and methodological toolbox.

The vignettes included in this section, *Tending the Garden*, illustrate the similarities and differences I experienced in and around science education in three geographically distinct locations. I explore my memories of experiences in and the classroom as a teacher and as a district-level strategist (middle leadership) to provide insight into the ways in which the processes, programs, infrastructure, and outcomes are similar or different between each system in which I worked.

Isolating Variables

[*What are the similarities and differences across my experiences?*]

Ever a scientist in work and play, I have greeted each new experience over the past decade by identifying and taking stock of the variables in action. My approach to gardening and teaching in various ecological and social climates is the same - to make sense of and reconcile my new surroundings by identifying, isolating, inspecting, and cataloging each variable. I carefully turn the variable over in my mind, comparing it to variables from other experiences I have had that were similar in nature. Tucked away in my mental menagerie I organize the element as similar, different, or incommensurable, and use this classification to proceed in what I deem as the most pragmatic manner. I have computed many problems with variables unknown to me to solve the equation. This too, is the basic tenet of algebra, where one must 'isolate the variable', in order to solve an equation with an unknown variable.

Science students are taught from a young age that to conduct a scientific experiment, one must ensure only one variable is changed at a time (independent or manipulated variable) so that one can measure the impact of the variable on the outcome (dependent or responding variable). In comparing my experiences in education over so many different contexts, it is impossible to identify or isolate variables when taken as a whole. But, I can begin to categorize and identify similarities and differences, even if single variables cannot be isolated.

To identify, categorize, and summarize many common variables I observed to impact science education in each context, I created a table (see Table 4.1). Some of the data are public knowledge and present in available documents (e.g., teacher unions, school grades/rankings, science technicians), while other points are based solely on my lived experience. In the latter case, I selected the indicator I felt reflective of most of my experiences. All data included in the table is compiled from my own observations and experiences in each context, compared to one another for different variables directly or indirectly impacting science education instruction. The table is a summary of all variables gleaned from the following vignettes (Part I to III) and serves as a summary.

Table 4.2

Personal observational data collected from 2012-2023 in and around science education

Variable **Sample size (n) noted on right*	**Alberta, Canada** *Schools n= 3* *Teachers n = 7*	**Southwest England** *Schools n=1* *Teachers n= 7*	**Nova Scotia, Canada** *Schools n = 11* *Teachers n = 17*	**Southwest Arizona** *Schools n = 14* *Teachers n = 200*
High teacher efficacy for reform-based science	☐	☑	☐	☐
High teacher content knowledge	☐	☑	☐	☐
High teacher pedagogical content knowledge for reform-based science	☐	☑	☐	☐
Strong teachers union	☑	☐	☑	☐
High teacher stability (more teachers than permanent positions)	☑	☑	☑	☐
School grades/rankings	☐	☑	☐	☑
National / State / Provincial Standards	☑	☑	☑	☑
High-quality science curriculum	☐	☑	☐	☑
Hands-on	☐	☑	☑	☐
Inquiry-based	☐	☐	☐	☑
Phenomenon-based	☐	☐	☐	☑
Created by Educational Resource Company	☐	☑	☐	☑
Science Technician	☐	☑	☐	☐
Science resources	☑	☑	☐	☑
Science infrastructure	☑	☑	☑	☐
Instructional support personnel	☑	☐	☐	☑
Administration with past science or secondary science classroom experience	☐	☑	☐	☐
Standardized assessment culture	Provincial Science testing Grades 3,6,9,12	National Science testing Years 4, 11	Provincial Science testing Grades 3,6,9,12	State Science testing Grades 5, 8, 12
OECD PISA ranking (2015 results)	5	10	15	25
Average teacher salary (as of 2022) **cost of living (CoL)*	$80,000 CAN *High CoL*	£27,003 *Low CoL*	$76,000 CAN *High CoL*	$58, 000 USD *Medium CoL*

Insider Connections

[*Engaging students in authentic school science requires more than the resources provided*]

My connections to science were something I never took for granted in the science classroom. They provided me with access to otherwise unavailable opportunities that I could share with my students. Through my connections with scientists, I was able to organize day trips including: a research day at my old Cell Biology Department to tour labs and meet research professors (Alberta), a trip to the electron microscopy facility (England), and a marine microbial sampling and analysis day (Nova Scotia). I am continuing to bring experiences to students with my partner, a professor, where we bring the wonder of discovery to Latinx/a/o middle school students by sampling and naming new desert protists (Arizona). Planning for these events always takes an enormous amount of time and energy navigating the various bureaucracies of schools and universities.

A theme from my experiences with Albertan science education outreach was 'let us bring science to you'. This was very convenient—all I had to do was arrange a time and someone would bring scientific tools to my classrooms. During my B.Ed. I quickly found the university science education outreach center and explored all it had to offer. It provided a centralized and streamlined source for all things science education outreach. In the short six months that I taught in Alberta, through my connection to and knowledge shared from the outreach center, I was able to arrange the delivery of a portable scanning electron microscope that enabled students to view their samples and a telescope that they could look through to see planets in the day. There was also a molecular DNA outreach organization that would come and provide DNA technique training to students at schools. To deliver the activity through an inquiry-based lens, I opted to pick up the materials myself (DNA gel electrophoresis boxes) so I could use it for an inquiry-based activity that I designed.

My connection to the outreach center deeply impacted my future pedagogy and research trajectories. I kept seeing ways to improve upon what the system provided, furthering the reform-based goals of the system within which I worked. My relationship with the assistant director of the science outreach center, who shared many of my feelings about education, helped to solidify my ideas of how to improve upon it. I would drop in on the center for guest lectures or just to casually discuss the problems of science education. Despite the two decades of age that separated us, we quickly connected and bonded over our outsiderness to the closed realm of education research (I came from cell biology and they came from environmental ecology and law). We both did not have permanent contracts. Perhaps because of this, we chatted informally and freely as equals, outsiders to education looking in, at the vast sea of discrepancies and problems. We were united by our motivation to get in and do something about it and by our lack of formal permanent positions.

Moving to England, I had no connection to the science outreach community. However, using my previous skills, I was able to find outreach opportunities nearby that were surprisingly vast and varied. In contrast to the Albertan 'let us bring it to you' mentality of science outreach, the theme in England was 'come and get it'. Most opportunities were focused on bringing students physically onto university campuses to get them in their doors and using their science equipment (in highly supervised and organized ways). As such, I found several university-sponsored outreach days that were filled with students from other schools. I worked at a publicly funded school with largley lower and middle class students. In my visits to the University, it seemed to me that the other attending schools at all of these events were "public" schools (a strange term for private schools in England) with crisp fancy uniforms, starkly contrasted by my small-town students in their polyester uniforms. Some examples of outreach students engaged in at Universities include a day-long mini cell biology conference (I'm a Scientist, Get me out of here!), a murder mystery DNA lab, and an inquiry-based practical chemistry competition.

One outreach program that I came across, grew out of a pint of real ale at an ale festival. I was making small talk with a former member of the lab to which my partner now belonged. My new acquaintance now worked for an outreach branch of the Society for Microbiology. They told me about an opportunity for selected schools to partner with a nearby university to investigate soil bacteria with the goal of discovering novel antibiotics. They encouraged me to apply. And so, I did, and successfully obtained a grant to be a partner school for Antibiotics Unearthed, a national program through the Society. Microbiology resources were dropped off at our school. Usually, all work was done at the partner university; however, owing to the distance and my previous experiences, we could do about half of the work in our classrooms. After six months of work, student results were written up and displayed as a scientific poster at the Society for Microbiology conference in Liverpool. Myself and two students were able to attend. They presented their poster, and I was asked to give a talk to present our results (Wideman, 2016). Although much of the bureaucratic burden remained in my hands in England, because in most cases infrastructure was available from the universities, I largely only had to coordinate my end of things—such as field trip forms, class coverage, and permission from the school. Planning the activities and collecting the reagents was not my responsibility, which made outreach easy.

In Arizona, I have not been directly teaching in classrooms. Instead, I had the opportunity to research, investigate, and provide various outreach opportunities. As part of my work as an 'Inquiry Science Outreach Coordinator' at an R1 institution I performed several tasks: I co-designed, developed, and delivered teacher-centered inquiry based science professional development workshops for various schools; mobilized knowledge and understanding between researchers, administrators, and teachers to build mutually beneficial connection; collaboratively developed and designed instructional materials and online professional learning courses; contributed to research, scholarly writing, and philanthropic grant writing; and presented research findings at state and international conferences.

After being an Outreach Coordinator, I started a role as a district 'Science Strategist'. In this role I have organized two outreach programs. The first is called Technolochicas and pairs my district with Telavisa, a Mexican telecommunications and broadcasting company. With community college students as mentors, Technolochicas is a for-Latinas-by-Latinas computer programming after school program. In the second, I have partnered my district with my partner's research to bring the wonder of microbial discovery to junior high students. Even though I am in a leadership role, I am still drawn to these experiences.

What was consistent about my experiences is that if I had not engaged and facilitated the outreach, none of it would have happened. I concluded that three ingredients are needed for outreach to occur. First, a considerable amount of commitment is required in the form of funding, infrastructure, resources, and personnel to ensure the continuation and success of these experiences. Second, educators must take on the onus of seeking, finding, and coordinating these experiences for their students. Third, while many great outreach opportunities exist, they are out of reach for most educators and their students. Thus, questions of equity and privilege surfaced. I wondered: What sort of schools and educators are taking advantage of these publicly available opportunities? Why is outreach so out of reach, especially for those students who would benefit most from it—underserved and underprivileged students who don't have parents or teachers linked to STEM professions? And what purpose does outreach serve if it continues to serve the privileged, rather than the underprivileged?

Step into my Classroom

[*Even with the best intentions, reform-based science education occurs only sometimes*]

In England, the design of my science classroom ecology, my pedagogical approach, and my teaching philosophy were all informed by my experiences in scientific research and driven by the desire to create engaging, student-centered, inquiry-based, and meaningful learning experiences for my students. To the best of my abilities, my approaches to enacting instruction were informed by science education research. Scientific literacy and critical thinking skills were the desired outcome of my practice. Scientists were regular contributors to my classroom—either they came to me (with microscopes, telescopes, biodiversity studies, or inquiry-based activities) or I took the students to spacientists (science laboratory visits, microscopes, protist biodiversity discovery, and antibiotic bacterial discovery).

To this end, the classroom rules, routines, structures, expectations, and activities I fostered reflected the values and assets that I brought to the classroom. Classroom rules and expectations were co-constructed with the students. I was always engaged with my students. Sometimes, when administrators or other teachers came into my room, they might ask the students “Where is your teacher?!” I was there, but I was kneeling down next to kids’ desks or mulling around their experimental lab benches (I am only 5’4”, after all). Desks were clustered for collaborative work and students were strategically grouped based on learning needs, assets, strengths, and personality. Students had access to scaffolds and learning tools readily available to them on their desk clusters. Students were given extensive written feedback on their work, expecting to re-submit with corrections.

I liked to display the colorful student work, drawings, photography, models, and/or designs on my classroom walls. Instead of teacher-led lectures, I instead used student-centered techniques including evidence-based structured debates, scientific argumentative writing, and annotation of adapted primary literature on controversial (relevant) scientific topics. Students engaged in debates and were required to argue both the side they supported and the side they were against. I tried to the best of my abilities to foster and nurture equity of voice. When content was amenable to being learned outside, we went outside (e.g., biodiversity study in the school 'garden', velocity and acceleration races/calculations, parachute drops, rocket launching, immune cell tag). In-class hands-on activities happened a minimum of twice a week. Outside of class time I organized and led an outreach trip or experience for different groups of students in various grades - averaging one every two months or so.

I focused a lot of my efforts on many aspects of the policy standards that are not directly tested: positive attitudes and beliefs, scientific literacy, engagement and enjoyment, scientific inquiry, and scientific identities. However, despite this long list of efforts, they merely punctuated the 'ordinary' non-reform based science education (e.g., note taking, worksheets, cook-book experiments/practicals) that necessarily predominate any classroom.

There's Always Room for Dessert

[*Hands-on activities are integral to scientific education*]

As a child my mom always had baking available - pies, cakes, cookies, pavlovas, mousses, squares—there was always room for dessert. Dessert is just part of every meal. I feel similarly about hand-on activities. These are not add-ons or optional. They are an integral part of science class. They are part of the meal.

I have struggled with traditional, teacher-driven instruction my whole life. I have always resolved to provide my students with multiple modalities to interact with, express understanding, and demonstrate mastery of concepts. I do not believe in the ‘one true way’ (as is oft prescribed by the current popular educational milieu) to teach science education. Rather, I believe in many ways, for as a scientist I experienced learning through multiple modalities. There are times you need to sit and memorize information; ponder conceptual ideas; engage in discourse to varying degrees (talk, debate, argue) about scientific data, hypotheses, and conclusions; follow rigid step-by-step methods; explore limitations of methods by changing variables that drive a new and novel method forward; design and or apply models; create figures and analyze data, among others. Above all, the best part of being a scientist is not only using your mind but more importantly, using your hands. And so too, do I believe that there is a place for hands-on for the sake of hands-on in secondary science classrooms, as part of a healthy diet of science education.

Perhaps the single best-selling point of science compared to any other school subject (aside from Physical Education) is the allure of hands-on activities, that is, time away from textbooks and note-writing. The impact of these hands-on activities may not correlate with enhanced scores on standardized assessments (OECD, 2016), but they certainly do for student enjoyment and engagement with the content area (Gatsby Foundation, 2017a). In Alberta, I structured all of my hands-on activities around student-driven inquiry tasks as I did not have a science technician to prepare materials or clean up, so I concentrated my hands-on experiences on more complex activities (quality not quantity) or, I leveraged my science outreach connections to bring authentic hands-on inquiry experiences to my classroom. In England, I had

‘Science Technicians’ to prepare and clean up my experiments, and as such, I incorporated at least one modeling or hands-on activity every other class. As someone who provided a well-balanced science education diet, I believed there was always room for dessert and hands-on activities.

—

Crackers and Margarine

[Are children really the same everywhere?]

It's raining outside. Again. It’s 8am, but the sun hasn’t risen yet. Inside the clammy and cold Science staff break room, a small plastic circular washing-up basin sits in the sink with a few dishes in it and some residual greyish water. A soggy, year-old deteriorating dish sponge accompanies the few items in the washing-up basin placed in the kitchen sink. The kettle boils, whilst mugs nearby hold dry bags of PG Tips, the common English ‘builder’s tea’, awaiting their fate. A plastic pint of milk sits on the counter gathering condensation on the outside, ready for dispatch. A few sleeves of biscuits are scattered on the table, soon to shrink in size as the day wears on, only to be replenished with new full sleeves the following day.

Sallow-faced and reticent, the Post-war relic, a science ‘student support’ classroom aid, sits at our break table, politely taking restrained and calculated bites of crackers meticulously scraped with a thin layer of margarine. When the mood strikes them, they accompany their margarine on crackers with sporadic and sardonic comments that pierce the air. I wince and politely smile. My colleague, friend, and mentor, the Fiery Irish Spirit, laughs heartily and wholly with the Post War Relic. The Post War Relic was the only thing we didn't quite agree about.

On one occasion, I was sipping my PG Tips and milk with a few biscuits over break, sharing to the table that I was totally at a loss with how to manage the behavior of some of my students. I admitted I hadn't seen anything like this before—either students were too reserved and didn't participate, or all hell broke loose, and I couldn't control them. They were complacent or they were beasts. The Post War Relic responded, "Oh for bloody sake, children are the same everywhere!" These students were nothing like the students I had previously taught. However, their words, have stuck with me—perhaps there are more similarities than I had thought—noting similarities and differences along the way.

Factory Farming and Creationism

[*Cultural context provides a backdrop for effective teaching and learning*]

Similarities between students in different countries, admittedly, are relatively generic. Poor classroom behavior can reflect the behavior management strategies used by the teacher. Over time, I think I improved my strategies for the British classroom. Although, in a sense, children are the same everywhere. How students are grouped together to form a school, and how student behaviours are tracked or managed changes from place to place. Thus, different contexts result in different spectra of behaviours—such as how many behaviour and learning codes students has, if the student's family is on social welfare, if the school is of religious affiliation (e.g., Catholic), or if there are private schools nearby taking students out of the encatchment area. Further, the cultural norms of the school, families in the area, and the country itself bleeds into what expected behavior should look like (e.g., regarding in-class behavior and homework expectations). In many ways, there are cultural behavioral differences, but once you learn how to adapt to them, students are indeed, rather similar. It just takes time.

Similarities and differences also existed within the content of the educational standards. Evidently, England was scientifically progressive in the relevancy of their science curriculum regarding new or emerging scientific technologies or discoveries. Local, place-based learning is also a factor to consider; for example, the oil sands is taught within the Albertan context, whereas the ecology of the blue tit is taught within the English context. Moving from Alberta, Canada to England I hadn't considered how substantial the differences are in the 'what' of science that is being taught. Equipped with engaging minds-on activities I developed and insight into common student misconceptions in Alberta, I walked into my first year of teaching in England, assuming it would translate. I was in for a surprise.

In Alberta, I always approached teaching evolution through the lens of anticipated conflict. Thus, prior to instruction, I would soften the vocabulary of religion and science by urging that neither need be discarded. Each answers different questions and both could co-exist if they were relied on in different ways. I Alberta, we did an open Q&A period where students could ask and explore any ideas or notions they had about the topic. For the most part, this quelled most of the resistance to engage. However, there was one particular student, a skinny small statured 7th Grader, who refused to complete the homework research task regarding the topic of 'what evolution was and how it was central to the study of Biology', which required at least 3 citations to support their claims. This student declared themself a 'Young Earth Creationist'. I suggested they might write two separate papers - one outlining their beliefs about the origin of life and one outlining the science of evolutionary theory. I was expecting a similar breadth of opinions about evolution when I came to England.

It turns out, Charles Darwin, the father of evolution, was on the five-pound note. Evolution is as embedded in British culture as is the pasty. Students looked at me with blank stares, asking - 'what you on about, miss*'?* Needless to say, my lesson plans for the next three days were ruined, and my ego was bruised. How *daft* North Americans are, their eyes said.

I had a similar experience when I decided to teach my students about factory farming. In Alberta, factory farming (in addition to GMOs and Fossil Fuel extraction/use) was on the rise and rapidly becoming an issue for biodiversity and environmental management. In my Albertan classrooms, I created scaffolded research tasks that explored all sides of these issues for students to complete to build their arguments that they would later use in fervent debate.

When I pulled out my factory farming research and debate resources I had developed in Alberta, students didn't even understand the term—once again looking at me with blank stares. They explained they had nothing like that, but rather, a series of small, family-owned pastures that produce the meat, dairy, and vegetables for much of the country. This corroborated my own experiences later, as I bought this very produce from the farm stands, traversed the pastures, and crawled over the stepped stone gates as we did our countryside walks. Evidently, factory farm creationists do not exist in the UK.

What these two stories illustrate is that ultimately, "sameness and difference are a matter of context and point of view" (Bateson, 1994, p.89). Some things are the same, while others are different. Some impact instruction, others do not. Culture is at the heart of education – at the classroom, school, and national level. This culture unavoidably and invariably seeps in and intermingles with instruction. To make sense of the cultural shifts—whether it be about classroom expectations, content, or strategies, (embedded within the larger cultural context) required me to frequently engage in "reinterpretation and translation", which Bateson (1994) notes is, “so useful in moving from one culture to another” (p. 86). However, to survive and transfer my cultural learnings between countries, despite the differences, I had to rely on my ability to recognize continuity (Bateson, 1994).

—

Practical Practicals

[Technicians are practical solutions to the extra work required to prepare hands-on activities]

In English schools, experiments are called practicals. Students would always beg for practicals: ‘*more practicals, more practicals*!*’* I had no problem appealing to these desires as we had two full-time technicians and fully equipped classrooms that made providing these experiences for students, practical. In every science classroom at my school, there were multiple sinks and science workspaces around the perimeter of the classrooms. Additionally, every classroom was equipped with a class set of Bunsen burners and flint sparkers, microscopes, clamp stands, glassware of various shapes and sizes, test tubes, goggles, crucibles, Petri dishes, Newton meters, stopwatches, masses, and ramps. Each class was equipped for the execution of science experiments of all types.

The Year 7 - 13 Science team consisted of 7 or 8 teachers each teaching 5-6 classes a day. Longitudinal instruction was the expectation of this school, and as such, I taught every Year almost every day. This required lesson planning for five or six different lessons every day. Between break and lunchtime duties, there was no time in the day to prepare/clean up practical work. Luckily, we had two fantastic technicians who purchased, prepared, maintained, disposed of chemicals, and cleaned materials and scientific tools needed for practicals. All we had to do was provide a requisition for all the needed items the week before our planned practical. Requisitions were due on Thursday mornings. Mine were always late but the technicians were gracious enough to fill them anyway.

I once asked my colleagues if science technicians were common in schools in England, and they looked at me confusedly—'*But of course! How else would science teachers do practicals?!*'. So, while science technicians were not novel entities for my colleagues (Gatsby Foundation, 2017a), they were for me—and it was this novelty that contributed to my consistently packed weekly requisitions. For me, thanks to the technicians and the underpinning system of cultural values and educational policy provided funding for their position (Gatsby Foundation, 2017a,b), practical work was made practical.

Storm Chips

[Stormy liminality of a substitute in education in the East-coast of Canada]

Substituting. Most teachers either start their teaching career substituting until they can get into the system, or, come back from pensioned retirement for extra cash. I only substitute taught while living in Halifax after my few years in England. Clearly, I wasn't a new teacher, nor was I coming out of retirement when I took to substituting. Teaching in England burned me out to a crisp. Knowing that our situation in Nova Scotia was temporary, combined with my burn out, I was in no space to take on a full-time job in yet another culture. I instead chose to embrace the liminal. For me, substituting felt a degrading, dehumanizing, and deprofessionalizing. I felt like a scab, peddling my CV around the city just for a few hundred dollars a week.

Eventually, when I got into the rotations at a set of eleven schools, it was admittedly easy to embrace the job once I realized no one was judging me for the professional feats I achieved, or my innovative approach to science instruction, or the fact that I was a scientist, or that I was in an EdD program. I was a substitute, a legally certified body to fill a classroom, and that was all that they needed. So, I embraced this position—for the first time in my life I woke up without stress associated with my job. I went out to shows, played late-night frisbee, and went hiking or canoeing right after school let out. As long as my depression didn't weigh me down, I signed up for a sub opening for the next day. I didn't plan lessons and I didn't mark. I arrived a few minutes before the first bell and left a few moments after the last. If I had a prep, I read education research papers in preparation for my EdD, or went outside and napped on the school greens in the sun while everyone was in class. Eventually, I was able to get onto several rotations as one of the main subs at different schools and knew in advance when I would be subbing.

The downside was that I didn't have a real contract, had no benefits, and had no guaranteed income. The pay was poor, and sometimes I wouldn't even get paid. Halifax is notorious for its horrible winter storms, called Nor'easters. 'Storm days' are days when school was cancelled. On 'storm days' even if I had been scheduled to work, and school got cancelled, I didn't get paid. Storm days occurred frequently in the late fall, winter, and early spring months. It would snow several feet in a white-out blizzard for hours, which often would be immediately followed by an aggressive downpour of freezing rain. Sometimes the severity of a weather system approaching would be anticipated and announced, at which point, everyone would head to the grocery stores and stock up on storm chips, clearing out the aisle. In fact, this phenomenon was so common an occurrence that a local snack manufacturer created a special blend of chips called *Storm Chips* (containing several different flavours of chips all in one bag!). Though I did not get paid, I certainly enjoyed the storm chips.

The Death of Classroom Microscopy

[Specialist knowledge and skill is required for many hands-on activities]

Classroom microscopy is now largely antiquated—perhaps, rightfully so. The following vignette will outline my argument to support this statement. Microscopes are finicky things, and to no fault of the students, they get miscalibrated rather easily due to use and misuse—a microscope, after all, is a real machine used by scientists. Teachers are not formally trained in how to use microscopes, evidently it was assumed or expected that they learned how to use and fix these tools in previous educational experiences. The following observations corroborate these tenets. In my classroom in Alberta, Canada, microscopes never saw the light of day, encased in Styrofoam and boxed up. In England, microscopes were miscalibrated and abandoned. In the Arizona, U.S. they are ghosts of the past. Like photography, microscopy is close to my heart. It was the centerpiece of my graduate studies, it is my connection to the inner world of the invisible. I sought to bring the beauty and magic of microscopy through science education.

I have taught Grades 7 through 12/13 as well as university science laboratory courses. No matter what grade or age—students encounter the same problems when learning how to use a microscope. Most of the amazing student discoveries turned out to be a ball of dust or the edge of the slide or some miscellaneous particulate. Microscopy requires time and patience. One year 7 class (6th-grade in North America) in England, I had spent the year outlining my instructional plan to embed as many microscopy opportunities into my classroom as possible— for microscopy is a skill that needs to be honed and practiced over time. The other years I taught (Year 8-13) had much more rigorous content I had to get through with them, and thus the Year 7 classes were prime candidates to dive deep into microsopy. By the end of that school year, my Year 7 students were able to troubleshoot, navigate, and even discover (to my surprise) how to take pictures of their findings through the ocular piece with their smartphones.

I went through painstaking efforts to get our microscopes serviced, upon noticing that the majority were unusable. The science technician, who had worked there for at least a decade looked at me like I was daft when I asked, for they had never been serviced before, so why should they be now? No one ever complained about the microscopes not working until me, so they assumed my class had broken the microscopes. However, upon a brief explanation of my background in science, and reviewing each microscope in the entire science department with them, it was clear that out of a class set of 15, only 1 or 2 were in working condition. This suggested to me that for several years either the microscopes were not being used, or neither the students nor the teachers were using them correctly. Both the teachers and students were simply going through the motions of "microscopy" without confirming what they had seen. This echoes my experiences teaching university science laboratory classes in Alberta, Canada, when students would claim 'Ya, we did microscopy in school, but it never worked, we never saw anything'.

Because of its difficulty, perhaps it is understandable that microscopy has fallen out of fashion. This trend is apparent in new science curriculum learning activities and state or national standards—microscopy is no longer mentioned (e.g., National Research Council, 2013). I am of two minds about this. First, I am sad. Microscopy provides a beautiful opportunity for students to connect with the everyday invisible to discover the microcosm. Second, and more pragmatically, I am indifferent because the activities did not provide students any benefit because they were rarely used, and even if they were, the microscopes didn't even work anyway. For microscopes to work, they need to be maintained and serviced almost every year.

Nevertheless, it remains my personal crusade to keep some sort of connection to microscopy in the classroom. In the coming year, with my partner I am implementing an outreach program in which we will bring protistology to underserved communities in the desert southwest of the U.S. Our goal is to engage students and their teachers in authentic scientific inquiry to discover novel protists in the desert. We will bring small field microscopes to the class and project images in the classroom. Unfortunately, these microscopes are not kid-proof and need to be handled by adults, but they are portable to bring the microcosm to students.

Aside from our desert protist project, there are other science outreach microscope renegades out there, fighting the good fight. This has further fueled my passions and inspired me with ideas. For example, the most wonderful science center, Micropia, exists in Amsterdam, Netherlands, where they have reconfigured expensive million-dollar microscopes to work like an etch-a-sketch using a modified table on 2-D thin glass with concentrated cultures of incredible microorganisms. The Small World Initiative of the Society for Microbiology invites students and their teachers to work alongside researchers to discover novel antibiotic-producing microorganisms (Wideman, 2016). Many science outreach university trips bring students to microscopy labs (Plymouth University's Electron Microscopy Laboratory) or bring scanning electron microscopes to students (the University of Alberta's Center for Mathematics, Engineering and Technology Education). There is much work being done to keep microscopy alive, but unfortunately, it remains an opportunity that is solely provided to the privileged students who have teachers that seek these opportunities out. Microscopes have, and continue to be even more so, tools for the few privileged, not the many, despite efforts to shift the narrative.

As I reflect on my own childhood experiences, I wonder, how did I come to have this passion for microscopy, and I realize it came from an unlikely place. I attribute my love of doing and teaching microscopy to my mom. I spent my junior high years waiting for my mom to get off work. After school, I would walk to her work and do my homework from a textbook in the empty waiting room from 4-5 pm. She worked as a technician in a medical lab. My father didn't respect her job. He wished she made more money. He failed to understand that her job was scientific and technical and worthy of respect. I gained an early love for microscopy thanks to lax restrictions in the '90s such that when the lab was empty, my mom let me look at some samples through her high-powered microscopes. A whole new world was revealed to me, all thanks to my mom, who let me into a world otherwise unavailable. I only wish to keep the magic of microscopy alive in some way, even if it is dead in the classroom.

Teacher Technicians

[The extra burden of teaching science seriously]

My first teaching assignment was for a maternity leave position at a Catholic junior high in Alberta, Canada. I came into the classroom halfway through the year. While I was grateful to see plenty of counter space in the back and miscellaneous science equipment stuffed in the science closet, I, unfortunately, didn't get the opportunity to use any of it during class time. Hands-on experiments during my instructional class time were absent. Either the units I came into were not amenable to school experiments, or I didn't have the necessary resources available. Determined to provide some form of engagement, I created engaging minds-on debates, research projects, and discussions for the students to engage in about the content area. Further, I leveraged the school's 'Friday Flex Days' to provide students across the school with inquiry-based activities. Friday Flex Days were part of a school initiative where students would cycle through rooms of their choice to support their learning needs, instead of attending regular classes. Other teachers provided 'study-hall' type sessions for their students, and word quickly caught on about my interactive sessions, and students across the school filled my sessions to capacity. During these sessions, students engaged in themed inquiry-based activities I had prepared for them (e.g., CSI unit, Zombie Apocalypse, Scanning Electron Microscopy school visit, DNA Electrophoresis murder mystery).

None of the three Albertan schools I had experience teaching at nor two others at which my acquaintances taught had science technicians. Most schools had some scientific equipment and some degree of appropriate laboratory infrastructure. Upon asking my two B.Ed. mentor teachers about hands-on experiments, they rolled their eyes and scoffed with a sentiment of '*…And just when would I find time to do that?'*. Talking to an acquaintance who taught at two different high schools rolled their eyes at me, with a similar sentiment. When I asked the other three Science teachers at the junior school where I held my first teaching position, what sorts of science experiments they did, as sweet and lovely as they were, they confessed they never did any as they 'just couldn't find the time—the curriculum was too full and they had no time to prep'. It is notable, that while teachers were at some time provided provincial standards, textbooks, and a hodge podge of miscellaneous science 'equipment', there was an absence of curricular materials for inquiry-based experiments that aligned with the standards.

Like my personal experiences in Grade 6-12 Science in Alberta, even a decade later, things were still the same. As a student, I recall that any experiment I did in junior high was homework for a "research project" of my own making to be done afterschool, outside of class time. In high school, I did one frog dissection near the end of Grade 12 in Biology, two experiments in Physics, and one field trip to the big city's indoor roller coaster park. I did not do any experiments in Chemistry. I can count the number of in-school hands-on experiments/activities I did as a student over a span of 6 years in secondary science on one hand.

The phenomena of teacher technicians and the resulting outcome of far-and-few-between in-class hands-on and/or inquiry experiences were also observed in the majority of the science classrooms I substitute taught at in East Coast Canada over a period of one-and-a-half years. Across three high schools and eight junior highs, none of the schools had science technicians. Notably, while there was science infrastructure (e.g., workspaces, generic science equipment) in some of the high school science classrooms, there was none present in most junior high classrooms. While subbing in classrooms I talked to the students about what sorts of things they did in the science classroom and how often they got to do hands-on experiments. The answer was overwhelming that they rarely did such activities, but rather copied out of textbooks and completed worksheets. I would always look around the rooms for artifacts of inquiry-based activities but rarely found any such evidence. In the lunchroom, I would make small talk with the teachers - some of which would be science teachers and ask them about their experiences with hands-on experiments. I received similar answers to those of the mentor teachers and my past fellow colleague in Alberta.

Over the year-and-a-half I lived in Nova Scotia, I became professionally closer with two science teachers, one middle school and one high school teacher, who provided me with some deeper insight into the system. The junior high teacher was, of all things, British and had moved to the East Coast of Canada in their mid-twenties, and 'hadn't looked back since'. At the time I met them, they were four years from retirement. This person shared that they had been asked to collaborate on the new upcoming provincial Science curriculum. Currently, they were experimenting with what would be the new curriculum in their classroom as a beta before it went live the following year. Although, they admitted that the curriculum they had been tasked to collaboratively create was nowhere near being completed, it was interesting to hear their perspectives on the curriculum design process—that they, along with other teachers were part of the process, but not really driving or designing it, and rather 'along for the ride'. That was four years ago. Looking at the current (22/23) outcomes and curriculum guides for the province, they only have "new" outcomes (a three-page document), but as of March 2022 "The curriculum guides for Science 7, 8, and 9 are old and do not match the current outcomes" (DoEECD, 2001).

The other teacher I became acquainted with was an AP high school chemistry teacher who was totally and completely obsessed with inquiry-based hands-on experiments and mind-on activities. We bonded over our commiserations. They spoke of their frustration with the system: how the provincial outcomes required hands-on/inquiry-based experiments to be conducted and yet schools were not provided science technicians or all of the materials required to conduct these experiments. Further, they noted that even in the absence of technicians, science teachers were not provided additional time to prepare or clean up after these experiments. They shared how they were consistently one of the first science teachers to arrive (to prepare the experiments for the day) and the last teachers to leave (to clean up the experiments for the day). When I asked if these frustrations were shared by their colleagues, the teacher responded 'no', and that 'other teachers generally opted to avoid the hassle altogether'. In my experiences, in both Albertan and Nova Scotian science classrooms technicians were absent. Instead, teachers were left to shoulder the role in addition to their teaching load, which all but a handful chose to do.

Kit Culture Couture

[Repair and maintain, or simply replace: hands-on science resources]

The American approach to science education materials is to sell pre-packaged science kits. These kits are sold under the illusion that ready-made science will make it easy for teachers to execute science in their classrooms *without* needing to provide the necessary permanent infrastructure or high-quality resources. The science kit culture in America lends itself to align with the consumerist, neoliberal inclinations of the U.S. The common expectation (of both the buyers and the sellers) is that these kits (should be) replaced after 5 or so years with the newest and greatest. Obsolescence is both expected and premeditated. Perhaps the vast differences between the approaches to hands-on science are a symptom of the greater cultural differences between England and the United States.

In every country I have worked, curriculum companies compete with one another to provide educational materials (aligned to state, provincial, or national standards) for schools to purchase. In Alberta, the extent of offerings was textbooks from one of two approved vendors. In England, there were two approved companies to choose from that offered pre-made slideshows and assessments aligned to national standards and assessments. In the United States, there are endless companies from which to choose from. In stark contrast to the textbook science Albertan model and the permanent science UK model, American Science kits contain boxes of curated materials for pre-designed science activities that are designed for a scripted curriculum aligned to the science standards. All you need to do is follow the script on the PowerPoint slides, open the kits, and, in theory, there you have ready-made quality science resources and materials for phenomenon-driven inquiry-based science instruction. The specifications and format of the science kits were intentionally designed to account for commonly cited variables that prevented hands-on science from taking place in the classroom. The science kits were intentionally designed to remove all the guesswork, preparation, and planning from the equation—an open it up and 'go' product. Just as the appearances of drag queens are deceiving, so is the case with the American science kits, albeit without the fun theatrics.

The school district in Arizona, for which I am a Science Strategist, chose to adopt a rigorous and standards-aligned curriculum (Amplify Education, 2019a,b; Nilsen et al., 2020). Before my arrival, the district convened a committee made up of teachers and the preceding strategist. They reviewed and piloted curricula from four different vendors. In the end, Amplify Science was selected by the committee and adopted. The Amplify Science curriculum is one of the reasons why I chose to work at the district, the other is to serve the diverse population of underserved students by bringing them high quality science experiences. Through my previous research at the university outreach center (see vignette *Insider connections*), I already had high opinions of this program.

Although I was immediately curious about its origins, it took over two years to get to the bottom of Amplify Science. No one in the company I spoke with knew who or how to find out who might know anything about its origins. Yet, eventually, persistence paid off, and I was able to trace its roots to a professor at the University of California, Berkeley who was historically tied to the origin story. The following information comes from a conversation with the professor who graciously answered my probing questions, which to this day, I have been unable to find documented elsewhere on the website or in academic journals (although, I have since found the Wikipedia entry for it: https://en.wikipedia.org/wiki/Amplify_(company)). From this conversation, I discovered that Amplify Science originated as a grant-funded project out of the University of California, Berkeley through the not-for-profit Lawrence Hall of Science, a public science center that focuses on educational science programming. Previously the Lawrence Hall of Science created and disseminated the infamous "FOS" kits (Full Option Science System), the first generation of a kit-based science program, which, the rather complete and unused remains, fill a substantial portion of my sizable district science room. In response to the Next Generation Science Standards (NGSS) released in 2013 (National Research Council, 2013), The Lawrence Hall of Science sought to create a literacy-rich, phenomenon-driven science curriculum aligned with the focus on the science and engineering practices that drive the NGSS. However, the ability of the Lawrence Hall of Science to robustly develop and distribute this curriculum was limited by the few million dollars they had received in grants to develop the program. This required them to partner with a series of publishers and companies (first Wireless Generation and then Newscorp which eventually developed into Amplify Science). By partnering with a for-profit company, nearly a hundred million dollars was made available for investment to further develop and scale up the distribution in ways not possible with the more meager grant-funded budget of a non-profit. That is loosely how a science education research-based curriculum was born in the crucibles of academia, which now dominates the neoliberal landscape of K-8 Science education in the United States.

It is important not to forget of course, that despite best intentions, this research-based curriculum is after all, a product sold by a for-profit company. Like much of consumer society, my personal experience with Amplify was that the company rep is excellent at upselling and quickly producing quotes for kits, materials, and digital subscriptions (with sums totaling over one million dollars), but harder to track down for support after the sale is made. In the drive to create a profitable product from a well-intended idea, we have found out that a few corners have been cut. As a district we had to purchase over ten thousand dollars of items to stock the kits with what the company deemed as "teacher-provided materials" (e.g., mixing bowls, kettles, flour), not to mention several thousand more dollars and hours wasted employing someone to purchase and distribute into kits across the district. Without a doubt in my mind, Amplify is the most rigorous and NGSS-aligned science curriculum out there (Nilsen et al., 2020)—perhaps the best money can buy. However, this doesn't mean the program isn't without flaws or worth the value it is selling for. After all, this is a multimillion-dollar company that netted over $100 million in revenue in 2018 (Wiki). The profit must come from somewhere—the question is at what cost and whose expense?

Unlike the high-quality materials gracing the science resource room in England, many of the kit items are of exceptionally low quality (e.g., flimsy plastic bar magnets that demagnetize after one use, the plastic bins handles easily break, and sticky-notes are no longer sticky). Having spent several years in the classroom conducting similar hands-on experiments, I can immediately tell that the non-consumable items will not last very long, as the quality certainly does not have staying power. Upon sharing this information (along with the associated costs of fixing these errors) with the sales rep, I was met with the annoyed defense 'Well, go find a curriculum that does better than ours. There isn't. It could be worse'. Which, I know to be true. It is an unfortunate shame that marketing and 'the sale' has superseded quality and well-intended origins, reducing the curriculum to its neoliberal fate, the product of a company whose primary objective is to gain profit from being the best.

The illusion of the American solve-all to the science education crisis, an all-inclusive ready-to-go science kit as advertised by Amplify are not as inclusive or ready as they are advertised to be. The company is selling the illusion of something that is different than the purpose behind the original intended design, all in a flashy package. This illusion perpetuates the

American cultural mindset of replacement consumerism. Perhaps it makes sense that replacement consumerism is the dominant discourse, given the wise words spoken by Dr. Wong to Pickle Rick (the main character, Rick, who turned themselves into a pickle to avoid family therapy): "Because the thing about repairing, maintaining, and cleaning is… it's not an adventure. It's just work. And the bottom line is, some people are okay going to work, and some people … well, some people would rather die. Each of us gets to choose" (Dr. Wong speaking to Rick, Rick and Morty, Season 3, Episode 3: Pickle Rick) (Harmon & Roiland, 2017). Somehow the science American kit culture has perpetuated the avoidance of work for repairing and maintaining science education systems, preferring the flashy, but dispensable, new science kits.

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What'd You Get on the Test?

[Inherent problems with standardized assessments impacting the culture of educational systems]

The question, 'What'd you get on the test?!' has followed me since I can remember receiving my first marked assessment, and one that continues to persist well into my adult life. Milliseconds after the assessment results land on a desk or are uploaded virtually, they are snatched up - by students, teachers, administrators, policymakers, government officials, and the general public alike. I see this same urgency reflected across the educational landscape, where every waking moment is spent working towards achieving 'the grade' at all costs, for it has seemingly become the only real measure of success or growth at all levels. When the PISA results for student achievement in Science, English, and Math come in, OECD countries blast their results across the newspaper headlines - whether good or bad. In England, every school was audited once every three years by the national government Office for Standards in Education (OFSTED). Student growth, learning conditions, school culture, and instructional quality were assessed, resulting in the delegation of one of four standings (Outstanding, Good, Requires Improvement, or Inadequate). In Arizona, U.S., The State Board of Education annually reviews every school based on criteria to determine the 'A-F School Letter Grades'. A large part of this grade is the student academic growth and proficiency of English Language Learners. In Alberta, Canada, which consistently ranks in the Top Ten for the Science PISA, close on the heels of Finland, the government does not rank schools.

Each country follows different assessment structures. Thus, the time spent assessing students in each country varies. In the UK, students are only subjected to two standardized national exams - one in Year 4 and one in Year 11. At the school I taught at in Devon, England on the Southwest coast, regular assessment was a prominent expectation for KS3 (Year 7-8) and KS4 (Year 9-11), as teachers were expected to monitor the growth of students every quarter. The grades and growth of each student were compared between subjects to identify trends and support. Part of the OFSTED grade our school received was related to the growth and achievement of our students in the Year 11 national assessment. In Alberta, Canada, students are assessed through provincial-wide standardized assessments in Grades 3, 6, 9, and 12. As such, assessment is very much embedded in the educational milieu and takes precedence in the classroom. In Arizona, U.S., students take a standardized science assessment in Grade 5, 8, and 11. However, in Title 1 school districts, (districts that have been identified as having schools with high percentages of children from low-income families), the state provides additional "financial assistance to help ensure that all children meet challenging state academic standards" (https://www.azed.gov/titlei). This funding is incredibly helpful, but it does come at a cost, for much of this funding is tied to additional assessments. According to the testing coordinator at my district, over six full weeks of the school year are taken up with testing. Testing is top of mind in the K-8 district and is often cited as a reason why teachers cannot keep on pace with instruction—especially at the K-5 level.

I saw this phenomenon of 'what'd you get on the test?!' in all typologies of students I taught - the keeners, the average students, and the unengaged students. They were looking for something in this assessment grade—somewhere in between positive or negative reinforcement. I saw this phenomenon in teachers when their students' state, provincial, or national assessment scores roll in. In the case of Arizona, state assessment scores are loosely tied to 'performance pay'. In the case of England, a cultural sense of pride and professionalism was tied closely to student growth and achievement.

This phenomenon also exists at the school administration and district level. In the case of Arizona, school site grades are intimately dependent on student achievement and growth. The district I currently work for is driven by the desire for growth and achievement on state and grant-required benchmark assessments throughout the year. Thus, the district requires students to be tested regularly using frequent benchmark assessments in Math and English. Schools are measured and compared on a regular basis for student achievement and growth, the results of which are displayed in district-wide meetings or communications.

In all cases, the unmatched eagerness to see a grade is inversely proportional to what comes after, which is usually nothing. The chase was in the grade or assessment result, not in the work that needed to be invested afterward to strive for better. Similar is the case with a health scare - we wait with bated breath to hear the results of a health test, vowing to do more exercise, floss more, and eat better from now on. Then the result comes back negative, and we exhale with relief as we carry on with our *modus operandi*, forgetting these resolutions immediately. So, too, is the case with assessment in education - the hammer drops, and with it comes relief, disbelief, or indifference. And the day-to-day modus operandi largely resumes unchanged, regardless of the outcome.

Overstuffed, Underpaid, and Overworked

[*Is effective science teaching possible in current conditions?]*

There are three common unifying themes across all teachers I have met in Alberta, England, Nova Scotia, and Arizona. First, they feel that the curriculum is overstuffed. Second, they feel underpaid. Third, they feel overworked. In my experience, some of these are more true than others, when comparing contexts with the experience in three vastly different systems other than the one in which the teachers are situated. There are challenges to consider such as cost of living, available health benefits, availability of stipends, and the presence and/or strength of the teachers' union. All things considered, here is my personal assessment of these claims that I experienced in relation to each of the contexts, compared against each other.

England was where I experienced the phenomenon of an overstuffed curriculum and where I felt the most overworked. Not only were there numerous rigorous instructional standards, expectations, and policies but the follow-up on the enactment of each of these was relentless. The college (Year 7-13) had extremely high expectations - for professionalism, instruction, and content knowledge. As per the National requirements, my colleagues all had full degrees in the science they predominantly taught in addition to a separate teaching degree. My fellow A-Level Chemistry colleague, the Fiery Irish, was ABD (all but defense) for the Masters in Chemistry. One person was fired because (among other things), they incorrectly taught a physics concept while the headmaster was in their class. If you did not meet their rigorous expectations, you were terminated before the end of year. Unbeknownst to me, prior to my hiring and arrival, the entire Science team (barring the Science Department Head) was dismissed. At the end of my three years at the college, only myself and my Irish colleague (who had been hired along with me) remained. Step up or step out.

At the Year 7 - 13 college in which I taught, the expectation was that teachers taught all grade levels (I was told this was common practice at other schools, too). I have coined this as ‘longitudinal instruction’, meaning, I concurrently taught seven grade levels at once - Year 7 and 8 (Key Stage 3), Year 9, 10, and 11 (Key Stage 4), and Year 12 and 13 (A-Levels). This required me to create seven individual lesson plans and laboratory requisitions daily. I recall having only three prep periods per fortnight. This meant my evenings and weekends were spent lesson planning or marking. In addition to this, my personal desire to engage students in authentic inquiry-based science experiences was as strong as ever and I relentlessly sought to provide engaging outreach opportunities for students. I planned several trips over the course of the three years I taught there, on average, four to five per year spanning the various grade levels I taught.

Expectations for departmentalized Professional learning communities (PLCs) were very high, and as a result, our PLCs were like clockwork. Once a fortnight we met to analyze data from our common summative assessments, backward design, and/or engage in marking circles. By necessity, we had to teach similar content, using the same common formative assessments at a similar pace. Instructional pacing was always raised as a challenge by all team members, although, I admittedly struggled with it the most, as I always did more hands-on practicals and debates with the students than my colleagues. The curriculum was by far the heaviest and most overstuffed I have experienced. Practical scientific skills, scientific writing, along with in-depth content were required to be covered to fulfill the standards. The UK Science curriculum was by far the most rigorous and robust curriculum I have taught or supported.

Our marking was assessed on a fortnightly rotation, where an assistant principal or our department head would come and do a 'book check' on a random class. They were looking for the enactment of the rigorous marking and feedback policy at the school: every student's book must provide evidence of feedback once a week. The teacher would mark in red pen - leaving a question or suggestion of how to improve their work. The student would respond to this feedback in green pen, and following the feedback given, respond to the question, reflect on their learning, or provide the corrected answer. This would have been a more manageable task had I only taught a few grade levels.

Every student in England has a target goal and this target goal is metaphorically stamped onto their forehead. The target goal is a grade that the students are given based on their achievement from the national standardized test they take in Year 4. This target goal represents the grade that that student should achieve at the end of the Year 11 National Exams. As a teacher, it was my duty and responsibility to do everything in my power to support each student toward achieving that grade. If they fell behind in their growth towards that grade, (especially with respect to other subjects), I was required to justify why and provide evidence of all the scaffolds, supports, and additional help I gave students.

Colour-coded classroom maps/keys were required for every class as evidence of intentional and differentiated student groupings. The maps had to show the behavioral or learning need codes of each student, if they had free school meals, and their target grade. Students were required to be grouped in differentiated and diverse groupings to show that students' needs were being supported by intentional grouping. In most of my classes over 35% of students had at least one code.

At the end of every quarter of instruction, we had to identify the level of growth each student made over the term. This was challenging from a Science perspective as some students excel in one subject area over another (Physics, Chemistry, Biology). Also, one had to take care so as not to show too much growth of a student (even if it was accurate for the quarter in question) as we were assessed on how much our students exhibited growth over the course of the year, and so continued exponential growth was expected. I have never taken on so much ownership of student success. Quarterly report cards needed to be completed for every student, requiring extensive written feedback to each student about their progress toward their target grade, growth areas, and strengths.

In my opinion, England proved to have the most overstuffed curriculum and the most overworked educators. Yet, the British adage ‘Keep Calm and Carry On’ rings true. I rarely heard anyone complain, for that was what the job entailed, and after all, this was the profession they chose. We just ‘got on with it’. From this experience, I learned a lifetime of lessons in instructional excellence in a mere three years. Interestingly, I never heard teachers complain about their wages, either. Every teacher I knew owned a decent car and a decent house and vacationed in Europe for the holidays. The quality of life was high (nationalized universal healthcare) and the cost of living was low (inexpensive fresh farm produce, artisan cheese, and pints of real ale).

Teaching in Alberta, the same three themes emerged – that curriculum is overstuffed and teachers are overworked, and underpaid. My father always resented the fact that my mother didn’t pull a teacher's wage - “We’d be rich if she did!” he’d frequently lament. I constantly heard teachers claiming they were underpaid, which, for some odd reason, usually sparked debate between the nurses and teachers, which led to them taking turns attacking the others' wage, each claiming the other was paid too much, and they were paid too little for "what they did". It was a common narrative I was used to. However, putting this scenario in the context of my other educational experiences, Albertan teachers in relation to the other contexts, are paid incredibly well. This may be owed to the strong provincial teachers' union or the oilsands raising the provincial wage expectation. Something that I grew up knowing, but has only been further reinforced since teaching elsewhere, is that Albertan teachers have incredible benefits (such as regular massage and annual multi-day teacher conferences that are fully compensated (food and lodging)). In Alberta, the only degree required to teach in secondary education is a Bachelor of Education.

Regarding the overworked claim in Alberta is also speculative. Typically, teachers taught only one or two grade levels. Sometimes junior high teachers taught more than one subject or more than two grades, but these assignments were largely given to new teachers entering the professions with the more senior teachers holding onto their two different grades (junior high) or up to three different grades (high school). My first teaching assignment was Physical Education, Science 9, Science 8, Math 8, and Religion 9. However, the PE class was a co-taught class (plus required no marking), and for all the other classes, I only taught the same 2 groups of students. It was the easiest teaching assignment of my life, a true dream. As far as I am aware, however, teachers did not get compensated for supporting extracurricular or sporting activities - it was considered a professional expectation for teachers to also take on coaching or extracurricular activities leadership roles - again usually, but not always, reserved for either new teachers or the PE teachers.

Regarding the claims that the curriculum was overstuffed, I can only speculate as my experience was limited. I knew that scientific skills and literacy were part of the founding pillars of the provincial standards, but when in classrooms and talking to my colleagues, their students rarely, if ever, engaged in scientific discourse (written or verbal) or hands-on activities, leaving only the facts of the content. That being said, for my first year in the classroom, my fellow Science 8 and 9 colleagues encouraged me to give the last unit of study as a 'homework packet', because there simply wasn't enough time to get 'through' the content and that this happened to them every year. In fact, in anticipation, they had already printed the unit homework packet for both of us, as they had done every year prior.

In Nova Scotia, listening to conversations across many lunch breaks I heard each of the three common themes - overstuffed curriculum, overworked, and underpaid. Owing to the high population on the peninsula of the capital city, coupled with strong unions, there was a lot of competition for any teaching positions that opened. Like in Alberta, the teacher union was very strong, and once one had passed their 'probationary period' unless they committed a serious misstep, teachers were locked into those positions for life. New teachers to the profession or city were placed in endless substitute or short-term positions. New postings were opened up in staggered waves. First, positions opened up to teachers with the highest seniority, and if no one in that category took the job, then it was opened to teachers with subsequently lower seniority, and so on and so forth, until, if there were any scraps left at the end of this process, new and/or substitute teachers were then allowed to fight over it. There was absolutely no way to get into the system from the outside, aside from waiting it out. Needless to say, educators' jobs were highly protected, regardless of instructional efficacy or student achievement. In Nova Scotia, the only degree required to teach in secondary education is a Bachelor of Education.

Arizona ranks around the 5th to 7th lowest state for teacher salaries in the United States. It also ranks among the lowest funded state. While historically the cost of living was once low, it has since increased drastically. Teachers are paid for every additional element they do outside of instructional planning and delivery, such as coaching sports, extracurricular activities, curriculum mapping, leadership commitments, etc. Teachers get one prep period per day and middle school teachers do not teach more than two different grades, although most just teach one. In some districts, but not all, curriculum along with instructional and student materials are purchased for the teachers. Curriculum maps and pacing guides are provided by district personnel. In most, but not all, districts, teachers are required to hold at minimum, a Bachelor of Education. In the K-8 district I work in, there are several “emergency certified” teachers who hold no degrees, teaching or otherwise. Some districts, usually limited to Title 1 districts, provide additional support such as academic coaches and content strategists to build the capacity of teachers. With the teachers I support in my current district, I have heard many times how underpaid middle school teachers are, and how challenging it is for them to complete the whole (rigorous) curriculum our district adopted. An additional variable that is unique to Title 1 district schools is the requirement of student testing for English and Math literacy in addition to screeners and diagnostic tests at the beginning of the year (BOY), middle of the year (MOY), and end of the year (EOY). Some of this testing is to justify Title 1 grants, and others are state assessments that are used to rank the quality of schools. Regardless, students are intermittently taking tests for approximately 4-6 weeks of the school year.

In all four contexts, to varying degrees, teachers raised similar themes - teachers felt the curriculum was overstuffed, that they were overworked and underpaid. I feel that I can compare these four different contexts and believe that some of these claims are more grounded than others. There are many variables to consider when evaluating these claims such as the micro, meso, and macro politics, the strength of teacher unions, economic conditions, and population density. Overall, from my own experiences, the most underpaid I is likely Arizonan teachers, the most overworked I have been is in England, and the most rigorous and overstuffed curriculum I experienced was also in England. In all cases, teaching is a tough job, but someone has to do it.

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It's Elementary

[*Scientific engagement should start early in education, when students are natural scientists*]

I have spent the entirety of my adult life looking for answers to the problems of science education. As stated earlier, my own experiences in elementary science as a student were lackluster but as lackluster as it was, I at least have some semblance of a memory of elementary science education. Elsewhere in the world, it appears that not all students had access to even lackluster science education.

In Southwest England, when I had the opportunity to teach at a Year 7-13 school, my two favorite Year levels I taught were the Year 7s and the Year 13s. The excitement and enthusiasm that the Year 7 students had were unparalleled and the Science classroom was our oyster. Conversely, the science I got to do with my Year 13s was intellectually stimulating and at the university level. The real challenge from Year 8-12 was trying to keep that enthusiasm alive as the students progressed through more complex and structured content on their long journey to Year 11, the end of the road for their compulsory education.

On Primary school preview days, when our school would welcome Year 6 primary students from nearby primary schools onto our campus that would be enrolling in Year 7 the following year, without fail, the students always said Science was the subject they were most looking forward to. During preview days, our Science classrooms, we would always have various experimental stations set up for Year 6 students in each of our classrooms, and their eyes were as wide as saucers, mouths gaping open, cheeks rosy with unbridled enthusiasm. I personally don't recall having these feelings myself as a young person and was left to wonder where this enthusiasm came from. Upon asking my colleague to provide some cultural insight, they answered that this was because they didn't *reall*y do Science in Primary.

Talk about a *tabula rasa*—what a dream! I dug into this and sought to ensnare the minds and enrapture the imaginations of my Year 7 students every day. Together we went on incredible science adventures—both in the classroom and on the school grounds. Every single lesson. That they had been denied Science for so long saddened me and thus, I made it my goal to make Science class the most engaging and explosively interactive experience possible. But also, what low-hanging fruit it was! It was so easy to enjoy science together with these fresh, malleable, and excitable young minds.

In the desert Southwest of Arizona, however, is where I really dug deeply into the K-5 world and stumbled upon my new love—elementary science education—because of the Amplify curriculum. I was initially hesitant (actually, terrified, is more appropriate) at the thought of having to work with students and their teachers in the K-5 elementary setting. In previous years in this district, Science instruction didn't actually take place at the K-5 level. Of course, there were a few teachers that always taught some form of Science, as there were state-mandated Science minutes and grade-level standards. Unfortunately, however, there was no accountability or follow-up on the state level as to if these minutes of science were being taught. According to most K-5 teachers (150) in my district, my fellow strategists (4), administrators (11), and academic coaches (11), science was *really* not part of daily instruction in the K-5 classroom. Our district required K-5 teachers to put in "Science Grades"; however, upon investigation, teachers shared that out of compliance they put something in, based on the science-themed texts they were reading with the students during English.

Prior to my arrival at the district, there was no adopted science curriculum or program for K-5 and Science instructional minutes were not enforced. My colleagues continually remind me that whatever I was doing and providing, is better than whatever had existed before, because there was nothing. After working closely with 3rd to 5th grade teachers for their first year of implementation of the new science curriculum and program the district adopted just prior to my arrival, I saw very quickly how fundamental K-5 Science education is to the development of attitudes, beliefs, and skills of students early on. Through our adopted high-quality curriculum program, I saw 3rd to 5th Grade students evaluating evidence, debating claims, sharing their reasoning, conducting hands-on experiments, asking questions, writing scientific arguments, developing and using models, and designing and conducting their own experiments. The lift to engage these young students were so little, they were so hungry for it, they were so ready for it, and yet the outcome was so awe-inspiring.

With these experiences in mind, as I reflect on my own childhood experiences outside of the classroom, children are natural scientists that continually inquire, hypothesize, and experiment with their surroundings. My experiences with this new K-5 science curriculum is the first time I have seen educational systems leverage and nurture these natural inclinations of children, rather than placing them in rigid boxes of education that destroy and wash away any trace of scientific inclinations. It is the most excited I have been since I read my first academic article for science education. The way forward for education is to break the cycle early and start building scientists and empowering critical thinkers from a young age.

Summary

The vignettes included in Part I: Tending the Garden have provided textured accounts of my experiences observing the interactions between stakeholders and the innerworkings of science education systems. The tensions I felt emerge from the disparity between theoretical research-informed recommendations and the practical lived experience in and around classrooms regarding science materials, equipment, and support was highlighted in this part. The following summary will reflect on the suppositions relevant to the data presented in this section: Supposition 1: *Research-informed recommendations and science outreach resources for inquiry-based science can help achieve the goals of reform-based science* and Supposition 2: *Science technicians and experimental materials can help achieve the goals of reform-based science.*

If science outreach is provided and recommendations from science education research papers are followed, enacting reform-based science aims seemed possible to me. Reflecting on Supposition 1, I observed a common theme emerge across my experiences teaching, researching, and leading in Canada, England, and the United States. I found that while science outreach resources and research-informed recommendations improved access to reform-based science experiences, these experiences were limited in frequency, depth, and reach. The vignettes *Insider Connections*; *Teacher Technicians; An Inquiry Into Inquiry; Hiding In Plain Sight* highlighted how each context had different expressions of outreach and research-informed supports, yet, the net takeaway was that while outreach and research was useful to enhance reform-based science opportunities, they were limited in their accessibility, utility, and equity. For example, my experiences employing research-based pedagogical strategies and leveraging science outreach opportunities aligned with reform-based science in Albertan pre-service teaching programs, Canadian junior high classrooms, and Arizonan middle school classrooms, were infrequent, limited to small groups of students, and/or occurred outside of class time and were therefore not scalable.

If science technicians and science materials are provided, enacting reform-based science aims seemed possible to me. Reflecting on Supposition 2, within the context of my experiences in England, Canada, and the US, I found that while science technicians and experimental materials increased the incidence of hands-on activities, there was no notable increase in 'minds-on' (e.g., critical thinking, discourse, scientific literacy) learning opportunities for students. As identified in the vignettes *Step Into my Classroom; What'd You Get on the Test?; Overstuffed, Underpaid, and Overworked,* some of my peers and colleagues (myself included) from Canada and Arizona cited, among other factors, the absence of a designated science technician and a general lack of organized materials (Beyer et al., 2009; Powell & Anderson, 2002) was a barrier to providing hands-on learning experiences for students. As identified in the vignettes *Practical Practicals* and *What'd You Get on the Test?*, I found that in England, despite having a technician and the experimental materials necessary to enact reform-based science (Gatsby Foundation, 2017), I regularly experienced challenges due the lack of time or space in the curriculum to provide reform-based science learning experiences to all learners.

In Canada and the United States, I experienced the negative impact that the absence of a science technician had on 'hands-on' science – manifested as few hands-on opportunities for students highlighted in the vignettes *Teacher Technicians* and *Kit Culture Couture*. Yet, even in

England, which had instructional policy that provided funding for science technicians and high-quality maintained experimental equipment, my experience was that the activities of science were limited to more cook-book, confirmation (rather than exploration) hands-on experiences (see vignettes *There's Always Room for Desert* and *A Thespian Affair*). My experiences in England, was that there was a culture for hands-on experiments, contrasting my experiences in the US and Canada where there was little culture for hands-on experiments. Yet, regardless if there were hands-on activities or not, I experienced infrequent encounters with a culture for minds-on science that reflected the goals of reform-based science. For example, assessing student understanding of the nature and skills of science were lacking, as were assessments of student attitudes towards science. The main findings that emerged from Part I, to be discussed in Chapter Five: Discussion (see *Classroom Infrastructure)* include:

- There are too many variables impacting classroom instruction;
- Science outreach is positive, but is neither equitable or scalable;
- Standardized assessments detract from reform efforts;
- Science technicians increase hands-on opportunities;
- High-quality instructional materials are crucial, but not in isolation;
- Time for policy change varies depending on the culture of the school, district, and country.

Part II: Mind The Gap

In the UK there are signs found on the platforms at train stations that read, *Mind the Gap*, which really means to say - *watch out there is a space between the train and the platform, and please don't fall in it - consider yourself warned*. During regular work hours, train staff can be found popping out to provide short wheelchair ramps for those who need them, but otherwise, every lager lout, small child, nan, and person must indeed, mind the gap. It is considered bad form to look down at the gap, which everyone knows is there – it is not a matter of if there is a gap, but rather, how wide and tall. All around the UK, people board trains with their eyes up whilst their feet cross the crevasse, doing their best to not to slow the person behind them.

In science education, I wonder what might happen if we spent more time looking at the gaps, rather than politely minding them—the gaps that undeniably exist in science education in all sorts of shapes and sizes between research, practice, and policy. I wonder what might happen if we pause to think hard about what we are losing by passing over these gaps, leaving them unnoticed. Might we benefit systems more by investing greater effort and time to dig deep down to fix the gaps, rather than expecting stakeholders to 'mind the gap' without missing a beat, offering only an occasional and temporary ramp, as the English have done with their trains.

Hordes of papers have been published over the past three decades that identify the contributing variables impacting gaps between actual and idealized reform-based science education enactment. However, there are few, if any, that aim to close the gaps through education research and policy that address the issues head-on across all stakeholders.

The vignettes that compose this section, *Mind the Gap*, are selected to illustrate the long-standing 'gaps' that have and continue to exist in science education. Practice, policy, research, and leadership are all undeniably faced with 'gaps'. Too often, much like the British attitude towards platform gaps, stakeholders in science education have long looked on in polite indifference at these gaps while donning the flag of progress.

If You Can't Do, Teach

[Who is to blame for low-quality science education opportunities?]

Thanks to the rebirth of dialogue from Bernard Shaw's 1909 play, *Man and Superman* in Woody Allen's 1977, *Annie Hall,* I grew up with the common cultural narrative that "those who can't do, teach". In high school and later in my Bachelor's degree, I ran into similar narratives when I asked my friends or acquaintances 'What are you going to take (in university)' or 'What are you going to be (after university)'. For those of them who had not very good grades and/or had a self-professed lack of a focused passion, they responded something similar to: 'I dunno, I guess I'll go into education - the grades to get in are low and you get summers off'. Nietzche speaks of this very phenomenon in their 1872 lectures, *Anti-Education*; "…far too many people with no true calling end up as teachers, and then, due to their overwhelming numbers and the instinct of *similis simili gaudet,* they come to define the spirit of those institutions" (Nietzsche, 1872/2016, p.40). True or not, this has certainly been assumed as a common social discourse regarding teachers - with prominent exceptions in Finland, South Korea, and North American private schools, where the profession has been socially and politically elevated. For all these reasons and more, not once did I ever have an inkling or desire to ever become a teacher. In fact, when I eventually decided that teaching was where I needed to go to do the work I sought to accomplish (to bring authentic inquiry-based science experiences to disadvantaged students), I admittedly did so with some degree of self-loathing and shame, knowing what some people might think of me.

As a child going through K-12 Albertan education, I had three teachers that truly impacted me - my 1st Grade teacher, my 7th Grade teacher, and my 11th Grade English teacher. They were kind (1st Grade), enthusiastic (7th Grade), and fiercely intelligent (11th Grade). In total, I had over sixteen teachers, none of which inspired me to go into science. I often heard the stories of my significantly younger cohort in my Bachelor of Education degree shared about how their own teachers inspired them to go into teaching, or how they dreamed of being a teacher since they could talk. I was inspired by my desire to bring authentic science experiences to students and to correct the wrongs of the educational system so that no child would have to experience the terrible drivel of a science education I did. Even now, as an adult educator, I always begin my first set of professional development sessions by asking the educators, administrators, academic coaches, and/or support staff to share their science experiences of their youth. I hear stories from both ends of the spectrum, although the ratio is typically skewed - the majority have a similar shared experience as I had, and yet, heartwarmingly, there is always one, sometimes a few, that had positive, student-centered, engaging, and experiment-based science education. As time has passed a few past students have found my contact information and they have thanked me for inspiring them to pursue graduate education and careers in science. To me, hearing that they went into science, not education, is a badge of honor.

I have done and I have taught: I did *do* science (I published a few papers – e.g., Baier et al., 2014) and I also *taught* science (for about four years). I often catch myself thinking that teachers that have done scientific research will make better science teachers, but that is in no way pragmatic considering the current reality of teacher shortages that are far too common. It is not a question of where in the educational system that people have been failed, but rather, for how long and how often? I wonder, what would happen if the narrative changed from “those who can’t do, teach” to “those who can really do, teach”. Teachers are *the* greatest asset and tool any country has for enhancing intellectual capital, innovation, and socioeconomic welfare, as Nelson Mandela once said, “Education is the most powerful weapon which you can use to change the world.”. Yet, this potential for the positive change that Mandela had in mind is not as evident as perhaps it should be.

Two Courses is Not Enough

[Should pre-service teachers have more training?]

The Bachelor of Education degree that I was required to take to become qualified to teach science at a secondary school level required only two courses that specialized in “science education”. The rest were “general education”. Is this enough training for our teachers to achieve the lofty goals that reform-based science education policy has charged us with?

While conducting research for my first independent study course, I came across an article titled “One course is not enough” (Akerson et al., 2006). And I couldn’t help but seeing that reflected in my own experience in my B.Ed. For a variety of reasons outlined in this paper, and as I saw evidenced in my own experience, the majority of my cohort peers lacked in-depth scientific knowledge, let alone science pedagogical knowledge.

The two science education courses I took - one per year - did not prepare me for delivering what was required to acheive the goals of reform-based science education. In one, the ‘aquatic chimp theory’ was championed. Unfortunately, at least two students walked away with the belief that the aquatic chimp theory was credible and the desire to include it in their own classroom practice (misconceptions were created, rooted, and reinforced). In the other course, cook-book hands-on experiments were promoted as 'authentic inquiry experiences' that did involve scientific concepts but stopped short of promoting scientific practice and process.

Unfortunately, how to teach authentic scientific ideas, practices, tools, literacy, and discourse was not covered in these classes. All that I had come to experience and understand in science as a scientist, was absent from these science education courses. How could all of these people go forth and teach this amazing program of study that speaks of scientific literacy, practices, attitudes, and beliefs, without experiencing it themselves? Nietche's words rattle me "The incalculable hordes of teachers who have cast their lot with the existing educational system cheerfully, and unreflectively want to continue it." (Nietzsche, 1872/2016, p.40). Teacher education in and outside of the classroom has failed to inculcate teachers to this new, reform-based modern culture.

Further, how would pre-service teachers know what to expect and how to prepare for managing the inquiry and discourse classroom, if they hadn't read the primary literature on it? My opinion is that two courses on science education would not have been enough for me to teach at the level required to acheive the goals of reform-based science educaiton. I felt equipped and ready because 1. I had extensive lived experiences in scientific attitudes, skills, and behaviors; 2. I took two additional research-based courses on science education, and 3. I had experience teaching inquiry-based science labs. Is it possible to reform teacher training so that we can better achieve the goals that our policies set for us?

If They Can't Fish, Give Them Fishes

[Can effective curriculum make up for low teacher efficacy?]

Consider the adage, "If you give a person a fish, you feed them for a day. If you teach a person to fish, you feed them for a lifetime". In this context, fishing is an end in and of itself - to provide food. Operating from this context while considering the aforementioned variables, it is worthwhile to note that teaching a person to fish is actually quite challenging and nuanced, and might not necessarily yield a successful catch. It requires years of practice to understand and adapt to the seasonal cycles. They may know how to cast a line, tie a hook, and gut a fish, but they might not know how to fish the water after spring runoff which has changed the topography of the river floor. Or how the changes in temperature change the water column the fish occupy. Thus, from a practical perspective, it might help to give them a few fish too, for teaching how to fish might not translate to actual fish caught.

This very phenomenon can be applied to how to train teachers deliver reform-based secondary science, for it is equally as challenging and nuanced as teaching someone to fish. And yet, few teachers have been properly taught or mentored how to do so. The system does not prepare science teachers for the realities of classroom teaching. As mentioned above, two science education courses are not enough preparation. Furthermore, most teachers do not have in-school mentors to facilitate professional development. And finally, teacher practices are reinforced by their own lived student experiences. They have not experienced reform-based science education and do not necessarily have the skills and experiences to deliver this new method. In sum, teachers have not been given any fish nor taught the skills of reform based science education.

Recently, in Arizona of all places (among the lowest teacher pay and lowest funded state for education), I stumbled upon what I thought might be the answer I had been looking for in the

Amplify curriculum. Amplify is steeped in minds-on, student-centered learning through activities focused on verbal discourse, written argumentation, evidence evaluation, and engineering/design. I felt Amplify was a better and fancier version of the types of lessons and activities I develop. I really loved the curriculum. It was the first time I had seen these kinds of resources. I was ecstatic when I found it. Finally, a high-quality, science research, and science education research-informed curriculum existed and was being sold throughout the USA. There was no need to teach every teacher how to develop these resources. We had found the fish. We could feed the country.

I was lucky enough to be employe by a district that adopted Amplify science. Over the next three years of implementation, I found that although this curriculum changed the classroom practice of educators, there remained a lack of a shift in attitudes, belief, and mastery of the pedagogical content knowledge. Although the materials were available, the curriculum's spirit had not been adopted by the teachers. Perhaps, giving teachers the fish isn't the answer either, they still need to believe in the message and goals of reform-based science education.

Despite the research-informed, high-quality curricular resources and the monthly professional development sessions, the single most important thing has failed to happen, teachers themselves have not embraced this new culture of reform-based science education. This is exacerbated, and perhaps even rooted in the institutional systems that educate, guide, and regulate science education practices. If teachers are not taught to teach to the new reform-based science education standards, then what hope is there to achieve its goals?

The main objective of my current job description as a district 'Science Strategist' is to, in essence, help build capacity for understanding the "shifts" in instruction for the new standards across all educational stakeholders—the teachers, academic coaches, administrators, and district-level leaders. Ultimately, to build capacity is also to develop a culture, by shifting mindsets and practices away from traditional methods of teaching and learning science, and towards reform-based science practices.

The particular context of my work is rather unique and there are some important variables to consider that may contribute to or account for the observations that follow. The first year of implementation of the standards-aligned high-quality curriculum was done virtually during a pandemic. The second year of implementation was done in person amidst an in-person pandemic and the stressful conditions that resulted from it. After the fourth year of implementation, only one teacher out of the original twelve have undergone three consecutive full years of teaching with the new curriculum and receiving coherent and aligned monthly professional development. Yet, this trend of teacher retention and efficacy for reform-based science is not unique to this one context, staff rotation was also common in the UK. Thus, building capacity in rotating staff is almost impossible when attempting to implement a new style of curriculum.

Building capacity to develop culture for reform-based science is a long and difficult task. There is no urgency in leisurely fishing. But I cannot seem to adopt this mentality in my work. Perhaps the parting words of Bateson (1994), are worthwhile to consider to conclude this vignette "the deepest changes may take generations, with old attitudes concealed beneath efforts to adapt" (p.89). I wonder at times if perhaps I am looking at the wrong scale of time for change, but then I remember, that cycles of reform have been occurring for over a century without much progress. The system, not the actors, must be inculcated for the culture of reform-based science.

Put Me In, Coach!

[Academic coaches help, but the burden is too great]

In the sporting world, coaches are essential elements to every sport, for every team, and at every level. Coaches not only manage the logistical elements, but they craft and execute drills to develop skills and build strength. They foster community and a shared sense of pride towards a common goal - winning. They choose who plays what positions, when, and for how long. Some coaches scream on the sideline while others sit and observe with a patient and quiet demeanor. Coaches decide who is on the team (sometimes), who warms the bench, when to play the star players, when to play the bench, and in general, how to win.

Just as players need coaches to develop, so too, do teachers. Just as top players need to be coached, so too, do top teachers. From my experience, academic coaches are a phenomenon unique to the USA, as I did not hear of or see them in Canada (Alberta and Nova Scotia) or England. The role of a coach is defined as building capacity for instruction. An academic coach is a mentor for teachers in that coaches facilitate co-lesson planning, co-teaching, reflective conversations, coaching cycles, and modeling lessons to enhance practice and/or shift practice by shifting mindsets.

In the copious volumes of educational coaching literature, there is much talk about what coaching is and what it isn't, and all the different frameworks, models, and approaches that exist. I have worked with over 25 coaches over four years at my current school district and I find that coaches tend to focus on teachers with the highest need. Often I find myself spending most of my time with teachers whose instruction is lacking, as opposed to coaching the high fliers to fly even higher. This contrasts with how coaching works in many sports, wehre the most talented athletes will get a lot of attention. In theory, academic coaches coach teachers of all efficacy levels;

however, in practice, at least for coaches in my own district, their time is largely used up by focusing their work on teachers who are lacking the fundamental elements of instruction. There is little time for direct coaching of teachers that are highly effective.

Academic coaches are effective. I have observed and collaborated with coaches that have successfully built the capacity of the teachers they support. However, not all schools have the funding for coaches. In my district, we have additional funds from Title 1 funding sources used to employ school coaches and district strategists. Considering the instructional realities related to the challenging working conditions in our school district - the high poverty and low-performing state of our high-need students (75-80% of students are below math and English proficiency levels), high-quality and effective teachers are not drawn to our district. Despite this reality, our schools do have several amazing teachers who are elevating the profession and supporting our students above and beyond. In the last four years, 50% of our hires were foreign teachers and 26% were from the Teach for America program. Now, these mechanisms can result in excellent teachers. However, the numbers suggest that our turnover is high, our retention is low, and the number of local applicants is almost non-existant. The teacher turnover rate for middle science over the past four years was 93%. Needless to say, the academic coaches' hands are full of trying to train new teachers into our current systems. It seems that while two Science Education courses are not enough, the academic capacity builders (science strategists and academic coaches), and a high-quality and standards-aligned curriculum are also not enough.

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The Revolving Door of Reform

[What is the alternative to the persistently change of educational systems?]

Since I was a child, having regularly been surrounded by my father and his colleagues, I have been listening to the gripes of teachers regarding the constant "reforms": 'It was once this, now it's that. We used to do that, but now we have to do this. We used to teach it that way, now we have to teach it this way. We used to call it this, now it's that'. This was more important than that, but now that is more important than this.' Endless gripes. It seems that these trends are cyclical. What once was passé is now back in vogue - fashion and education are the same in this way.

I have heard stories of, and experienced myself, 'the ways of the system'. New words are used to describe old ways. Old ways are rebranded and repackaged to be sold on the neoliberalized educational market as new and fresh solutions. Changes happen, but so quickly and with such resistance, that by the time the next change happens, the first one hasn't been fully rolled out, but the next change on deck is reliant on the previous one taking hold. It is why science education has been plagued by the lack of inquiry-based science for a half-century in the classroom, and why educational systems across the Western world are still failing their young citizens by failing to provide adequate education to create critical thinking, environmentally minded, and compassionate citizens. It's why science standards put in place six years ago (Arizona) or ten years ago (Alberta) are still not commonplace in science classrooms. The ever-changing terminology for effective science education creates confusion between the public and educators alike. What *really* is hands-on vs. inquiry, anyways? Is the alternative, rote memorization a valid runner-up? What was once good (inquiry) is now bad ('it's phenomenon now, inquiry is a relic!').

Are these nuanced descriptions of "new" science education moving the needle, or are they pushing teachers further and further into the recesses of what they know to be 'tried, tested, and true', the sage on the stage? How is it, that after decades of reform moving in approximately the same direction, are there still teachers who teach as the expert and purveyor of all knowledge, with no opportunity for student discourse and ownership?

New books are written, bought, read (or shelved), and used to direct school and district policies - in the hopes that the new coming of educational reform will be upon them soon to solve their problems. This revolving door of reform creates the illusion of progress in educational systems, especially in science education. Looking at journal articles from over thirty years ago, some of the same problems in science education persist—for example, inquiry is not being used in the classroom, hands-on activities are not happening, students are not developing scientific mindsets, and teachers continue to have low pedagogical content knowledge. And yet, at least in Arizona, I see tons of money pouring into the district I work at, with little gains to student achievement. The needle is not moving. Millions of dollars are spent on programs, but the teacher retention rates are abysmal, while the number of qualified teachers and wages remain low.

I have shared these sentiments with frustrated colleagues for over a decade. Most recently, a district-level colleague stated 'the system needs to be dismantled". I had thought that profound because Wilhelm von Humboldt a mere 200 years earlier had attempted to advocate for the very same thing. And yet, here we are again, entrenched in a deep cycle, with many mini-cycles to keep and divert our attention from the lack of true, systemic, and lasting change, progress. We need to break the system completely to rebuild it anew. We are trying to supplement the impoverished state of our educational system with ad-hoc changes that are not taking because the fundamental foundations are not there to permit these changes to take root and take hold. This system is so broken that trying to fix it is futile. Maybe I am wrong about all of this. Maybe there are incremental changes. But with public trust in science at an all-time low, I do not have much hope at the moment.

Timing is Everything

[*Why do some changes in education happen more quickly than others?*]

Having observed the changing of the guard for national, state, and provincial science standards play out on various implementation and enactment timelines in three countries, it is evident to me that change of this scale requires three variables: time, resources, and accountability. In the absence of accountability and resources, the timeline for implementation and enactment of the new standards is increased substantially, as outlined below.

During the three years I taught in England, I taught two different sets of standards (and thus used two curricula designed for these standards). For the first two years, I taught the existing curriculum that was designed for the then current standards. Then, in 2015/2016, a new national curriculum was instated, one year after it was published in 2014/2015. The timeline for the instructional shift was immediate. In accordance with national expectations, the new curriculum was implemented the following year. While there were no significant shifts in pedagogical approaches required of teachers, there was a shift in the instructional content and rigor expected of students. The new standards (and thus accompanying curriculum) were more rigorous with an increased emphasis on emerging scientific discoveries, methods, and technologies, coupled with significantly higher expectations for scientific literacy of students in both writing and reading.

Curricular resources were polished and ready to go well before the nationally required roll-out of new standards. There was an undeniable alignment and synergy between the national science standards and the development of curricular resources. Schools were given the agency to choose resources from one of two nationally approved curricular resource providers. When I asked my senior colleague the difference between the two providers, they responded by saying that it was more about historical alliance/preference than anything else. These resources included instructional resources (e.g., PowerPoint slideshows, worksheets, rubrics, experiment methods, and preparation instructions) and exam resources aligned with the national assessments (unit-level assessments and rubrics). My experiences in the USA and Canada were starkly contrasted to the seamless and aligned experience of England.

In Alberta, a ‘new’ reform-based Program of Study was released in 2003 (with minor revisions in 2009 and 2014). This reform was released after I left the K-12 system, and so I never experienced this reform to science education in my own classroom experiences as a learner. However, ten years later, when I entered the “new and improved” science classroom as a teacher, the educational landscape appeared relatively unchanged from what I experienced as a learner. Some of the old textbooks were still around.

The reformed Albertan program of Study called for the development of scientific attitudes and beliefs, scientific literacy, to “help [students] become lifelong learners—maintaining their sense of wonder about the world around them”. Further, it states that students will be prepared to “critically address science related societal, economic, ethical and environmental issues” so that they can develop the “skills that will enable them to understand and interpret their world and become productive members of society” (Alberta Education, 2014, p.1). Further, the Albertan Program of Study (Alberta Education, 2014) states that:

> To ensure that programs are relevant to students as well as societal needs, a science program must present science in meaningful context—providing opportunities for students to explore the process of science, its applications and implications… Diverse learning experiences within the science program provide students with opportunities to explore, analyze and appreciate the interrelationships among science, technology, society and the environment, and develop understandings that will affect their personal lives, their careers and their futures. (p. 1)

When I first read the Alberta program of studies I was truly moved - I was delighted, ecstatic, and inspired. But above all, I was relieved. I thought to myself - finally, critical thinking, scientific literacy, student-centered, pro-social, environmental stewardship and meaningful learning opportunities through diverse learning experiences are being championed and promoted at a provincial level! Finally, I thought to myself, antiquated science education is the past! Here is the future! At one point in my B.Ed., I had even had the passing thought that since the Alberta government has created these beautiful visions and goals for the education system, and thus, that its teachers must be doing a spectacular job as a result of this amazing program of studies, perhaps I didn't even need to go into education. From a distance, it sounded like people were already on it, and I started to consider that perhaps my services were not needed.

When it was time for my practicum and my own classroom teaching experiences, I was excited to have the opportunity to step into classrooms to see what amazing things teachers were now doing in the classroom with these new guidelines. I anticipated a stark contrast to what I expected to be an antiquated memory of the 'olden days' of science education in Alberta: sage-on-the-stage lectures, few hands-on experiences, and note-taking from scrolling transparencies. I was looking forward to bragging about how far science education had come in Alberta - how 'back in my day' science was barely a shadow of what it was then. However, moments after stepping into my B.Ed. program courses, listening to the professors, hearing my cohort peers engage in discussion, and doing my practicums in secondary classrooms, I realized that this was absolutely, and tragically not the case. In the classrooms, I directly (three) and indirectly (nine) experienced, traditional textbook teaching, and worksheets were the dominant discourse. Hands-on experiences were few and far between, and inquiry was a far cry away. In both my teacher practicums and the classroom I taught in as a certified teacher, the students had absolutely no understanding of 'inquiry' - they were totally lost as if I was speaking a foreign language. It was evident, by their flabbergasted faces that they never had experienced this type of learning before. The learning that was championed as a goal and vision of the Provincial standards implemented five years prior to my entering the classrooms as a teacher, was nowhere close to what I saw and experienced in those classrooms.

In 2012 in the United States, the Next Generation Science Standards (NGSS) were released. The NGSS was a "new set of voluntary, rigorous, and internationally benchmarked standards for K-12 science education" (https://www.nextgenscience.org/). Note that the verbiage states "voluntary". This is because each state is designated as its own sovereign state, as per the constitution, and thus, each state followed suit according to its interests. Officially, twenty states adopted the NGSS and twenty-four states developed their own state standards based on the NGSS. Six states did not adopt the NGSS. It is of interest to note that while the state of Arizona was one of the 26 states involved in the design of the NGSS, the state opted to design its own version largely based on the NGSS, which was released as the Arizona Science Standards (AZSS) in 2018. From my practical analysis of the NGSS and AZSS (including the alignment document), they are, for all intents and purposes, very much the same. Aside from a few changes in when particular standards are addressed at which grade level, there is little theoretical or conceptual difference between the NGSS and the AZSS. The only thing this review and modification did was delay the implementation of these standards by six years. However, that is assuming that the 2018 AZSS was actually fully adopted in 2018, or at the very least, 2019. However, that was not the case. It was not until 2021 that the current district I work for adopted a legitimate curriculum that provided high-quality resources aligned with the new state standards. The new science standards had existed for nine years before implementation in the classroom at the state level.

When considering the gestational time for system-wide change in each of these three discrete examples of standards implementation and enactment—England, Alberta Canada, and Arizona U.S.—it is helpful to consider the variables. In each of the three examples, the environment changed, and yet only in one context, England, did the educational system and teachers readily adapt to this changing environment. The government educational infrastructure was tightly aligned between the standards and the approved curricular resources. Coupled with the high expectations at the school level, the outcome resulted in preparedness for immediate implementation and enactment in the classroom.

In the example of Arizona, the educational system lacked alignment. New national standards were made, but the infrastructure at the state level, along with the educational curricular resources were not prepared in advance for this change. Some, but not all districts are provided state funds to purchase a high-quality curriculum aligned to the state standards. The district I worked for purchased such a curriculum in 2020 and implemented it in 2021, three years after the new state standards were released, and nine years after the national standards were released. At the school district level, the implementation was immediate when the NGSS-aligned curriculum was eventually adopted in 2021. Enactment, of course, being an entirely different story (as outlined in other vignettes).

Alberta is the most perplexing case, for there was neither government nor school district impetus or follow-up on the implementation of the standards. New standards were released in 2003 and 'updated' in 2009. From my experience, they were still largely not adopted over a decade later, around 2013/14 when I was in and around the science classroom. The only curricular resources provided in the three schools I worked at were textbooks from the early 2000s. Science outreach organizations and the Government of Alberta created some interactive online tools; however, in all three schools, teachers had not used them and were not aware of them. Teachers created their own curriculum and resources. The result was largely reliant on the textbook, which to my knowledge preceded the current standards and if anything, only superficially addressed the novel elements of the new standards.

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Keeping up Appearances

[*Teachers cannot do all that is expected of them, all the time*]

I learned an important lesson during my first year teaching in England from my Fiery Irish colleague. Overwhelmed by all the new pedagogical expectations in addition to preparing lesson plans and lesson materials for seven different grades and living in a new country, I was struggling to keep up with all the expectations that were piling up on my shoulders. This school had very particular policies regarding instruction (e.g., no-hands up rule, extensive seating charts designed for differentiation according to students with behavioral and learning codes, uniform expectations, frequent checks for student understanding, student discourse opportunities, writing expectations, annotation routines, etc.). There were also very specific policies about marking and feedback (e.g., we had to mark student books at least once every two weeks and provide extensive written feedback, which students had to respond to, which we subsequently again were required to correct). Classroom walkthroughs, seating charts, and marking audits were frequent. Our professional learning communities were rigorous, requiring marking audits and comparing our marking accuracy of department-wide assessments. Every hair had to be in place, every shoe polished, every book, marked. As a reminder - I taught seven different grade levels, sometimes teaching multiple classes within the grade level. We had only three prep periods every two weeks.

Admittedly, I really struggled with everything on my plate for the first year. My classes were full to the max, I had several students with behavior and learning codes (sometimes both), and Southwest English children are not at all interested in foreigners. It was a rough go and a completely different experience than what I had in Alberta. It was a lot. My Fiery Irish colleague saved me. They showed me the things that were essential to do, those that were important to do when I could, those that I should ‘appear’ to do when it was ‘go’ time, and those that I shouldn’t do (until after my first reprimand). They showed me that all the things that are asked of you can’t be done, and thus, do what you can for the essentials. Ultimately, the goal is to do all the things, but until then, keep up appearances that you are doing those things.

Now that I am on the other side—the accountability side, the walkthrough side, the district side—I see how many layers of expectations are required of teachers and that we expect them to do all of it. I have tried to advocate for teachers in upper district, but the answer they give back is that it is what is best for students and thus, they need to do it, now. I am trying to help teachers focus on what is essential, but there really is, just so much. Not just at a site level, but also at the district level. On the flip side, I certainly do see instances of superficial facades, instances of 'compliance', where a teacher will crack out brand-new books for the first time the very lesson I appear in their classrooms, and try to pretend as if they had been teaching it the entire time. Unfortunately, some teachers are not that well versed in the art and science of 'keeping up appearances', for a central element to this strategy is to actually mostly do the things asked of you, and have contingency plans for the things you can't get to.

The most common thing I hear from teachers in my district is that they are overwhelmed with all the things they need to do—they can't keep up with it all. I am very much empathetic with them - I get it, it *is* a lot. There *is* a lot of testing of our kiddos (for Title 1 compliance). There *are* a lot of initiatives and new programs happening, on top of the new science curriculum. For some added context, they *do* get one prep period a day. They *only* teach at most two different grades (usually only one). But, all of it *is* best pedagogical practice and there *are* high expectations of teachers. The teachers who are doing it are rocking it. The good news for them too, is that the current curricular adoptions are here to say, at least for the next decade. There are undeniably competing initiatives that teachers and administrators are faced with - definitely a result of the district-level interventions in the teachers' classrooms and administrator's school culture and climate, something I did not have to navigate myself as a teacher.

I will say that the practiced art of keeping up appearances resulted in a trained awareness of my practice and an exponential increase in the efficacy and robustness of my practice. I also see this same phenomenon with the teachers who do it all. They are excellent, hardworking educators who persevere against great odds to bring meaningful, engaging, and robust learning experiences to students. The learned art and practiced science of keeping up appearances actually made me a better teacher and a better professional. I didn't enjoy many aspects of the process, it was stressful and it burnt me out, but thanks to the Irish Spirit, I was able to stay afloat to navigate it all such that I not only survived, but thrived. Yet, after three years of our time in the UK, when my partner found out that they had an opportunity to stay in a professorial position, I made it explicitly clear that I could not do another year in the system. I had burnt out. I had amazing national test results, developed engaging, inquiry-based, and/or discourse-oriented learning opportunities for seven different year groups, did science outreach, and organized science trips and extension activities. Coupled with the strain of living and working in a different culture, I knew this couldn't be a life I could continue to lead. So, while I did succeed, I burnt out. Perhaps I did more than just keep up appearances, but I have no regrets - it was for the kids. I just knew I couldn't keep up with it all anymore.

Looking at Science Education Through Rose-Coloured Glasses

[*People are not looking deeply enough at science education systems to see problems*]

Although I know it can't possibly be true, I like to imagine that I look at science education with realism and skepticism, through clear glasses. I like to get the word on the street and to *really* hear what's going on, what the issues *really* are, and what the needs *really* are - so I can do my job better to support, remove barriers, and build capacity. Often, it is my voice advocating for teachers in the 'trenches'. I try to seek out the sticking points, stumbling blocks, barriers, anxieties, resistance, and hard-to-hear truths. I do want to find out what the real issues are, and do what I can to amend or at the very least, lessen the impact of them. I see no sense in avoiding the truths, for the only way to solve the problem is to face it, head on, much as the children do in Rosen's (1989) *We're Going on a Bear Hunt*:

> Can't go over it
> Can't go under it
> Can't go around it
> Have to go through it!

Too often, I have seen educators, leaders, and researchers avoid attending to the real barrier by seeking to find any other way around the problem. This makes sense, considering that "The webs of perception and meaning that human beings construct tend toward integration. What does not fit is likely to remain invisible, unnamed, unattended to" (Bateson, 1994, p.57). These barriers, issues, anomalies, problems, challenges do not bring the system towards focused integration, but rather, create messiness that needs to be carefully sorted through.

One thought I often come back to is that a lot of education research is conducted at the best schools with the best students, thus leaving a rosy tint on a lot of research. The researchers that I know are often much more optimistic than I am. Sometimes I wonder if it is their outsider nature that might bias their view. Or perhaps I am just that pessimistic. Maybe teachers are 'just keeping up appearances'. When outsiders come in, everyone is on best behaviour to keep up appearances showing them what they want to be shown. I've even done it myself. What I find most interesting is what is not said in science education papers - for example, how long have the researchers been connected (directly or indirectly) to the school (or staff), and how did they select the teachers? I am left wondering - what attributes might teachers who volunteer for such ventures with education researchers have in comparison to their peers who do not volunteer? What personal connections are needed to maintain the goals of science education? What sorts of schools have connections with education researchers compared to those that do not? Is a model of science education suitable for all schools and all students?

Hiding In Plain Sight

[*Evidence for failed enactment is ubiquitous in classrooms*]

There are some obvious indicators that be used to determine if you are in a science classroom - namely, the presence of some sort of science equipment, science textbooks on the shelves, and posters on the walls with some sort of artistic rendering of a scientific process, organism, or facts. Unfortunately, while these indicators may prove useful to identify the content taught in the classroom, they do not indicate to what extent it is taught and in what ways. It is challenging to identify static indicators of a student-centered classroom, but a quick look around the room for artifacts of student-created work on the counters, shelves, or walls can be a hint.

One element of my current job as a district level Science Strategist is to conduct classroom walkthroughs and identify student actions aligned to effective science instruction that, in alignment with the state standards, focuses on students engaging in scientific and engineering practices (e.g., Asking Questions and Defining Problems; Developing and Using Models; Planning and Carrying Out Investigations; Analyzing and Interpreting Data; Using Mathematics and Computational Thinking; Constructing Explanations and Designing Solutions; Engaging in an Argument From Evidence; Obtaining, Evaluating, and Communicating Information) (National Research Council, 2013). To determine if there is evidence of past or present student engagement in these scientific practices, I look at the walls for evidence of student-identified questions, hypotheses, and co-constructed work. I look at the shelves and counters to see if there is evidence of student-sense making or experimentation. Finally, I watch student actions to see if they are engaged in learning opportunities in which they are leading their own learning through natural inquiry - whether it be through reading a story or informational text and annotating it, designing a solution to a problem, asking questions about a phenomenon, developing or testing a model, conducting an experiment, or engaged in argumentation with their peers, among others. When you look for it, evidence of reform-based science education practices is easy to spot.

A theme, across all three countries (Canada, England, and the United States) I observed was that there was scientific equipment and resources hiding in plain sight, left untouched by students. The country that was the best at providing students with hands-on experiences (albeit not much for scientific practices) was England. As a reminder, we had two full-time science technicians that serviced seven science teachers for teaching Year 7 to Year 13 students. All but one teacher (who preferred to do a few teacher-led demonstrations over student-led activities), shared resources and engaged students in hands-on activities, models, and practicals. Yet, from the least recent (Alberta) to the most recent (Arizona) experiences in Science education over the past decade, I have seen many examples of unused science resources hiding in plain sight. Below I will outline one example from Alberta and two from Arizona.

The Unopened Microscopes

[*Unused science resources fill the closets of classrooms across continents*]

My introduction to science education as a professional in Alberta was during my first teaching assignment at a Catholic Junior High. The school was composed largely of a low-middle socioeconomic population of children originating from Catholic families, with a significant proportion being relatively recent Filipino immigrants. The school itself was relatively new, built about 10 years before my arrival, and had an incredibly innovative and forward-thinking principal. The school had one-to-one technology for students in the classroom as well as computer "pods" embedded throughout the open-concept school. There was onsite technology support designated to the school one-third of the week. Science classrooms were spacious with ample counter space, storage cupboards, and a science prep room to store materials and equipment. Every single student was a relative delight. I recall one staff member saying – "this school will ruin you forever" – not because it was difficult, but instead, because it was so easy compared to anything else I might face. There were nearly no behavioral issues, the families were supportive and active school community members, and students did the homework asked of them. It would be an understatement to say it was a delight to work there.

Excited to get my first set of students engrossed in my own scientific passion, microscopy, I asked my fellow colleague where the microscopes might be. They, along with the other peers I had asked, mentioned they knew they had received them some years ago, but they weren't sure where they had gone since their arrival. Always up for an adventure, I started to investigate and scour the cupboards of my own classroom and the cramped quarters of the small science prep room wedged between my own classroom and the neighboring one. The cupboards of my classroom and the prep room were filled to the brim with all sorts of dusty items haphazardly hidden away. It would take me some time to sort through all the equipment and materials. Busy with the stress and work that comes with teaching for the first time, sorting through these resources was the lowest of my priorities. Every day after school I spent some time cleaning out various cupboards.

One day, late on a Friday afternoon, something caught my eye in the uppermost corner, above the cupboards. I jumped up onto the cupboards, and on my tippy toes, I pulled out one of the similar boxes stacked beside and on top of one another. I blew the dust off the heavy but small box down and placed it on the counter. After cutting through the tape that sealed the box, I was greeted with a snuggly-fit solid styrofoam block. I cringed as I pulled the styrofoam cast out of the box, blowing off bits that have dislodged on their journey as it passes out from their tomb and into the light of day. Ready to open the encased treasure, I pried the cut styrofoam apart to find a microscope laying, untouched for nearly a decade, in its firm foam bed. As I pull the microscope, freeing it from the stiff embrace, I sigh. The proof is in the pudding- this microscope has indeed, never been unsheathed from its styrofoam. I was the first person to have wedged it out.

Knowing that the instructional Biology unit on Cell Biology was taught just prior to my arrival, I found myself struck with two emotions. First, a sense of disappointment. Cell biology is my show-stopper unit – after all, I was a cell biologist focused on microscopy for three years. But, every cloud has a silver lining - I exhale relief at not having to encounter the auditory horror of emancipating those microscopes from their prison cells. I stuff the microscope back up into its rigid tomb, hum loudly so as to not hear the cringe-worthy screech of styrofoam as I force it back into the box, and eventually place it back up in its' dusty corner, along with its 15 comrades, and shift my gaze to the rest of the room.

I approach the room like a crime scene, trying to get some sense of the time and place of the items last used, where did they belong the day before their last use, and how long ago was that day? The most recent of items appeared to be the remnants of a hands-on activity, unclear if it was an experiment, or art project. I started with that and put all of the dirty glass test tubes and misc. glassware into the dishwasher, which was somehow tucked into this pie-shaped science closet, and pressed the *Start* button. Next, I open the cupboards, to put away the miscellaneous (dusty) bottles of chemicals strewn about. Only to find more, dusty bottles of chemicals, some without labels, with no organization (alphabetical, IUPAC storage class, or instructional unit) shoved into the cupboards. I lower my gaze to the bottom cupboards, I bend down to find bits and bobs that would be useful for physics and perhaps biology.

Impressed with my organizational efforts over the past few days, I look back and take notes with a mental visual before/after image. I also cataloged in my mind what I have available to me to use for the remainder of the school year – 5 months. I toss three extra large garbage bags out that I filled with miscellaneous useless or broken bits and shut the door behind me. Despite my best intentions, aside from storing students' skateboards, I can't say that I opened that closet door again for the rest of that year.

The Graveyard

[*It is easier to hide and forget reform-based resources than use them*]

It is curious that the phenomenon of unused science materials transcends space and time. The very phenomenon I observed as a classroom teacher in Alberta, Canada, I observed a decade later as a K-8 District Science Strategist in Arizona, United States. Upon starting my job at an inner-city K-8 School district, I heard rumors of a room that was whispered about, but not shown. I was delighted to learn that a 'science resource room' existed. However, for a variety of reasons, namely, a pandemic, the absence of in-person instruction, and a massive workload, I didn't get to even see the room until a year later. I sought out the secret key (only two exist and I now have one of them) from the protective keeper of the key. The room was housed in a separate building off one of the middle schools. I recall opening the door for the first time and being met with awe at the expansive 1000 ft^2 high-ceilinged room. This massive room overflowed with various items stacked high to the ceiling over nearly every square inch. It felt like my very own room of requirement, albeit much less magical than Harry Potter's at Hogwarts. The room was wall-to-wall chaos, filled with textbooks from the mid-90s, endless photocopied worksheets, coil-bound books of 'fun' science experiments, craft materials, beakers, ramps, and even more boxes, sealed. These artifacts date back to the mid-1990s, with most of them likely never having been used.

My first course of action was to create a maze through which I could navigate, calling in backup from the warehouse personnel. I was determined to make use of this room and turn it into a functional space that could become my very own office and a space for Grade 6-8 professional development sessions. So, I spent the summer moving boxes to the edges of the room, tossing over 50 large bags of *basura* (Spanish for trash), finally unearthing tables and chairs. There was much left to be desired, and much left to be done, but nevertheless, it was my own, and it was functional, albeit a bit chaotic.

All sorts of items were amassed in this room over decades. Aside from a few dead (and also living) cockroaches, the room was filled with boxes and teacher manuals from purchased curriculum adoptions over the past few decades, with no current utility. Upon closer inspection, as an archeologist uncovers artifacts from the non-living from times past, I discovered an overwhelming majority of these boxes were filled with science kits containing items that had never been used or opened. Determined to reuse the items within the kits, I resolved not to discard them and consider how to repurpose the items, of which there were at least a hundred thousand dollars' worth. Four years later, this resolve has not waivered, but admittedly, in the wake of supporting three separate first year adoptions for science (K-2, 3-5, and 6-8), I still have not had the time to develop an outreach plan for these items. I continue to be surrounded by the graveyard of science kits that tower over me, a constant reminder that having the needed resources available does not guarantee that science will be taught as intended in the classroom, as I continue to try to breathe utility into the new science kits dispersed in classrooms across the district.

The Disappointed Parent

[Even parents know science resources are not being used]

Nearly a decade after my first experience in Alberta with unused science materials hiding in plain sight, I was confronted again with the same phenomenon in Arizonan classrooms, but this time I feel the blood is partially on my own hands. As a District K-8 Science Strategist, one of my roles (in addition to building capacity for science instruction, among other things) is to support the management of materials in the science kits that accompany the purchased curriculum. This work happens in the summer months, when classroom instruction is no longer taking place, and the kits have been returned to a centralized location in each school so that they can be serviced, which I coordinate. I had to go to great lengths to convince my director that kit servicing was a necessary requirement, something that neither the director nor the district had thought about or planned for. There is much grant money available for shiny new things, but not for maintaining, cleaning, and repairing old things. Leveraging my previous experiences learning from the science technicians at the school I taught at in England, I was able to convince the director of allotting a small budget to ensure the kits were properly refilled and serviced. After all, that consumable items need replacing is an excellent indicator that at least the hands-on elements of the science program are taking place (although on a few occasions, as I observed, it can also be an indicator of atrocious classroom behavior management, and all the items disappear).

Following the model I experienced in England, I was able to coordinate that each school has one or two designated 'Science Kit Technicians' (from existing support staff at the sites) whose job was to inventory, clean, and service the kits for the teachers in each school, ready to be used every school year. The assumption, of course, is that the science kits are used and therefore, need the replacement of consumable items. When I sought insight from the Science Kit Technicians about their observations on the state of the kits and the work they had completed, each site admitted that several teachers hadn't even touched their science kits.

One of these Science Kit Technicians also happens to be a parent of (at the time) a 3rd grade student at the same school in which they worked. While checking in with the Science Kit Technician about the state of the science kits at the school in which they worked, they shared that over half of the 3rd, 4th, and 5th grade teachers did not use the science kits. They mentioned that as a result, on the one hand, while this made the kit servicing easy, it was massively disappointing for them. It was then that they divulged that their own child was a student of one of the 3rd grade teachers at the school, and that not once had their child come home and told them what fun experiments or activities they had done in Science class. In fact, they admitted they were not even aware that their child had Science. This made them quite disappointed because science was their own favorite subject as a child. This story is powerful for a few reasons. First, just because a teacher has appropriate resources, does not necessarily mean they will use them. Second, several indicators can be used as evidence of student-centered Science learning, including artifacts of non-usage. Third, that pressure for instructional change can come from any level - including support staff.

After three years of working with 6-8 teachers, two years working with 3-5 teachers, and one year working with K-2 teachers, I found that even with my efforts to support over 175 classroom teachers in building their capacity through monthly teacher-centered professional development, modeling lessons in their classrooms, conducting classroom walkthroughs, individual planning support, providing pacing scaffolds and resource management support, some science kits were still being unused, and science instruction was often not being taught as intended by the curriculum. The vice superintendent, my director, school administrators, and fellow colleagues are quick to remind me, however, when they see me get down about this reality, that so many more teachers are using science kits and teaching science in numbers and ways that our district has not previously seen. And while this reminder is uplifting, the graveyard in which I work remains a constant reminder and source of motivation to continue to build capacity and crusade for authentic science experiences within, inbetween, and beyond the classrooms of the school district in both hidden and plain sight.

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If You Caused Change, But It Is Not Maintained, Does It Matter?

[*What makes change initiatives effective?*]

The first direct leadership conversation I had took place during my final evaluation in England, before my move to Berlin. The conversation was with my very English department head—brilliant, strategic, frank, and direct. They not only had high (but fair) expectations, but they also lived out these high expectations - leading by example. The conversation had a lasting impact on me, the echoes of which I still hear today.

During the meeting with my department head, I proudly shared all of the digital folders of various resources and activities I had developed for all the courses I had taught from Year 7 to

13. I also shared a folder of outreach resources - contacts, handouts, flyers, drafted permission forms, health and safety requests, timelines, and pictorial artifacts. In response, I had expected praise from my department head, but I was instead met with skepticism. Rather than praise the work I had done with and for students in addition to the work of organizing these outreach resources for my colleagues, they simply asked a question - had I found someone to commit to continuing on this work? I responded, no, for the reason that my colleagues never expressed interest in the activities I had done, nor had they asked any questions. I wasn't in a formal leadership role, and the activities I did were all extracurricular or tangential to the standards. For these reasons, I never thought that my antics were deserving of telling anyone about. My department head had me questioning myself - was it a waste if I hadn't shared it with my colleagues, that I built up this system for just myself and my students? Their comments were spot on, but I though I had neither the impetus nor the leverage to impact my colleagues.

Yet, I've since thought I had been (albeit indirectly) leading by example. No way of knowing if through indirect observation, I had inspired a colleague to carry on one of the things I had started after I left. I have no longitudinal data to prove or disprove the efficacy of my efforts after I left these educational systems. I am still left wondering, were the interactive, discourse-oriented, hands-on activity resources I developed and enacted in Alberta used by the teacher upon her return from maternity leave? Were the debates, outdoor physics activities, student-centered inquiry-based experiments I created and left for them used by my then present and future colleagues? Were the outreach trip resources and contacts I forged leveraged ever again? Or did they remain hidden and untouched in a virtual folder on the shared drive of our network? I am left to wonder if the resources I have made in my current role as a district science strategist will survive after I leave.

The only feedback I ever have received are emails from a few past students who had experienced these opportunities or activities, sharing that they had forever impacted their trajectory - they were now pursuing degrees and graduate degrees in Science. Considering the question from my department head that I've since reframed to be, "If you caused change, but it wasn't maintained, did it matter?", I see two answers. The first is that the small change I made did matter because it mattered to, at least a few, of my students. The second is that the change I made, which was not subsequently readily taken up or maintained by my colleagues, didn't impact the future of the institution. At the time, I didn't seek to create long-standing changes to the system. My mindset was not focused on leading, but rather on doing, to do right.

I now see this mindset in a few teachers at schools I support across the district I currently work at and am left wondering the same thing as my old department head. In all cases, they lead by example, but at all costs, avoid taking on formal leadership roles or actions. In some cases, these teachers are not even aware of the pedagogical brilliance they possess. The main work I do with them is make them aware of all the things they are doing that are amazing for student engagement, scientific attitudes, and achievement. They just do what they do, as they always have - keep on keeping on. Just as I had.

I find myself having similar conversations with these teachers to the very first one I had had with my old department head. In my current district, an experienced teacher of 25 years in the Science classroom, who had experienced numerous rounds of reform approached me. We have a good rapport and professional relationship - something I worked hard at in my first year as they were a seasoned teacher and an institution in the district. Over the past three years, I have been working to build awareness of both their instructional excellence and their leadership capacity. Recently they shared with me that I had given them the confidence and desire to pursue school leadership and lead within the district-wide science team. Perhaps I am finally starting to effect long term change.

Around the same time, my own boss, the director of my department, sat me down for my annual evaluation. They know I shy away from titles of "expert" or "leader" - as I have stated in various leadership professional development sessions that strategists have undergone alongside school administrators. My director stated something that resembles the following: 'I know you don't identify as a leader but know that you are and have been a leader to everyone on this team through your modeling, the artifacts you design and contribute, and your professional process and practice'. It is true, my fingerprints are now found across our department's processes, procedures, documents, and artifacts. In fact, it is the first time I was able to visibly see my imprint on an educational system, and it is exciting.

Yet, I find myself returning to that question that echoed in my mind "If you caused change, but it wasn't maintained, did it matter?". I don't know what will happen when I leave the district, or what will happen five or ten years down the line when it is time for a new curriculum to be adopted, as is the status quo in the U.S. Already, the preceding *modus operandi* prior to my arrival has been trickling back into the minds of people at all levels - questioning if we as a district are really staying with this curriculum and for how long will it be around, already expecting a change to the next thing before the six-year implementation is up. It is my hope that I have imprinted upon each stakeholder in the system, a belief in the importance and value of meaningful student-centered science education for our students that will continue on, well beyond the implementation of this curriculum. But inevitably, the fear of relapse creeps in, keeps me true, and working hard against the possibility of relapse into previous, entrenched, ways of teaching and learning science.

This fear is not a problem unique to this district. I see it rampant throughout the academic science education literature I read. There are many volumes of studies that go into classrooms or schools for a brief stint, a few months, a year or even a few years to implement some sort of "change". Equally, there are hordes of funding opportunities, especially in the U.S. for education that come from philanthropic foundations, and commercial businesses. In both cases, when the grant, researchers, and/or money leaves, it is pertinent to ask - what remains, years after they were there. This is the data that is largely left undiscovered and unstudied. Again, "If you caused change, but it wasn't maintained, did it matter?"

At the beginning of this vignette, I shared how I found myself wondering how the local changes I made to my own classroom ecology could be maintained by others in England. At the end of this vignette, I shared how six years later, I still find myself obsessed with this question, albeit, I now have acquired a position that provides me with the platform to influence change at a system-wide level. In my district-level strategist role, I have had many conversations with school administrators and district-level strategists about previous districts they had worked in regarding the permanence of culture. As a district-level team, we reviewed initiatives and systems of the past decade. We found only one example of permanence - the presence of curriculum maps. Every other initiative, structure, or process has gone by the wayside with the changing tides of educational policy and reform.

Ideas can be inculcated, systems can be structured, initiatives can be reinforced, and culture built up over time. However, is such a system self-sustaining, or does it require continual intervention to maintain the work done? After all, even the strongest and oldest of buildings need repair and maintenance after weathering decades and centuries of the elements. In due time, a manicured field left untended will inevitably return to the natural wild. How is it then, that we can expect change in science education to be maintained and sustained without continual intervention and grooming?

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Critical Conversations

[*Implementation and enactment are not the same phenomena*]

In terms of my understanding of implementation and enactment, I must start with *the* critical conversation, which subsequently informs all those that followed thereafter. The conversation occurred over lunch in the second year of my doctoral studies with an education research professor. At one point, I had started speaking passionately about (what I had understood to be at the time) implementation when they paused me to ask a question - 'do you mean to say, enactment?'. To which I answered, 'I don't know, what is the difference?' To which they replied, 'well, let me tell you'. Stated simply here, but explored in detail elsewhere in this dissertation, implementation is the plan and provision of conditions and/or infrastructure needed to execute (enact) the plan. Thus, enactment is the messy reality, the execution of the plan. Enactment involves the use of infrastructure and resources to achieve the ideas, visions, or goals of the implementation plan.

This was a critical conversation for it not only illuminated a misconception I held, but in doing so, prepared me to engage in future critical conversations on the very same topic with stakeholders at the district, school administrator, and curriculum company level. As had once been true for me, the administrators, district directors, curriculum company managers, and the education researchers affiliated with the design and development of the curriculum program I spoke with did not have enactment in their lexicon - only implementation. Having experienced this same phenomenon, I set out to engage in the same work with them as had been done to me - to delineate and define implementation and enactment.

Equipped with research-based underpinnings from my first critical conversation years ago with the education researcher over lunch, I have engaged in critical conversations delineating and defining implementation and enactment with district leaders, site administrators, and the curriculum company researchers/managers I work with. Each stakeholder has responded in different ways. Over the course of three years, I have been working with site-based administrators to build their capacity in understanding the shifts in expectations for standards-aligned science instruction (implementation), and for identifying the presence or absence of this instruction in the classroom (enactment). When engaged in discussions about the curriculum enactment with site-level administrators, I am commonly met with one of the following statements, administrators state that they observed:

- Nothing, They hadn't made it into science classrooms recently (note - only Math and ELA state scores are used for school grades);
- Science being taught (but weren't sure if it was the curriculum we adopted);
- Curriculum resources being used (but were not sure if the teachers were on pace);
- Curriculum resources being used, but the instruction was not student-centered;
- Curriculum resources being used, and the instruction was student-centered.

In each case, we unpack their observations and co-create action steps together - such as conducting classroom walks together to increase the enactment and/or efficacy of enactment for the curriculum. The fundamental difference between their role and mine is that I am not evaluative - I am supportive. I can bring the horse to the water and try to entice it to take a drink, but I cannot make it drink.

Just as I had once experienced myself, I had come to find that the director of my district-level department didn't separate implementation from enactment. Sadly, I had to inform them that the curriculum was not being enacted as envisioned. I brought them up to speed that the current adoption procedures were not being followed, resources were not being used, textbooks and past curriculum were hidden in closets, and even that Science was not taught (for K-5). It was eye-opening, to say the least. From this crucial and critical conversation, however, together, we have been able to close the gap between the theoretical implementation and the actual enactment of various district-level and site-level policies, procedures, and resources.

Perhaps the two most perplexing critical conversations I had were with the curriculum company manager of professional learning and the principal investigator that was a part of the initial curriculum design collaboration between the university and the company. In both cases, neither had yet differentiated implementation from enactment. The curriculum company manager of professional learning always spoke of "implementation" and after a conversation about 'teachers actually teaching the curriculum as designed' shared with me an 'Implementation Continuum' for teachers, administrators, and district leaders that they designed to reflect the shifts in instructional practices aligned to the curriculum (relating to student discourse, language development, and ownership of learning).

When I asked the manager the very question I was asked "Do you mean enactment"? They were confused, just as I had been. After explaining the difference to them, they responded with a bit of "company line" that the company makes and provides "support" for the curriculum. They admitted they were more on the implementation side of the work and that the term “implementation continuum” was something they made themselves (not widely used across the national company) to help districts self-assess how the curriculum was going and if they were, in a sense successful in using the curriculum as it was intended. This is interesting, as the manager has an idea of the importance of enactment but does not have the language or theoretical underpinning to support their ideas. This person has since moved up in the company and I hope they take that idea with them!

I was able to track down the principal investigator at UC Berkeley that developed the initial model for Amplify. They provided me with fascinating facts regarding the historical, economic, social, and political details of how a grant-funded education research-based science curriculum started at a university and became the product of a multimillion-dollar educational company. And while the researcher was very knowledgeable in sharing the intricacies of the curriculum development, they too had not differentiated implementation from enactment. With this education researcher, I shared the experience I had had with the curriculum company manager in hopes of answers or insights regarding the implementation/enactment conflation phenomenon I had seen play out on several levels, including that of the curriculum company. After explaining it to the researcher as had been explained to me, they had admitted they were unaware of this term or field, agreed on the importance of it, and acknowledged that it was altogether absent from the conversations at the curriculum development level that they led. This prompted me to ask the question myself - at this company or the research surrounding the curriculum, did anyone study enactment? Was anyone interested in the percentage of enactment, or, is it as found to be the case in the U.S., ‘all about the sale’? My initial probing suggests the answer is no, but at the very least, I recently was able to squeeze in one short sentence about the distinction between implementation and enactment in a recent publication (see Abbott et al., 2023).

Summary

The vignettes included in Part II: Mind the Gap have provided textured accounts of my experiences and observations of the interplay between stakeholders and instructional support infrastructure. Building on the ideas presented in Part I: *Tending the garden*, in this section I noted infrastructural variables, barriers, and challenges that can build capacity for, or impede, enactment of an implementation. Part II focused on the gaps I experienced within and around science education systems relating to the interactions between constituents within the spheres of practice, policy, leadership, research and ultimately, how those interactions through instructional policy can impact enactment of reform-based science education. The following summary will reflect on the prominent suppositions relevant to the data presented in this section: Supposition 3: *High-quality, reform-based standards-aligned curriculum can help achieve the goals of reform-based science* and Supposition 4: *Implementation of reform-based science classroom infrastructure can achieve reform-based science aims.*

Because infrastructure is an essential element to inform and support the what and how of science education, it seemed plausible to me that reform-based science aims might be achievable if instructional infrastructure and high-quality reform-based standards-aligned curriculum are provided and implemented. Reflecting on Supposition 3 and Supposition 4, I experienced different manifestations of curriculum quality and classroom infrastructure implementation in Canada, England, and the United States. The variations I experienced were likely a result of context-specific instructional policy that provided support for the provision of infrastructure, but also the implementation of the provided supports as well. In three different countries I experienced variation in infrastructure including: materials, space, standards, curriculum, assessments, professional development, instructional techniques, school and district level policies, school schedules, instructional supports, school routines, and performance evaluations. Although the varied nature of the instructional infrastructure provided, instructional policy, or implementation efforts, sometimes improved student opportunities to engage in reform-based science educational activities, enactment of government-based educational policy was still relatively sparse. I will briefly summarize the similarities and differences between my experiences detailed in Part II, below.

In Alberta and Nova Scotia Canada, it was my experience that teachers were provided little in the way of a curriculum (a textbook at most), but had access to high-quality experimental resources. Because of tradition or other pressures, teachers in my experience did not use provided science experimental resources and often due to time restrictions largely ignored the non-content based elements of the educational standards (e.g., nature of science, scientific attitudes, and skills) were largely ignored in favor of content-based elements (see Alberta Education (2014) and vignettes *The Unopened Microscopes*, *Looking at Science Education with Rose-Coloured Glasses, Keeping up Appearances*). Thus, although resources were provided a lack of oversight

In England, it was my experience that teachers were provided with instructional and experimental materials that were closely aligned to national standardized assessments. Within the school I taught, common department assessments and a culture focused on student achievement resulted in little deviation from the content-focused and cook-book experimental provided materials. While the instructional infrastructure supports increased quality knowledge (content)-

based instruction and cook-book, confirmation-style hands-on experiences for students, there were few minds-on experiences that helped students develop scientific attitudes or an understanding for the nature and processes of science through different science enquiries (see UK Department for Education, 2013 and vignettes *A Thespian Affair*, *Timing is Everything, If You Caused Change, But it is Not Maintained, Does it Matter?, Keeping up Appearances, What'd You Get on The Test, There's Always Room for Dessert*). Thus, although students were required to experience hands-on activities, there was little room for students to engage in activities that helped develop their understanding of the process and nature of science.

In the United States, teachers were provided all-in-one science kits alongside a high-quality and reform-based curriculum aligned to state and national science standards. In contrast to my curriculum experiences in England (assessment-focused curriculum) and Alberta Canada (outdated textbook-based curriculum), my first encounter with a high-quality, reform-based standards-aligned curriculum was in Arizona, of the U.S. (Amplify Education, 2019b; Nilsen et al., 2020). In my role as a district-level Science Strategist, I was responsible for leading the implementation of the curriculum and providing instructional supports to build capacity of teachers and leaders to support enactment of this curriculum over the course of four years (see vignettes *Professional Professional Development, You get What You Pay For, Kit Culture Couture, Keeping up Appearances, If They Can't Fish, Give Them Fishes, The Revolving Door of Reform*). However, high teacher turn-over, low teacher pay, a waning/non-existent pool of teacher applicants, among other variables were found to limit the effectiveness of even well-designed reform-based curriculum. My experiences suggest that even when teachers were provided a high-quality, reform-based standards-aligned curriculum and research-based professional development, fundamental gaps remained in beliefs, attitudes, and pedagogical content knowledge that prevented the teachers from fully understanding the standards and delivering (or enacting) the curriculum as it was intended.

In sum, my experiences suggest that while high-quality curriculum, infrastructure, and instructional policy increased access to, and support for, reform-based science education, enactment was less than effective due to a variety of reasons unique to each context. The main findings that emerged, to be discussed in Chapter Five: Discussion (see *Instructional Policy*) include:

- Teacher pedagogical content knowledge is low, teacher education isn't helping;
- High quality instructional materials are crucial, but not in isolation;
- Policy change takes time, sometimes;
- The importance of striking a balance between pressure and support;
- Accountability measures for maintaining and sustaining change are absent from the educational landscape.

Part III: It's a Matter of Perspective

The vignettes in this section shed light on the tensions that I have felt about how science education is portrayed versus my experiences of the inner workings of science education from different vantage points. Here, I reference various stakeholders of science education along with their perspectives - teachers, intermediaries, administrators, scientists, education researchers, a curriculum company, philanthropic science education foundations, and education outreach.

Lost, and Found, in Translation

[*Each school, region, and country has its own educational dialect*]

Learning a language instills a spectrum of feelings - it can be humiliating, humbling, and exhilarating. I have dabbled in language learning for travel or work. I love travelling and being swept up and lost in the negotiation and sense-making of foreign tastes, sights, and sounds. I enjoy the challenge of puzzling through a culture's language by decoding cultural and language context clues in order to decipher and engage with the foreign language. However, when learning a new workplace language, the novelty quickly wears off. What is exhilarating and novel in travel and vacation is stressful, annoying, and embarrassing in the everyday minutiae of the mundane.

Even in moving from Canada to England, negotiations of language were often surprising. From the frisbee field to everyday slang, to trivial professional terms and acronyms, I felt as though I was learning a new language—even though I lived and worked in countries that were relatively familiar to me, English-speaking and of largely European (white) descent. Visually, I *appeared* to fit in. However, my accent, dialect, mannerisms, and confusion with terms would quickly betray me as a foreigner. This betrayal resulted in a variety of outcomes ranging from shared laughter to quiet embarrassment, to shock. Apparently, spunky is not a word to use in front of English children. Grocery bagging is a competitive sport in Germany. Tipping can be awkwardly insulting to an English Bartender. Even sports terminology can be wildly different as I found on the Ultimate Frisbee fields.

In the same way that frisbee players, pub bartenders, servers, and grocery clerks have looked at me incredulously, so too have education professionals. In most cases, they are as shocked as I. We are both products of our cultures and are only privy to and entrenched in one world or cultural view. My misstep and their incredulity indicate our unawareness of one another's experience. Perhaps they are protective of their traditions and norms, and perhaps I am embarrassed of my ignorance. Sometimes, others are visibly bewildered to find out that other ways of doing education exist out there in the world. Just as I was surprised to discover that the school I worked in was divided into 'houses' not unlike the houses described in Harry Potter.

When I read of multiple language learners' experience with language, they must simultaneously think in a variety of combinations and negotiate intonation, intention, and context for both the many inputs and the output. There is a constant sense-making negotiation that takes place, and the burden falls not on the other bystanders, but the person receiving and outputting language as they navigate the social and professional cultures with the "groping learning of an infant" and a loss of status as they become a beginner again (Bateson, 1994, p. 82), a humbling, and sometimes, humiliating process. I now know that any newcomer to a new job is in this infant stage of learning the new language of the microculture that they have just joined.

In my current district located in central Phoenix, the student population is 92% Hispanic and 40% English Language Learners. Many of the district policies and professional development

I provide are informed by these statistics. As educators and policymakers, the importance of supporting these students is clear. To do this, we must see language learners as having assets, not as having language deficits. I have experienced the frustrations of not being able to articulate simple sentences and having people focus on my cultural deficits rather than the assets I will brought.

It is rather curious that the very educational institutions that promote diversity and provide support for the language learner student population are insular towards those same attributes in their staff. While I have bureaucratically been welcomed into two countries and awarded a work Visa to fill the ever-depleted roster of science educators, the welcome lacks longevity beyond the paperwork. My own experiences as a white person migrating to predominantly white anglophone countries to teach science, while so much 'easier' because of my white privilege, was still difficult and stressful. I cannot imagine how difficult it is for anyone without the privilege that I had.

Language and mannerisms can be a defining feature of cultural belonging or discrimination. A slight hint of an accent, questionable word choice, missed expression, or odd gesture can quickly betray one's outsiderness—I often think of Tarantino's (2009) , *Inglorious Basterds*, when one of the good guys betrays himself an imposter by counting to three on the wrong fingers. In predominantly white communities and cultures, I largely pass for belonging based on my appearance and dress. However, the moment I speak, my foreignness is betrayed. In England, upon engaging in conversation, too often I was asked "Where are you from?", I would say "Newton Abbot". To which they replied, "No, where are you *really* from?" In any country, the smaller the town, the easier it is to be betrayed. I have felt my ears burn from embarrassment because someone was unable to understand my accent, I used a word that was inappropriate, or my accent was mocked. I can only imagine how much more amplified these experiences would have been if I was a person of color with an accent that is not represented in popular culture.

The best lessons in discrimination and resiliency I experienced happened in the school at which I taught in England. The entire faculty and student population was sitting in an assembly on anti-bullying. As part of this assembly, an anti-bullying video was shown about LGBTQ+ diversity and respect. The narrator had a nondescript North American accent, with no obvious drawls or intonations (to my ears). They sounded just like me. After the video, one of the assistant principals apologized to the entire staff and student population for the awful accent—sadly forgetting that one of their teachers had that accent. In retrospect, it is ironic that the moral of the video was about anti-bullying and acceptance of diversity. After that statement, all the staff and the students whom I had taught turned to look at me. I tried to keep my head held high and maintain a neutral expression, but inside I was devastated.

. On another occasion, upon a rather difficult conversation with a (different) assistant principal in which I brought up several of the challenges I was facing, I was told "If you don't like it here, or how we do things, go back to where you came from". I recall the same phenomenon happening in the small rural city in which I grew up - where the locals were unable to understand the rather mild accents of the very few non-white people that lived in the city. Giving the benefit of doubt, this was not because they were intentionally trying to be rude, but because they had limited exposure to hearing anyone speak other than the homogenous group to which they belonged. I had heard these same words being uttered to or about individuals who were struggling with assimilating to professional or cultural norms - if you don't like it, go back to where you came from. These stories exemplify that "the more closely one is defined by membership in a group, the more difficult it is to recognize the personhood of the "other" coming from outside" (Bateson, 1994, p.63).

Language learners include those who are learning an entirely new language, learning the culture and acronyms of a new system, or learning to navigate their existing language in another country. They are taxed with navigating additional cognitive burdens, in addition to the base social or professional tasks required of them. I have experienced language learning, and the tensions that come along with it. These tensions include navigating dissonance, discrimination, and exclusivity that come with the tell-tale indicators of bewilderment, denial, or even frustration when insiders are faced with information that does not align with their narrow spectrum of experiences and ways of knowing and doing.

Each educational system has its own unique culture, acronyms, expectations, values, norms, policies, and systems. Certainly, this is apparent between schools in different countries, but also between schools within the same city. My brief stint of substitute subbing in the capital of Nova Scotia illustrated this later claim, as I experienced, tangentially, the nuances between eleven schools in a single district - each having slightly different procedures, expectations, and programs. Much like the teaching climate in Alberta, as an outsider, it was near impossible to get access to a teaching position due to the tight union-regulated teaching positions.

Education systems love acronyms and these acronyms become so embedded in the culture that, when I ask what it stands for, in each country I have taught, the answer often is - I don't know - we just call it that. The acronym takes over as the identity and it is incorporated into the lexicon of the local school language, however, it is often the case that everyone forgets that it does not exist outside of that context. As I had done for my undergraduate physics classes, I would make up a formula sheet that I would have on hand to reference so I could attempt to engage in both professional and colloquial conversations without appearing too stupid. Similar to the experiences of language learner students, I tried to smile and nod to show I was hearing what was said, but not necessarily understanding it all. More often than not, this eventually resulted in accusations of not listening or not paying attention. In these situations, a translator would have been useful.

When assuming the role of translator, a seasoned multilingual language speaker can quickly switch between languages and contexts to identify dissonance and bridge gaps in understanding that may not be as readily visible to the person for which they are translating. In educational systems, a significant narrative of asset-based mindsets towards language learners is their cognitive ability to task switch and concurrently hold more than one set of cultural and linguistic knowledge at once - more than someone who only lives and speaks only one. My own inescapable outsiderness gifted me with a kind of multilingualism that enabled me to navigate complex educational systems using different languages. In my role as a district-level Science strategist, I quickly developed and honed architectural skills to forge bridges, build connections, and translate ideas between multiple stakeholders. I was able to simultaneously see the relationships between each element had to each other, and to the greater whole. Much like multilingual speakers who translate, I too 'task switch', donning different hats when I speak to different stakeholders in the systems in which I work. Reflecting upon my decade of learning the native languages of people who inhabit the different roles in different systems in different contexts and countries in which I have worked and lived, I have come to discover that while much has been lost in translation, more has been found.

Chinese Takeout

[*What does it mean to be 'authentic'?*]

Every New Year's Eve growing up, getting Chinese takeout was a family tradition. It was a special occasion and thus, *exotic* flavors were in order. I came from a small rural city, which at the time, only had one or two Chinese restaurants. I grew up understanding that this food was authentic Chinese food. As I got older, I learned this was 'Westernized Chinese food'. I still don't really know what authentic Chinese food is, and I still love 'Westernized Chinese food'. When living abroad, I would crave Chinese Takeout, but none of my cravings were fulfilled in other countries. Their 'Westernized Chinese food was not the same as mine. They had none of my childhood favorites—where were the pineapple chicken balls and ginger beef? I found that each country had its own variation - slightly different meats, different sauces, and different preparation styles. All variations on an ancestral theme.

I have reflected upon these varieties of authentic and Westernized foods and a parallel to authentic science experiences and education. Moving from the biology lab into science education I felt a tension between the experience of authentic science and how we teach students about science. When teaching science, we always seem to present a hearty, though perhaps sometimes misguided, and distorted version of science and its practices. It is familiar, because it is what I experienced myself as a student—mild, fluffy, comfortable, easily digestible, and foolproof. Is this our best representation of authentic science? Is serving its purpose as well as Chinese takeout? Are the different versions of science in the classroom equally representative of the authentic, with different experiences and backgrounds the only judge of its value? Or is there some way to determine which way is best? Is there any value in providing an authentic experience, or is the classroom version of science good enough?

My experiences in science education remain common across Canada, the UK, and the USA: it is an interpretation of science, much like Westernized Chinese food is an interpretation. It has persisted so long, that it is unclear to both teacher and student how much classroom science has departed from authentic science practices. Researching scientists learn by doing. When you do science, you don't always explicitly use the usual words of scientific discourse (e.g. models, analysis, hypothesis, data, argumentation, reasoning). In some fields, some words will be used more than others, but more regularly, you just do, the language and habits become a commonplace of your lived culture. Said another way, Scientists live out and live through a culture of scientific practices, rather than learning about scientific practices and their importance.

In bringing authentic science to the classroom, I am often left wondering who is invited to the table. What kinds of students and teachers are invited to participate? Are the schools and educators selected representative of the whole teacher population? Do teachers and schools engage in a 'trick and pony show', in that they change practice for the duration of the visit and go back to their ways upon the exit of the researchers or funding? It seemed to me that even the 'authentic' science experiences in classrooms were somewhat artificial. When I reported my feelings to my professor in my B.Ed., I was met with contradiction. I was surprised that what seemed so clear to me was not shared by someone I respected. I still feel that there is something missing in classroom science. I have written many of the pages of this dissertation exploring this feeling. I am unsure if authenticity in classroom science is necessary for a better student understanding of scientific process. But what is clear to me is that we have not achieved a consensus on how to assess this understanding. Perhaps we need to return, instead to questions of authenticity, to questions of purpose. Just like Westernized Chinese food satisfies its purpose, perhaps so can canned labs and classroom science. However, there may be times when authenticity is desired. But then we are left with asking How much? And Who for? And How often?

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Just, Only

[*What constitutes membership in educational spheres?*]

One day in Arizona, after delivering some particularly intense professional development sessions, my colleagues and I went for some refreshing libations. We had all just delivered our biggest in-person professional development sessions yet (85 people in attendance for each of our sessions). I was providing Science PD to the K-2 teachers in our district, while my counterparts were delivering Math PD to the 3-5 teachers. During the first round of drinks, my colleagues and I pleasantly shared our highs and lows from each of our sessions.

In our own ways, we all are a bit sensitive to our backgrounds. We all seek validation for our paths because each is a bit off the normal route. For example, the Math Strategist was a "TFA" (Teach for America) teacher with 5 years in the classroom (Grade 4 and 6). *Teach For America* is a program in the U.S. that seeks to increase qualified teachers in classrooms (usually in low-socioeconomic districts) through college degree debt forgiveness in addition to full compensation of a two-year *Master of Education* degree. They were a coach for three years prior to becoming a district-level Math strategist. They are currently in the process of becoming a "National Board Certified" teacher. The K-8 Language Learning Strategist is a home-grown, born and raised Arizonan teacher educated in a state university. They have a combined 4-year education degree and had taught for 11 years in two schools (grades K, 1, 3). They coached for three years prior to becoming a district-level strategist, are a National Board-Certified Teacher, and teaches sessionally at the state university. Finally, there is me, the K-8 Science Strategist. I have too many degrees already and was in the final year of my EdD. I taught in a classroom for almost four years in three locations (two countries) including Grades 7, 8, 9, 10, 11, 12, 13. I also taught university labs for 2 years. I also had some other experiences doing research or support. I did not coach prior to my strategist role.

The second round of drinks and conversation brought on some more intense conversation. We all share the same title. We are each a district level "strategist" for a different content area (Science, Math, and Language Development) and are approximately the same age (ranging from 32-38). However, we have had vastly different life experiences, disciplinary groundings, and classroom experiences that have led to the different paths we each had taken to get to our current position - this being the source of tension that was revealed over the second round.

Over my years in educational roles, I have observed much banter over what constitutes *full* or *legitimate* membership. There is variation between cultures on their "ideas of where membership begins and how it comes into being" (Bateson, 1994, p. 62). Educators, in particular, throw around their 'credentials' (e.g., the number of years in a classroom, the type of training, etc.) to prove their membership for professional efficacy and legitimacy. Anything less than an arbitrary number of years (e.g., 3, 5, or 10) of years of experience in a classroom is too often met with the qualifiers of *only* or *just* - closely paralleled to *not yet* or the *just about* qualifiers. Rarely have I heard teachers sharing their pedagogical approaches or diversity of experiences as a credential to prove their efficacy or legitimacy. Above all, it is my experience that the number of years spent in the classroom is the highest and solitary badge of honor for teachers.

Back to the bar. By the time we had started our second round of libations, the casual jabs had prefaced with *just* or *only* started to burn deep (e.g. "*just* having an education degree"; "*only* having 5 years of classroom experience"; "*just* being a TFA"). I was at first observing the conversation. Each of my colleagues were noticeably injured by the back-and-forth jabs. I was a bit delighted that the jabs for once were not directed at me. Comments flew back and forth between my colleagues largely regarding the type of degree and the number of years in the classroom in relation to efficacy and legitimacy in their eyes but also the biases and systems that reward certain types of backgrounds and experiences in education. I was relieved that I did not have to defend myself or my path.

Until recently, I had a fear of being 'found out' as fraud or cast out as a greenwood. I have always been elusive when questions surrounding classroom experience inevitably come up in the staff room or in conversation in every country and locale I have taught. Technically, I have only spent three and a half years teaching students as a full-time science teacher in the secondary classroom. But, collectively I have a decade of diverse experiences in and around science education. I always have led with the latter. Only now that I am in a position of "power" and that I have convinced myself that I have "proven" myself to the teachers, administrators, coaches, and upper district leaders, that I am starting to chime into these debates about what constitutes membership in education and why. Recently I have started to speak up - around the fact that quantity is not quality and that diverse experiences hold equal if not more weight than singular stationary experiences. Participating in this happy hour conversation, however, I found myself listening and facilitating the conversation more than sharing - as there was a rift taking place between the other two.

A prevalent and persistent misconception is that a correlation exists between years in a classroom and professional efficacy. Often I see and hear parallels drawn between the rights of passage transition from (unknowing) juvenile to (all-knowing) adult and the transition from inexperienced to an experienced teacher. This misconception has been entrenched in the pay scales of educators - more years in the same location equals more pay - and prevalent in teacher lounges in all four locations and three countries I have worked in. Undeniably there is value in experience from a cultural and lived perspective. Teachers who have several years of experience typically have a clearer understanding of the systems in place and have solid classroom management over newer teachers. However, after the first few years, there is relatively little difference in these two variables. What I mean to say, is that there shouldn't be assumptions of the efficacy of a teacher based on the years of teaching experience - on either spectrum - that veteran teachers are old dogs you can't teach new tricks and conversely, that green teachers aren't as effective as more experienced teachers. Yet, because of the persistence of this misconception, teachers on either part of the spectrum continue to perpetuate the false narratives as a means of protecting their own perspective.

In the bar conversation, we also talked about how only in education is there a "linear" flow from teacher to administrators. And how there is this misnomer that if you stay in the same role, you are not as good as your colleagues who 'move up the ed ladder'. We discussed how there are different skill sets to do each job well. Just because you were a good teacher, does not mean you will make a good coach, admin, or district leader. But, some time in the role is important - for we were questioning if the problem is the desire for causation and correlation. For example - this superintendent is bad, oh, they *only* had x years in the classroom - or they were *only* a PE or special teacher. Or perhaps this admin or coach was really good - oh it's because they have over 10 years in the classroom. Maybe it doesn't matter what your background is - what matters is that you are good. There is no correlation between years in the classroom or whatever. What matters is you are good at your job.

What we realized upon reflection as we departed was that although we were focused on our differences in the 'what' (what our degrees were in) and 'how' (how long our experiences in the classroom or coaching was) of our backgrounds, we were united by the same 'why' (to bring equitable, engaging learning experiences to underserved students who are so very deserving). Our concluding thoughts as we exited the bar (as written in the small black book I carry on my person for moments such as these) were "These conversations need to happen more often. We are so aligned in our 'what' and 'why' despite 'how' we got there". Our lived experiences and disciplinary grounding that shape our perspectives are vastly different. But we are bound by our passion for equity in education and our desire to build the capacity of educational systems for student-centered and student-driven learning. It is because of our diverse perspectives that we have been able to leverage our shared values, and that has been instrumental in driving the individual and collective work we do. As three individuals in a school district, we are working in this way to address the problems that plague our district.

One of Us

[*The challenges and benefits of obtaining membership for multiple groups*]

We all desire community, connection, and acceptance. We wish to be seen, heard, and understood by people who share our own interests and needs. We seek counsel and acknowledgment from those who, through a set of common shared experiences, can empathize with us. Assuming defined positions, roles, or identities is a pragmatic way to quickly find a community to which one can hold membership - professionally or personally. From royalty to punks to the unhoused, from teachers to administrators to district leaders, community membership is at the heart of what drives action. Membership to a group can be revealed in many ways—appearance, demeanor, mannerism, dialect, or seniority. And just as the rag-tag community of circus misfits in the 1932 film *Freaks* (Browning, 1932) chant '*one of us*' upon initiating a new member into their group, so too, do we quietly whisper to ourselves this chant, in the communities we inhabit and the memberships we hold.

Membership to one group need not mutually exclude membership to another group. I like to wear many hats. I like to attempt to transect cultural boundaries by holding multiple memberships at once. To gain a new membership, it can be helpful to know its language and gestures, values and beliefs, and basic vocabulary. Membership is akin to street cred, and as such, it is essential to maintain the illusion that one belongs, so as to maintain access to members-only conversations and insights. Even though at times it was clear I was not a full-fledged member nor was I eligible to become one, I still had to prove my outsider guest membership, which I did by demonstrating my understanding by mirroring their mannerisms and using similar language. Sometimes, I found it important, perhaps essential, to only wear the respective hat to the group I was in, and hide those of the others to which I could circumstantially belong (e.g. when talking to teachers, I had to hide my admin hat, and vice versa). My ability to wear many hats afforded me a dynamicity and a level of trust I would not otherwise be able to achieve wearing only a single hat. The following offerings outline the types of membership I sought or observed from the outside, in and around science education stakeholders and communities.

Educational politics and policy have their own cultural membership, giving off the allure of a secret society, that meets behind closed doors with people of power, usually old white men. When asked about the role of science education research in shaping educational policy at the provincial level, a seasoned science education researcher scoffed as they made reference to what they termed the “old boys club of policy”. I was in the first year of my doctoral studies, and over lunch, I had engaged in a discussion about science education research informing educational policy. They shared a few personal stories whereby they had prepared a several hundred-page reports for the Albertan provincial government and subsequently presented the findings. The response from what the researcher termed the “old boys club of policy’ had an air of unconcerned disinterest, and they disregarded the researcher’s results. I had a similar experience when I had been gifted an audience with the Nova Scotian Education Minister, the contents of our conversation were substantively controversial, to say the least.

I transect and transcend boundaries on a regular basis in my current role as the district Science Strategist. I broker knowledge between stakeholders (district leaders, school administrators, academic coaches, and teachers). I wear the hats of each of these stakeholders in order to speak in their language and uphold the values that are of importance to each one. In a sense, I feel like I am going undercover at times so that I can access, what I often refer to the stakeholders I work with as ‘what's the word on the street’. I’m aware that my presence, my title, and my role, impact what is said to me about what is really true and what the barriers really are. A huge element of this work is to build up ‘street cred’ with whatever stakeholder I work with. I do this by speaking their language and making connections that are relevant to them, their needs, and their values. I employ humility and often share stories that will encourage the stakeholder to trust me - something juicy to show I am a member, even if I don't look like one or hold the role of one. I sometimes market myself as a 'double agent'.

All of this is important to me, so I can ultimately build the capacity of an educational system for instructional innovation in science. I don't care what I have to do to get there, but one thing is for sure, I need to obtain and maintain membership in multiple spheres to do this important work. At any time if I do or say something within the broader context that blows my street cred, I have lost the trust and access to what is really happening behind the closed doors of teachers' classrooms or administrators' offices, and most importantly, why. Too often I have seen upper district or science education researchers claim they have obtained information about what is happening in science classrooms or schools via surveys or classroom observations, but in reality, I know they have been given the information they want to hear, not the real information. I have experienced this facade presentation as I walked into K-5 Science classrooms around the district in which I work, only to find teachers scrambling to shut down the math PowerPoint (announcing to the class that 'its time for science, kids' over halfway through the science block). In my role in the district, sometimes I have to be the bearer of bad news of classroom to upper district leaders, sharing the realities on the ground. In the past I had shouldered the brunt of the kickback from the district leaders: was I 'sure this was the case'? 'How is this possible'? 'That is not what I hear'.

Over the past four years, I have been working to bring to light the real issues and barriers and the reality that our district has faced prior to my arrival - the biggest of them all is Science in K-5 was not being taught in most classrooms. Others included no tracing system for resources or effective PLCs. My colleague called me TB "truth bomb" for several years because I brought to light all the inconsistencies and non-examples. This skill has become central to the success of the position I currently hold as a K-8 Science Strategist who builds system-wide capacity for an innovative science curriculum through collaborating and thought partnering with teachers, academic coaches, school administrators, and district administrators.

Holding multiple memberships affords one the ability to shift between different world views and perspectives. Just as when a prism is held at the right angle, many coloured rays of light disperse from a previously perceived single white beam of light, so too can exploring alternative perspectives shed new light on old ways.

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An Inquiry Into Inquiry

My first experiences with science was engaging in the process of inquiry as a young child. While other kids were playing ‘Barbies’ and ‘trucks’, I was out exploring and ‘inquiring’. I still love to ask questions, design solutions, and discover meaning through experiential learning. Professionally and academically, I am both driven and tormented by inquiry. It is an obsession that has driven my experiences in and around science education. It drove me into secondary science classrooms, science education research, outreach, and district-level leadership. The following vignettes will highlight my observations of the past decade spanning multiple perspectives and stakeholder positionings.

A Case of Mistaken Identity

[*Multiple interpretations and understandings of scientific inquiry exist*]

I have experienced that the term 'inquiry' is subject to cases of mistaken identity across three modes: definition, practical manifestation, and political utility. I have experienced cases of mistaken identity in three countries (Canada, England, and the U.S.) and between multiple stakeholders (government, administration, teachers, education researchers, and outreach intermediaries). From ten collective years of experience in classrooms, professional development sessions (that I have led and been a participant in), conversations with teachers and leaders, working with outreach centers and universities, collaborating with curriculum companies, and leading the charge for science in a K-8 school district, I have experienced that inquiry (scientific practices) is largely misunderstood. From my experiences it seems that inquiry has been mistakenly swept up into an either/or dilemma that lends itself to being dumped into one of two binary buckets - either it is this or it is that, either it is done in classrooms or it is not, either it is good or it is bad for student achievement, either it is important or it is not. This binary perception pervades science education research, politics, and classroom practice. Systemic tension arises when stakeholder beliefs, attitudes, and perceptions about the value of their interpretation of inquiry (and scientific practices) are in opposition. This dilemma is further complicated by the power of politics stemming from standardized assessments which simply favor applications of facts over inquiry.

I have experienced the spaces in and around science education being rife with ambiguous terminology pertaining to inquiry (or scientific practices), which has somehow evolved to be of polyonymous nature - and not for the benefit of science education. Multiple meanings are used interchangeably, sometimes without knowledge of the existence of other meanings to explain the same object, science education. Yet the contextual and cultural lenses through which science education is viewed, and the values imparted by those lenses, impact both the practical manifestation and the meaning of those words that are used to explain it, resulting in a mistaken identity. Another variable contributing to this polyonymous nature is the unfortunate fact that the past fifty years or more have been witness to constantly changing definitions, semantics, representations, and manifestations emerging from new government initiatives and institutional policies.

Education researchers have had their share of commentary, debate, and critique on the matter (e.g., Furtak & Penuel, 2019; Southerland & Settlage, 2019; Osborne, 2019) which I feel can be a disservice to educational systems because of the impact of the aftermath of these conversations. Yet, inquiry remains a prominent element of science education promoted and studied by education researchers (e.g., see Friesen & Scott, 2013; Martell, 2020; Riga et al., 2017). For example, prior to the release of the American Next Generation Science Standards in 2013, inquiry was the dominant terminology. However, since the NGSS standards were released, inquiry has become an outlandish and antiquated term, presented as a paradigm shift away from "not just inquiry-based instruction" to a "culture of figuring it out" and "science as practice" (National Research Council, 2013).

This framing has surfaced in professional development sessions and mindsets of district-level science leaders through the National Research Council Framework and curriculum developers. I experienced a rather apparent distain for what they deemed 'antiquated' inquiry in professional development provided by a large university leading the charge of NGSS, professional development provided by a high-quality curriculum company, and the outgoing science strategist who I replaced. When I started working at an inner-city school district in

Arizona, this very narrative was reinforced by the professional development I received and by the outgoing strategist who constantly made a point of correcting me - “we don’t use the word inquiry anymore”. For the first time in my educational career I felt annoyed by this ‘throw out the old for the new’ mindset. I finally had experienced similar frustrations that I had heard educators share for decades about the revolving door of reform whereby past ways of teaching and learning is replaced, repackaged, and/or rebranded in the hopes that this ‘new and improved’ method is taken up with more vigor and understanding than the now ‘antiquated’ predecessor.

Problematically, I believe that the definition of the new age phenomenon-based instruction juxtaposes an archaic (mis)understanding of inquiry-based instruction which embodies the linear scientific method. Upon probing conversations with the individuals delivering the professional development and outgoing strategist, I found that they had never engaged in authentic scientific inquiry themselves. I asked each to explain why they thought inquiry was antiquated and what their own experience was of inquiry. Their answers were parroted versions of each other, namely that inquiry is an incomplete and outdated term and used the NGSS definition focused on the new word in vogue that replaced inquiry, phenomena. They stated that phenomenon-based education is where students ‘inquire, think, quantify, read, talk, write, critique, and argue like a scientist’. This is, in fact, the exact features of authentic scientific inquiry that I experienced as a scientist, and thus I persisted that there was no issue with the word inquiry, if used appropriately as at least in the scientific research world, and in fact little deviation from the ‘new and improved’ way of doing science education – through ‘phenomenon’.

I believe that focusing on semantics (e.g., inquiry-based, problem-based, hands-on, experimental, phenomenon-based) is hardly the issue. Rather than focusing efforts and criticizing word choice, definitions, or semantics, the energy of those involved in the conversation would be better served by spending their time analyzing and criticizing the systems and structures that have evidently prevented meaningful science education from taking root for the past century. Returning to Dewey's words: "Science has been taught too much as an accumulation of ready-made material with which students are to be made familiar, not enough as a method of thinking" (Dewey, 1910, p. 122), it is hard to imagine that this fate could have been avoidable *if only* we had, over 100 years ago, simply referred to science instruction as "phenomena-based instruction". What matters is not what we call science education, but rather, that the outcome is that students do science, not just learn it, and for what ends.

Definitions and semantics aside, it is clear that education research and government educational platforms, informed by education research, value and seek to promote and support science education that embodies the scientific practices, processes, mindsets, and attitudes of scientists. This is reflected in the national, state, and/or provincial programs of studies (Canada and UK) and standards (U.S.). In Alberta, the third Foundation of four in the Program of Studies (Alberta Education, 2014) focuses on *Skills* "Students will develop the skills required for scientific and technological inquiry, for solving problems, for communicating scientific ideas and results, for working collaboratively and for making informed decisions.". This foundation is supported by the first foundation, *Science, Technology, and Society* focused on the nature of science, and the fourth foundation, *Attitudes*, which proposes students are encouraged to develop attitudes that support the acquisition and application of knowledge to the mutual benefit of self, society, and environment". In the UK, the second aim of three in the Program of Studies focuses on *Working Scientifically* "the nature, processes, and methods of science through different types of science enquiries that help them to answer scientific questions about the world around them"

(UK Department for Education, 2013). Finally, in Arizona, the first dimension (of three) in the Standards focuses on the *Science & Engineering Practices* (ask questions and define problems; develop and use models; plan and carry out investigations; analyze and interpret data; use mathematics and computational thinking; construct explanations and design solutions; engage in argument from evidence; obtain, evaluate, and communicate information).

Personally, my main priority while working in science education in three countries was largely driven by the desire to achieve these aforementioned standards, aims, and foundations. This was contrary to the focus of most of my fellow educators and the systems in which I worked, which predominantly focused on the development of *scientific knowledge and conceptual understanding* (Aim 1 for UK), *knowledge* (Foundation 2 for Alberta), and *Core Ideas* (Dimension 3 for Arizona). In the latter case, the instructional practice of my colleagues and the systems in which we worked were largely driven by the aims, foundations, and dimensions which were the focus of standardized assessments.

So how is it that the general state of science education has lacked much progress despite the efforts of education researchers and governments to focus on the doing of science, rather than the learning of science? The polysemous nature of inquiry that has emerged from misunderstanding certainly plays a role, however, so too do the systems within which science education is couched, namely, the fact that these very systems which promote the ideals of a "proper" science education lack the structural supports and values to reinforce the enactment of these well-intending educational recommendations. This is no doubt in part due to the emphasis afforded to the various aims, foundations, and dimensions over others for both political and pragmatic reasons. It is tremendously challenging to authentically assess skills, attitudes, and beliefs, in contrast to knowledge, which is why knowledge tested in a multiple-choice manner largely accounts for the majority of standardized assessments. In one sense, it is pragmatic to systematically test this type of knowledge in this way over other domains and modalities. Yet what is lost is the ability to authentically assess critical thinking and ingenuity through other modes of demonstration. Resultantly, the politics and economics of education on a local, state/provincial, national, and international level are driven by these standards for assessing the efficacy of programs, through knowledge retention, and not critical thought.

The Programme for International Student Assessment (PISA) is the international driver of the economics and politics of education. It is an international measure of OECD countries and the “quality” of their educational systems. For reference to my context, the 2018 PISA results placed Canada in 3rd place, the UK in 8th, and the USA in 15th. The day following the release of the PISA results, newspapers splay the results on the front pages - as a badge of honor or critical disgrace, reflecting the economic and political welfare of the country. It too, makes sense that economics is tied tightly to education as it is the main selling feature of education to students. When children ask adults ‘Why must I go to school?’, the common response is ‘So you can get a good education to get a good job’. The implication is that good jobs bring good money, and good money brings good levels of happiness, or at least economic stability (individually and nationally). There is a longstanding history of economics being coupled with education. Nietzsche, (1872/2016) critiques 19th century (German) education for being dedicated to forming humans who are ‘valid currency’:

> ...Education essentially means acquiring the discernment that…tells a person all the ways to most easily make money… The true task of education, in this view, is to form people who are ‘*au courant*’ – valid currency… And that is the goal of the modern educational institution: to

> make everyone as 'current' as it lies in his nature to be, to train everyone to convert his innate capacity for knowledge and wisdom, whatever it may be, into as much happiness and income as possible. (p.16)

With the obsession of PISA results, it is evident that we have not so readily heeded the warning of Nietzsche (1872/2016) - "if we reduce the value of higher education to the material return on our financial investment, we will impoverish our culture and diminish ourselves" (p.17).

Already moral and cultural impoverishment is visible today – what will it look like when there are no longer material returns to be had? This is evident when one considers the damage done when PISA entered the inquiry conversation in 2016, when they, for the first time, shared their own data collection and analysis of the correlation between inquiry and student performance. Their main finding demonstrated that an inverse relationship existed between inquiry and achievement: "Perhaps surprisingly, in no education system do students who reported that they are frequently exposed to enquiry-based instruction score higher in science… Greater exposure to enquiry-based instruction is associated with lower scores in science" (PISA, 2016).

The fallout of this controversial publication had widespread effects on public, policy, and educational system opinion. One such example of fall out occurred shortly after the publication was released by the School Minister from the UK Department for Education in a speech titled "The evidence in favor of teacher-led instruction", in which Nick Gibb (2017) argued that research-based evidence should be used to refocus education on teacher-led instruction focused on knowledge-rich instruction to bring about real change. Among other things, this speech is a shining example of the mistaken identity inquiry that has been undeservingly bequeathed. This article (the medium through which I read the speech) came out while I was teaching in England under the proud banner of inquiry-based student-centered science pedagogy. I sat down and wrote a response that I intended on sending to a local newspaper, which I never ended up doing for a few reasons - one being that it included a significant amount of Albertan context, and secondly, I knew nothing about how to publish an editorial in a UK paper.

Returning for a moment, back to the Center where the Director with whom I worked, as a Nobel Laureate, we looked at this PISA report with quite the opposite reaction, identifying several problems with the collection and representation of this data. First, the data collected was student "self-reported" and not acquired through nuanced discussion by researchers who are trained and certified to identify if the learning experiences students being assessed were using as indicators of "inquiry" actually could be defined as inquiry. Second, a significant assumption was made by PISA that there is only one manifestation, representation, definition, and understanding across the world as to what "inquiry" entails. Achievement can be objectively measured by a cut score on a multiple-choice standardized assessment. Inquiry, on the other hand, cannot be standardized as an instructional practice or subjective learning experience by students. Third, questions consider if academic achievement should even be a measure correlated with inquiry. The Director argued that rather than correlating academic achievement to measure the impact of inquiry, other metrics should be used as indicators of successful inquiry-based instruction, such as student selection of science courses at branch points (middle school to high school; high school to university), engagement in class, citizenship, scientific mindsets, and motivation.

This further raises larger questions about the instructional practices of "modern" science education systems - are inquiry or scientific practices a process or a medium, and environment or a mechanism? Is it a process through which content, competencies, and skills can be obtained?

Or a medium in which content, competencies, and skills are developed. These are fundamental questions that remain unaddressed, all the whilst the conversation around the language of science education remains alive and well in the political and academic arenas, even if classrooms largely continue to mirror those of the 1900s that Dewey observed. Let it not be mistaken, however, efforts continue to move away from such realities - both on my part and the part of other science education researchers.

A Thespian Affair

[*Acting out the motions of scientific inquiry is not authentic inquiry*]

Theater can come in a range of forms: highbrow operas, underground cellar community theater, busking puppeteers, and social justice demonstrations, to name a few. I have seen theater take shape in many scales, locales, formality, platforms, and mediums. But never had I expected to see it in a science classroom. Though each locale has its own version, the best performance I've seen was in England, where students performed inquiry using a script. It makes sense why the UK Education Minister was confused with the role or lack thereof of inquiry in improving PISA scores.

In the UK there are only 2 exams that really count in a student's academic career. The Year 4 placement test, which fortunes what that student will achieve at the end of the Year 11 studies on the national exam, the GCSE (General Certificate of Secondary Education). It then becomes the teachers' job to make that target grade happen for the next several years. At least in my school, this became a competition of sorts - if one subject teacher could get the student to that grade in their subject and the others couldn't, you had to be prepared to explain yourself by showing all the ways you supported that child. Student success lies heavily on the shoulders of teachers. This was further complicated by the fact that teacher-administered grades did not count toward the student's final grades. Only one single grade ruled them all - the GCSE at the end of year 11. There was a substantial amount of mental jujitsu with trying to explain to parents and students alike, that ‘yes, this test was the only one that counted’, and ‘yes, their child still must complete the assignments and tests, even though they didn’t count towards the final grade’.

Up until the year after I left, the Year 11 GCSEs in science had a “practical component”, where the students had to complete a practical to assess their science skills and then answer two sittings of questions about the practical and assessment of their results. In total, the “examination” took 4 hours and counted towards 15 % of their Science GCSE mark. To my surprise, this was one of the ways to get “easy marks" because everyone knew how to cheat the system, without actually cheating, of course. I was hesitant at first to engage in these games, but then quickly became on board once my peer encouraged me that “this was the way we do things here”, as long as you were careful to cover your tracks.

What a fascinating experience the whole process was. I, their director, and the students, my actors, rehearsed for our performance diligently and with a severity of a surgeon performing surgery. Teachers were given a very close approximation of the type of experiment that would be assessed in advance (technical materials were required to be prepared) and given the small pool of GCSE historical practicals, one could easily deduce the task with a little bit of research. Our rehearsal was composed of conducting the experiment, data collection, and analysis. As their director, I critiqued the student’s experimental technique, graphing skills, and analysis. My colleagues and I built lessons around the anticipated graphing tasks and set of analysis questions, having students recite answers verbally and written. Interestingly, along the way, I did see some students who had never succeeded in traditional science class, benefit from the repetition and militaristic preparation - and they achieved incredibly high grades on their performance piece, boosting their self-confidence in their scientific abilities, and thereby encouraging them to actually study for the written individualized portion. I felt the pride I imagine a director does when their cast has a great performance. We practiced and practiced, and when the day came, they performed their "scientific" skills very well. Interestingly, the year after my departure, the new national curriculum was instated, and along with it, new GCSE examination requirements. They have since moved the "controlled assessments" of practical work to written response answers about how to do practicals, with no physical performance of the task.

While this is oddly the closest approximation of the assessment of inquiry I have ever experienced, it was simultaneously the least authentic. This begets the question - of how to inculcate a culture of inquiry and scientific practices in a system through authentically assessing scientific skills and practices. Any efforts I observed to do so, resulted in a theatrical performance that reinforced misconceptions and canonical misunderstandings of what inquiry and scientific practices really are. Conversely, in systems where inquiry is not assessed, it is dismissed in the classroom entirely. Damned if you do, damned if you don't.

Two Scientists Looking for Inquiry

Of all the ways and in all the places I sought to study inquiry-based secondary science, I never could have imagined myself working alongside a Nobel Laureate. Through a combination of unique circumstances and chance, the decade-long journey of my inquiry into inquiry led me to a year-and-a-half-long opportunity to work alongside a prominent Scientist (and Nobel Laureate). Their seminal research elucidated cell cycle regulation mechanisms, which pervade virtually every aspect of modern molecular cell biology. In graduate school, I recall being starstruck when I got to share a pint with a Scientist who authored the canonical *Molecular Biology of the Cell* textbook. But this experience was on a completely different level.

I joined the Nobel Laureate, the Center Director, at an R1 University in the center they created that focused on sustainability science education. During my time at the center, I engaged in several research projects including an analysis of philanthropic funding, reviewed existing resources available to teachers, investigated teacher perceptions of inquiry, and analyzed teacher-created inquiry-based lesson plans. The director and I met on a monthly basis where I would share findings from my inquiry into inquiry-based secondary science.

My main findings showed that while inquiry, as scientists define it, was very much central to the national educational science standards, sentiments of inquiry were largely absent from teacher practice, widely available instructional materials, and philanthropic contributions for secondary science education. Yet these results were not surprising to me as they reflected what I had seen in Canada and England over seven years prior. In scientific research, scientists seek to prove our results with statistical confidence, and to do that in biology, one requires a sample size, *n*, of at least three.

Until this work, I had felt largely alone in science education. For some reason or another, no one seemed to see the same things I was seeing, neither teachers nor education researchers I was in contact with. It was almost as if these individuals either donned rose-colored glasses (seeing science education for what it could and perhaps should be, not what it was) or blinders (unaware of what modern science education entails). The Center Director and I connected over our observations that the norms of secondary science education are largely perpetuated, 's*imilis simili gaudet'*, by people who think they understand science, but in reality, have never experienced authentic manifestations of science themselves (Nietzsche, 1872/2016).

The monthly meetings the Center Director and I had were centered on these findings. Both of us were puzzled by the state of science education - the director in their wisdom, was more intrigued, and I, more perturbed. I recall the director even asking me one day during one of these conversations - if you think the state of science education is in such disrepair, if you are so miserable about it, why do you continue to pursue an interest in it? I didn't have an answer to offer them then, and quite frankly, I don't have much of one now, even after exploring new areas of science education since then. As I mentioned before, it is an addiction, a puzzle I want to solve that I pursue with unwavering resolve.

Consistent with my research-to-practice track record, my work at the Center prepared me for my subsequent dive into the American (Arizonan) educational realities that I would experience. I explored inquiry-based science in four different facets of the American (Arizonan) educational system: a retrospective review of science education literature, science education philanthropy funding agendas, teacher professional development, and educational instructional materials. To frame our work, we (two scientists) agreed upon a definition of inquiry to be "students doing science, rather than learning science by investigating a phenomenon through asking novel questions, designing their own experiments, and collecting and interpreting their own data" (personal notes, 2019). We joined together on a quest to investigate the state of inquiry-based science in the broader educational landscape. The findings of these investigations follow.

An Experiment

[*What do teachers think scientific inquiry is and how do they do it?*]

Interested in seeing what teachers understood about inquiry-based classroom science, the Director and I sought to investigate the following questions with a small group of fifteen middle school science teachers: 1. What do teachers think inquiry is? 2. How have they implemented inquiry-based science? and 3. What barriers or problems they have had in implementing it? We met with the group of teachers on three separate occasions to get a sense of their initial understanding of inquiry and barriers to teaching in an inquiry-based manner but also to identify their interests in inquiry-based science and their needs for professional learning.

During our meetings, teachers shared that their barriers to fostering inquiry-based learning opportunities in their classrooms were most commonly limited by time, budget, space, resources, and materials. The teachers also provided insight that directed the design of the inquiry workshop. Teachers identified that they rarely had content-specific professional development at their schools, the opportunity to interact and collaborate with colleagues, and active learning experiences that were responsive to their needs. Based on these findings, we developed a workshop that was a teacher-focused, collaborative, and inquiry-based approach to professional development. The aim of the workshop was to provide a platform for teachers to evaluate and challenge their current classroom practices, beliefs, and knowledge as a means to increase self-efficacy and interest in inquiry-based pedagogy.

To determine what teachers understood about inquiry-based science, we asked teachers to complete a pre-workshop task that entailed providing details about a lesson that they thought was an exemplar of inquiry. Prior to the workshop, the Director and I reviewed all of the submissions, which included a range of activities, none of which fit our description of inquiry:

answering questions about a video, a prescriptive laboratory on chemical substances, a parachute design drop, modeling weathering with sand, reading about space explorers from a textbook, designing a boat to hold the most pennies. We concluded that the best of the submissions were examples of hands-on design challenges or problem-solving confirmation experiments, lacking any semblance of critical thinking through authentic inquiry or "students doing science, rather than learning science by investigating a phenomenon through asking novel questions, designing their own experiments, and collecting and interpreting their own data". It was evident to us that teachers held misconceptions about authentic classroom inquiry.

Resultantly, the two-hour workshop was designed to confront these teacher misconceptions and informed by best practices identified by research (Fitzgerald et al., 2019; Penuel et al., 2007). First, we provided a brief fifteen-minute seminar on what inquiry was using a spectrum adapted from Riga et al. (2017): Confirmation (prescriptive lab to confirm knowledge) → Structured (follow steps to find an unknown result) → Guided (teacher-provided question) → Authentic Open Inquiry (students generate own question and design of investigation). Following, the Director engaged the teachers in an inquiry-based investigation of the phenomenon of sensory perception according to the question and experimental design created by teachers. Teachers were then asked to reflect on that experience. For the second part of the workshop, teachers engaged in a "show-tell-seek" in small groups where they shared the inquiry lesson they brought to share with their group and evaluated the degree to which the lesson was inquiry-based. During small group discussions, the teachers were able to identify that the lessons they brought were either confirmation or structured. Teachers were charged with identifying opportunities to seek opportunities to 'level up' the lesson to be more of an authentic inquiry learning experience for students. According to the annotations on the presented lesson plans, they were able to apply the new knowledge they acquired about authentic inquiry, for example, by “getting students to ask the questions and design their own experiments”, however, they were unable to provide any specific explanation of how to go about doing that. Culminating the workshop, teachers completed a brief survey which showed that 50% of the participants would be interested in an inquiry lesson demonstration in their class, 50% would like a curated list of funding opportunities and 80% of teachers would like a curated list of digital resources. These survey results generated the next steps of my work at the Center.

In response to the needs expressed by teachers at the workshop, another facet of the work I conducted at the Center was to identify and curate a comprehensive list of widely accessible, high-quality, inquiry-based instructional resources. I found that while a plethora of freely available online resources existed, inquiry-based materials were sparse and difficult to find. This finding was corroborated by my own experiences in Canada and England of searching for authentic inquiry classroom resources. Further, a review of American philanthropic funding agendas elucidated that inquiry-based science is a scarcity in the philanthropic landscape for foundation origins, missions, goals, and values are as varied as the initiatives and projects philanthropies choose to support. For example, a brief review of the top science education grants from 2020 shows that of the 88 funders investigated, 26 used the term ‘hands-on’, 18 used ‘workforce’, and 8 used ‘engagement’. ‘Scientific inquiry’ was found in only 5 (Inside Philanthropy, 2020).

Inquiry-based resources and opportunities, however, do exist. Just as one does when morel hunting, you need to know what to look for and where to look for it. Based on my previous experiences working with scientists and university science outreach I knew these were the great places to focus my search. I reviewed over a hundred resources (e.g., websites, powerpoints, outreach opportunities, online simulations, blogs, etc.), and from this review, I curated a list with thirty resources that were high-quality. When presenting my findings to the Director, they stated they were "disappointed by the quality of teaching resources" (Personal Communication, 2019). Of the high-quality resources I curated, ten were identified as the top resources. Upon further analysis of the top resources, only a few were agreed upon by us both as inquiry-based science experiences. From this top ten curated list, the Director and I supported his undergraduate class in investigating ten of these inquiry-oriented resources and analyzing them for inquiry-based relevancy. We facilitated the meeting of undergraduates with five workshop teachers who identified that they would be interested in an inquiry lesson demonstration in a content area of their choosing. Undergraduates were provided feedback on their inquiry-based lesson plans that they designed from the curated resources. Just at the time when undergraduates were planning on going into classrooms, was when a global pandemic began, and thus, our inquiry into inquiry was paused, and then ultimately ceased upon my departure shortly thereafter.

30 Years Later, Why Is Inquiry *Still* Not Used in Classrooms?

[*How is it that the same barriers to inquiry persist over decades of science education?*]

The absence of inquiry in the discourse of education was something the Director and I agreed on. Together, we discussed many briefs and publications in prestigious science journals published in the past decade by scientists that commented on the state of disrepair of science education. This drove me to investigate further into history to determine how long this problem had been. I discovered Conant, Nietzche, and Humboldt all had thoughts on the matter.

While at the center, however, I focused on a little paper that I had found a decade earlier in the initial Undergraduate education research that I used as my guide in an attempt to avoid the pitfalls of inquiry-based science in the secondary classroom. It was published in 1986 under the title *Why Isn't Inquiry Used in More Classrooms*? Unbeknownst to me until I read the fine print while re-reading it at the center for the *n*th time, the article had been published by a faculty member of the university in which I was working. A quick internet search revealed they were a professor emeritus. I reached out to them and to my pleasure they were still in the area, and interested in a meeting at my office. When I asked if they were still actively researching they scoffed and shared they swapped research for golf, and in fact, they had taken off the afternoon off golf to meet with me.

Over thirty years ago, the question "Why isn't inquiry used more in classrooms" was asked by Costenson and Lawson (1986). Among other things, the authors sought to illuminate the barriers and potential reasons for this observed phenomenon. This wasn't the first work to ask this question (Hurd, 1980) and it was not the last (Fitzgerald et al., 2019). What I sought to figure out at the Center was why, after over fifty years of reform efforts to bring inquiry into the classroom, isn't inquiry used more in classrooms. The barriers, hesitations, and challenges remain relatively the same as they did over thirty years ago. It is evident that inquiry is the paragon of science education, and yet, it has remained a paradox for over 30 years despite the efforts of scientists, education researchers, and philanthropists through education outreach, national educational standards, and free open-source educational resources. I asked the author of the paper published 30 years prior if they would be interested in doing a retrospective review of the state of inquiry in science classrooms since their last publication, but they admitted that they took up golf these days, leaving the problems of science education to the next generation of scholars. I never wrote the paper myself, though I thought of a punchy title (30 Years Later, Why Is Inquiry *Still* Not Used in Classrooms?).

The one-and-a-half year-long inquiry into inquiry that I engaged in with a scientist at a center in an R1 university in the desert southwest largely corroborated my previous lived experiences over the past seven years prior. I have come to the understanding through my own lived experience - as an inquiring young mind to a graduate student to an education researcher that inquiry is much less about the lessons and resources. The director and I agreed - inquiry is a way of being, learning, and teaching. It is a mindset and a way of living through understanding the world around you. Inquiry requires a set of skills built up and honed over time, "burnished in the furnace of practice" (Bencze & Hodson, 1999).

For scientists, inquiry is second nature. Teachers, however, do not have these same experiences, nor have they been given the time or opportunity to access, nor are they encouraged to practice these skills. And yet, even though they are tasked with "teaching science" they themselves have never done science. Nor are they sufficiently equipped or supported by the very system that demands they teach the doing of science. Is it fair to ask this of them? Is this even the point of science education? My time working with the Director, a Nobel Laureate, gave me the skills and mindset to focus on the next area of interest that spurred from my research - building capacity from within a system as an intermediary. This work launched me into the work I did following my time at the center, as a school district science strategist implementing an innovative curriculum.

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Neoliberalization of Education

[Education is bound to economics]

Education is deeply rooted in, and influenced by economics (Ball, 1998; Fensham, 2009; Rizvi &Lingard, 2010). PISA results are internationally revered standards by which countries engage in a globalized fight to claim the title of the most educationally enlightened country in the world. For their country to secure a position in the global economic landscape, many countries acknowledge they must invest in education to create citizens who are among the best trained and intelligent in prospective technologies and their applications (Rizvi & Lingard, 2010). Even Finland, a social welfare state, saw in the 1980s, education as a means to improve national economics - it costs the state far less to educate citizens to a high level than it does to deal with the aftermath of the alternatives (Sahlberg, 2007).

It makes sense, then, given the high stakes that countries invest in training and instructional resources to increase the educational experience of their pupils. This, of course, costs money. Depending on the country and its social welfare policies, the degree to which educational funding is received and for what purposes, varies. Further, scientific societies, outreach programs, the broader impact sections of research grants, local NGOs, philanthropies, and universities also harken the call and see the value of diverting funds to support educational systems in ways that for one reason or another is outside the reach or abilities of the government. I have been a user of many of these support efforts - from grassroots science research outreach to multi-million dollar science curriculum purchased by a school district with government funds. I've looked high and low, small and big scale, and yet, no single solution have I found that has contributed robustly to bridging the gap between meaningful science education and the education that our students receive for one reason or another.

You Get What You Pay For

[*Companies capitalize on providing educational resources that should be free to all*]

It is said that in America, the land of opportunity, anyone can get what they want, for a cost. Fter all, this is the defining premise of capitalism and free market society. Thus, it makes sense that the best science curriculum I experienced across three countries (Canada, England, and the US) is available for purchase in the US - if you have the money. But, as the Notorious B.I.G. sings, “mo money, mo problems” (1997). Or in the case of science education, it appears: more money, *different* problems. In all my experiences, I sought to explain why authentic inquiry-based science was not being taught. I have experienced various contexts, and seen many mitigating actions, but I still do not regularly witness authentic science instruction taking place.

I became convinced that the secret to solving the science education problem was the creation and dissemination of a high-quality curriculum. I felt that I knew how to access or create as suitable curriculum, but it is so demanding that it is unrealistic to do for very long, or to expect teachers to do this kind of work.

Sadly, in each context that I have created materials, after moving to a new place, I had to start over. For example, educational resources I used in Alberta were no longer accessible from the UK. Sometimes I would use my VPN on my personal computer to make the internet think I was still in Canada to access some of them, but this was not a solution for student use. Further, some of the resources I had made in Alberta for project-based learning were unusable as the common assessment and pacing requirements of my new department in England didn't allow for any wasted time. My sign-ins no longer worked, and my rich connections and opportunities were lost. The educational resources were non-transferable. I was able to replenish my store of resources, and each time I left behind my tailor-made resources for others to use, but with no hope they would be taken up by colleagues who remained.

All these resources were widely available and free to the public. One only needed situational knowledge of how and where to look to find these resources. In the US, many such resources are available as well. While at the research center, I searched for and analyzed over one hundred virtual resources created by outreach centers, broader impact efforts from scientists' grants, and educational philanthropic centers. From this search, I narrowed down my list to 30, then to the 10 most robust resources for facilitating authentic inquiry-based learning experiences for students. The nature of these resources, however, was ad-hoc and not a comprehensive curriculum. I also reviewed American curriculum companies, and here was where the game changed.

Unlike the education companies that exist in Alberta (three government-approved textbook providers) and England (two government-approved providers of instructional materials (PowerPoint slides, assessments, experiment methods)), government-aligned resources in the US take on a much more entrepreneurial approach. This is reflected in the price one pays to play and with the increase in the choice of materials. American curriculum companies claim to include a one-stop shop for science instructional materials including "kit" materials, lessons, and assessments. When I reviewed the curricula for purchase in Arizona, one stood out above the rest, Amplify Science.

Amplify Science is a high-quality, literacy-rich, research-informed science curriculum designed and developed by the University of California, Berkeley. The curriculum is designed to take students and teachers through a student-centered learning experience wherein they take on the role of a scientists or engineer as they explore a phenomenon through a unit-long inquiry to solve a problem by engaging them in all of the eight national and state standards-identified scientific and engineering practices (ask questions and define problems; develop and use models; plan and carry out investigations; analyze and interpret data; use mathematics and computational thinking; construct explanations and design solutions; engage in argument from evidence; obtain, evaluate, and communicate information). To guide the students to solve the problem, teachers are provided with fully planned lessons, powerpoints, assignments, class discussion questions, content-aligned rigorous reading material, assessments, and science material kits. I recall the delight with which I was overtaken upon discovering this novel, innovative, and high-quality Amplify Science curriculum, for I felt that I had finally discovered the missing link.

Ephemeral

[*How can reform-based science efforts be sustained, rather than just left to dissipate?]*

Ephemeral entered my lexicon while I was at the Berlin Institute for Advanced Study. I don't remember how I learn all the words I know, but it is easy to remember embarrassing ones. I accidentally called the music of a world-class harpsichordist (who at the time was our friend with whom we drank the leftover wine, debated, and enjoyed music later after dinner), ephemeral. I had meant to say it had an evocatively ethereal permanence, but ephemeral is the word that came out. Deeply embarrassed by my error, I hastily corrected myself, but they responded it was indeed, ephemeral – that by nature all art and music inherently is.

If all art is ephemeral, perhaps other elements of culture are as well. As educational standards and policies change, artifacts of the past may remain, and these may be reused or repurposed, if the appropriate conservators are around to maintain and sustain. In England, the Science Practical Supply Room, which was monitored and organized through much effort by the two science technicians, was full of science tools, instruments, equipment, and models, along with many bits and bobs. The resources in that room were of high quality and had clearly been around for decades, standing the test of time and the abuse of thousands of children. I had a similar experience in the science closet in the Albertan school at which I first worked. But science education materials in the US are at a different level.

In the US, secondary science education resources are short-lived in their pre-packaged curriculum company boxes. Similar to the "meal kits" that have become recently popular (everything to make a meal comes in a box, pre-measured, packaged pieces that you "throw together" to make a meal), science curricular resources are "ready-to-go" science kits that have everything you need for a science experiment. In both cases, you pay for convenience, not quality. These kits are designed to be short-lived. With planned obsolescence in mind, these curriculum company science kits are designed to be ephemeral. Once every six years or so, it is common practice for curriculum adoptions to be completed. The intention, I believe, is to keep up with changes to state or national standards, but the necessity is the replacement of these quickly depleted and disappearing kits.

Science education must periodically change. The kits have been designed with this in mind, but also, in the neoliberal context of education in the US, to provide quick and easy solutions to school districts' science needs. Problematically, these kits will not even last the length of the six-year implementation. The handles of the plastic science kit boxes that contain the items break off easily and only after a couple years of use, at least 1 in 10 boxes already have broken handles. Magnets become useless slabs of metal after a few classes. Sticky notes are just notes. Almost all the kit items are made of cheap low-quality plastic that easily break. Compared to the intergenerational tools in England, the science kit culture of USA is flashy at first, but eventually embarrassing. Alas, we are left with the inescapable ephemerality of science curricula and practice. If teaching materials are not long-lasting and high-quality and easily repurposed for varied curricula, then we are stuck with cheaply made materials in kits that need to be replaced or restocked every year, which is costly in terms of money and time, both of which are in high demand in all educational settings.

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This Way, Hobbits

Leaders come in all shapes and sizes. There are many leadership styles, theories, and frameworks that these leaders employ. And yet, the canonical image of a leader in education remains to be someone in a position of power that is charismatic, articulate, and strong. If someone were to point a leader out, it goes to someone who is the face of the school or district - a superintendent, a principal, a director. This was exemplified by my everyday experiences in and around science education systems, but also in my education doctoral cohort - the overwhelming majority of people were either principals, aspiring superintendents, or superintendents. Left with no choice, myself and a few other cohort members, who were neither principals or superintendents found ourselves rather stuck in the Leadership track amongst the canonical type of leaders of our cohort. An insightful colleague of mine reminds me often that "people in positions of power are not always (or the only) leaders" (Personal Communication, 2023). There is of course some tension between those in power and those not. The vignettes in this section will explore these tensions.

Gollum, is an example of a non-canonical leader. Gollum, a creature consumed and distorted by the power of the ring, is the unlikely creature who leads Frodo and Samwise to

Mount Doom (Tolkien, 1954/1991), and is ultimately, though unwittingly responsible for the whole journey's climax. In Tolkien's fictional work there are many other leaders that help Frodo and Sam on their journey, too - strong, powerful, and valiant warriors, lords, wizards, and elven queens. Those leaders clear the path and help Frodo and Sam on their journey, but their abilities to help are limited. Gollum, a creature with insider experiential knowledge, knowledge that cannot be found on any map or spoken of in any story, successfully guides Frodo and Sam to and into Mordor. For the purposes of my argument let's ignore the fact that Gollum is leading with the intention of killing the hobbits to steal back the ring(!). Aside from these malicious intentions, Golum's intricate experiential knowledge of the hidden paths and secret caves of Mordor successfully leads the hobbits to their destination, Mount Doom. Unlike a canonical leader, Gollum leads by example as a participant, alongside the hobbits in the throes of the dangerous journey. Gollum leads through situational awareness, using hidden knowledge, and knowledge sharing. Similarly, those who lead from inbetween, employ similar tactics to Gollum - they lead by example as a fellow participant, leveraging insider knowledge, while skirting around canonical leadership approaches. The following vignettes in this section explore observations and experiences from a non-canonical leadership vantage point.

Professional Professional Development

[*Can teacher-centered professional development, develop professionals?*]

Professional development, or professional learning, is intended to provide learning opportunities for inservice teachers and administrators. As a teacher, much of what I received for professional development (PD) was sit-and-get. In Alberta, I experienced a multi-day professional development conference, it was a motivational, feel-good story—lots of people in one room watching one person. In England, we had regular brief staff meetings with a ‘challenge spot’ where one staff would share something they had been doing in their classroom (when asked by my department head, I delivered a few). In addition, we also had departmental PD, where someone from a science outreach program would come and do a hands-on practical with us, something that we could do with students, and have a mini lecture on the theory behind the phenomenon we just tested. It was practical—some experiments we did during this PD I incorporated into my classroom rotation.

In classrooms, moving away from didactic approaches is best practice, why is this not the case for most professional development? No one ever stopped to see what I understood and the way I understood it. No one ever asked me to reflect on my experiences as they related to students, nor celebrate my efforts, nor reflect on how to improve my practice. When I stepped into the role where I could conduct PD myself, I knew I wanted to change things up. To deliver myv ision of teacher-centered PD.

The first PD I facilitated was at a science outreach center in an R1 university (outlined above in the vignette *An Inquiry into Inquiry*). With twelve teachers in attendance, the focus of the session was inquiry-based science. Teachers were asked to bring a sample of an activity or lesson they thought was inquiry-based. The PD session was designed in collaboration with my colleagues. We applied for an IRB to collect participant data as voice data, which we transcribed. The PD was designed with two intentions: first, to provide a meaningful and teacher-centered learning experience, and second, to learn what teachers understood about inquiry-based science. We achieved both aims, but also uncovered something unexpected. We found that the teacher participants had previously not been given the opportunity to collaborate and sense-make with peers (Baier Wideman & Hale, 2020). Based on the observations (voice transcripts of participant conversations) and survey results, it was clear that we delivered something novel.

These experiences continue to inform the work I do as a district Science Strategist and professional development that I deliver. Part of the work I do as a district strategist is to develop and facilitate monthly professional development. I craft a theme for the year, with each term's focus progressing deeper into the theme. For example, this year's focus is "*Developing Student Agency and Language Through Science and Engineering Practices*". The PD I design and facilitate is focused on participant-centered learning that immerses teacher participants in the what, how, and why of reform-based science by engaging them in active learning strategies. Informed by universal design for learning principles, in each PD session I provide varied modalities to the teachers for accessing, processing, and expressing understanding of the learning. I try to develop clear learning objectives and a measurable outcomes for each session. I design learning to be teacher-led and interactive, such that I take on the role of facilitator. I celebrate teacher instructional efforts and give a platform to share best practices. I provide teachers with opportunities to exchange knowledge between peers, collaboratively work towards solutions for problems of practice, and co-construct knowledge to make sense of new learning. I end by asking teachers to reflect on their instructional practices and their learning in PD to set goals for follow-up. Every year for the past three years, I have monitored and adjusted my facilitation to meet the changing needs of the teachers I support, meaning no PD is ever facilitated twice. In collaboration with academic coaches, observations from classroom walkthroughs and weekly teacher PLC meetings, and feedback from teachers, the PD sessions are created in response to this data. It is my hope that by delivering PD in this way, perhaps teachers will bring these active learning strategies more easily into their classrooms.

Strategic Support From Inbetween

[*Support systems from within*]

As a Science Strategist for a Title-1 K-8 School district, I worked at the district level, however I did not officially hold any evaluative, authoritative, or disciplinary power. My role was to support and build the capacity for reform-based science of each constituent in the district. In this way, I see myself as 'inbetween' teachers and their administrators. I was the science content specialist and provided individualized and differentiated support to teachers, academic coaches, and administrators in one-to-one and group settings (both small < 10 and large > 75). My objective was to build capacity for coordinated, aligned, and coherent efforts from all stakeholders. As mentioned in the previous vignette, one of the roles I assumed was the developer and facilitator of monthly professional development sessions. However, the services I provided were all aligned to the learning taking place during the professional development and served as an opportunity to follow up and measure learning in the classroom. Moreover, each facet of work I did serves to bolster and reinforce other facets of my support, in addition to the district and school-based initiatives.

Working within an educational system, in between stakeholders (teachers, site coaches and administrators, and district strategists and directors), through strategic actions and interactions, is what I define as leading from in between. Leading from a position of inbetween, in between system stakeholders, is essential to identify the professional and lived realities at each level of the system, to meet each person where they are at, in order to build individual and collective capacity for understanding and enacting reform-based science. The coursework on leadership for systems, innovation, and capacity building that I completed as part of my doctoral program informed the development of my framework and approach to my work as a district-level science strategist tasked with implementing an innovative science program aligned to the reform-based science standards and aims (see Chapter Five: Discussion, *Building System-wide Capacity: Frameworks, Models, and Theories*).

The district I worked in was a Title-1 school district, (92% Latinx and 40% multilingual learners). This means that even though Arizona was one of the lowest funded states for education, our Title-1 School district received considerable federal grant money to increase student access to high quality curriculum, technology, and student services that other school districts do not have access to. One of the services funded by one of these grants are district content strategists, like myself. There is a content strategist to support each set of grade levels: K-2 ELA, 3-5 ELA, 6-8 ELA, K-5 Math, 6-8 Math. There is one K-8 Social Studies Strategist and one K-8 Science Strategist (my position).

At the district level I collaborated across content areas with my fellow strategists to make cross-curricular connections to reinforce language development and use. I also build the capacity of the upper district leaders: directors, the vice-superintendent, and superintendent. At the school level, I collaborate with and support teachers, academic coaches, and administrators to bolster clarity around reform-based science for all stakeholders. For example, I facilitated and built the capacity of teacher leaders through facilitation for cross-site and grade-level science PLCs and collaboration with site leadership to provide site-based professional development based on reform-based science active learning strategies.

To serve teachers I provided instructional scaffolds, pacing recommendations, model lessons, unit unpacking sessions, and lesson planning sessions. Moreover, I curated and facilitated blended spaces for teachers to share problems/solutions of practice. To serve academic coaches I collaborated as a thought partner, co-planned school-based PD, provided support with teacher coaching cycles, engaged them in professional learning, and conducted regular reflective classroom walk-throughs guided by reform-based look-fors. To serve administrators I engage in reflective data conversations, PD for reform-based science learning and teaching, and conduct regular reflective classroom walk-throughs guided by reform-based look-fors. Finally, I managed and supported science kit resource logistics including distribution, maintenance, and replenishment to over 175 teachers across the district.

I acted as an internal intermediary that served every level of stakeholder. This required me to don many hats and prove membership in many cultures. I leaned into my awareness that I "district", but also demonstrated through acts of service and dialect that I don't act like "district". Building relationships and trust were the foundation of my work. It is what allowed others to be comfortable enough to share with me their realities of the barriers and challenges that they experienced. Some district-level people were surprised by the observations I brought to light. Those individuals were looking through rose-colored glasses, seeing only what implementation should ideally look like (the 'what should be'), not the enacted reality (or the 'what is') of science education. With this insider data, I form teacher advocate groups to better understand the underlying barriers so I can help reduce the barrier and provide scaffolds to overcome them. I bring my insider information or what I colloquially call the 'word on the street' to district leaders or site leaders to get ahead of potential issues by addressing and ideally resolving inconsistencies or errors to mitigate the impact of those issues. My aim was always to increase transparency, coherence, alignment, equity, and timeliness of communication to reduce frustration, redundancy, and anxiety of all educators, especially teachers. Through these venues, I sought to build capacity for reform-based science education by shifting mindsets to developing a culture of commitment through understanding rather than compliance (Abbott et al., 2023).

Too Many Cooks in The Kitchen

[*Can too much support and too many initiatives have negative consequences?]*

Too much of a good thing, isn't good. Too many cooks in a kitchen causes chaos. Both come from the best of intentions, but unfortunately fail in living up to those intentions. The Title 1 School district I work at falls victim to this very same problem. The district receives a lot of additional government funding to better support our students who consistently underperform against state performance levels. There is ample money for things - multimillion dollar instructional resources (curriculum), school furniture, consultants, programs, frameworks, system assessments, and middle-upper leadership positions. But too much of a good thing - adopting too many curricular programs that are designed to improve outcomes for students, bringing in too many leadership frameworks that are designed to bring structure and clarity to systems, hiring too many consultants to find ways to improve schools and systems, ultimately become counter-productive. Teachers, administrators, district personnel, and the system can only handle so much change. Programs are purchased by well-intending individuals to use up grant funding, but clear and timely communication about implementation plans and timelines are often missing.

Since the time I began in the district, four years ago we have adopted four different leadership models, had three consultants, two different equity initiatives, and one language acquisition program. In addition, we concurrently adopted new curricula for all four content areas across K-8. Each new initiative adopted comes with professional development and binders of resources. At one point I was engaged in three book studies: one on Professional Learning Communities (PLCs), one for diversity, equity, and inclusion, and one for culturally responsive classrooms. They all sit in a pile on my bookshelf, unopened. This count, of course does not include any separate school initiatives under the purview of school administrators, of which, there are several. Aspirational and well-intended? Absolutely. Pragmatic and sustainable? No. Bateson (1994) has some wise words to heed about constant change, and the addiction that can be formed to it: “We know that keeping consumption at familiar levels is eventually going to deplete resources, yet patterns of consumption are oddly difficult to change. When change itself becomes addictive, it seems almost bound to lead to trouble” (p.93).

Resources, human resources, are arguably depleted. Since I began four years ago, only three of the seven strategists, three of the eight administrators, two of ten academic coaches, and one out of fifteen middle school teachers remain. Of those that have remained since I began, I hear too often about the strain these changes put on them as leaders, coaches, and teachers, and how they know they can’t bear it much longer. It is evident that consistency in leadership and staff retention is not a strong suit of our district.

It all comes from a good place, but too much of a good thing, isn’t good. Too much of a good thing has the opposite effect, leading everyone to a state of confusion, frustration exhaustion, and disillusionment. When considering implementation timelines for an initiative, any other initiatives that are implemented concurrently work antagonistically by competing for time, bandwidth, and energy. I hear all these comments from middle district leadership, academic coaches, and administrators. Yet the district pushes on, stating it’s what is best for children.

The result is a tangled mess of initiatives that teachers and administrators must learn, interpret, navigate, and make sense of within the district, their school, and classroom cultures. I too often have encountered the ‘close the door and ignore’ mentality while I was trying to peddle my own change initiative of building capacity of instructional innovation in science. Admittedly, strong teachers, school administrators, and district strategists were able to negotiate and juggle most of these initiatives to blend them into something meaningful and useful to their own values and initiatives. However, most teachers and administrators experienced the initiatives as layers that took away from what they valued and felt they needed to do, what was 'best for children'.

Each consultant that comes through is peddling their own version of the right model that will fix our problems. Like a village listening to the rat charmer traveling through, we throw our money at these consultants, hoping they will fix our problems. The most recent one, is an old friend from our superintendent's education doctorate cohort. From the superintendent's friend, a now educational consultant and entrepreneur, we bought a set of books, professional development, system-wide assessments, a beginning of year rally keynote speech, and attendance of select leaders at an out-of-state training. That is not to say that this person won't help improve the schools in our district, but it just adds to the already difficult-to-manage set of initiatives.

What remained absent from the implementation of these various theories and initiatives was an honest assessment of the clarity of vision, where the system was in relation to achieving that vision, what our constituents needed to achieve the vision, and having difficult conversations when actions were not in alignment to the vision. This admittedly is a challenge considering the three or four levels of vision that one must negotiate: teacher, school administrator, district administrator, and superintendent. Leadership emerges from the interaction between people and systems. It is dynamic and must be responsive to the needs of all stakeholders to build the capacity of each individual.

Not only is it all too much, but there are also too many cooks in the kitchen working on too many different recipes. Constantly cycling through different leadership models, frameworks, and theories confuses messages and exhausts leaders. We are learning to speak four languages at once without mastering the basics of each one before moving on. Despite all the new curriculum we adopted across all contents, all of the new leadership models and frameworks we implemented, and the consultants that have consulted, the bottom line is that our students continue to underperform on state language, math, and science assessments. There is no follow up to follow through, no time to make sense and dig in deep, no time to reflect on growth areas and next steps, no accountability or assessment of progress, only change. Constant change. Change without progress.

Great Expectations, Good Intentions, Mediocre Execution

[*Why aren't reform-based science expectations and intentions matched by execution?*]

My journey to find science education executed in such a way that matches the great expectations through the lofty goals of state, provincial, or national standards or programs of studies has spanned the course of a decade in three countries. Through well-intentioned and effective collaboration, scientists and education researchers have succeeded in creating a vision for science education programs that should be capable of producing scientifically literate, critical thinkers versed in science and engineering practices with skills that they can apply to address emerging problems of our time - great expectations, indeed. In turn, curriculum companies create resources, with teachers, schools, and districts adopting these curricular products with the best of intentions. Yet through a mangle of theory, practice, infrastructure, policy, and tradition, the execution of these expectations falls short.

Much as in my experiences with wine, moments of reaching great expectations in science education do happen, but alas, they are few and far between. Notably, I have never worked at a high socioeconomic status school - public or private. I read practitioner journals and follow edublogs where inspirational teachers share their practice and offer novel ideas. I read about positive case studies, with few teachers over a few years in education research journals making gains in mindset and pedagogical content knowledge. But I have few first-hand experiences of great execution in science education classrooms.

Alas, these vignettes, collected over a decade in three countries as a participant observer scientist, turned science teacher, turned leader provide a unique glimpse into the goings-on, in and around education systems and the efforts of stakeholders to enact reform-based science. My observations are from but one perspective, biased by my prior knowledge and experiences, and influenced by my own values, attitudes, and beliefs towards science education. In the end, it could all be a matter of perspective. I hope that is not completely the case. I hope that my observations presented here resonate with the lived-experience of others and are considered trustworthy by those whose professional reach lies outside the cultures discussed.

Summary

The vignettes included in Part III: *It's A Matter of Perspective* have provided textured accounts of the unresolved tensions I experienced between various stakeholders in three different educational systems. Building on the ideas presented in Part I, which highlighted the importance of infrastructure, and in Part II, which highlighted the importance of instructional policy, Part III: *It's a Matter of Perspective*, highlighted the importance of leadership that considers multiple perspectives and the use of leadership models that emerge from inbetween stakeholders to build capacity for enactment. The following summary will reflect on the prominent suppositions relevant this section: Supposition 5: *Intermediaries can build capacity for reform-based instruction of teachers* and Supposition 6*: Leadership frameworks, models, and theories can build system-wide capacity to achieve reform-based science aims*. As my experiences shared in Part I and Part II illustrated, establishing the conditions necessary to foster enactment of reform-based science requires a system to go beyond providing adequate infrastructure and instructional policies and employ internal intermediaries and coherent leadership frameworks.

In Part III, I reflected upon my experiences in different educational roles across different countries. I noticed that in different contexts, even within the same system, different words and ideas might be used to mean the same thing, or conversely, that the same words meant different things to different people. These differences in language were sometimes benign, but hinted at some underlying barriers to robust enactment. At times, because of my alternative experiences, I felt that I could have better helped translate in these moments, but in Canada and in England, because of my role as a teacher, I did not have any administrative power to effect change. For example, in different contexts, language use muddied communication efforts (see vignette *Lost and Found in Translation* and *Critical Conversations*) and varied perspectives provided different interpretations of conceptual understandings of reform-based science education (see vignette *Chinese Takeout* and *Neoliberalization of Education*). Further, differences in language provided tensions about what defines membership of a group (see vignette *Just*, *Only* and *One of Us*) and a lack of clarity about what sorts of activities are constituted as inquiry-based science (see vignette *A Case of Mistaken Identity*).

My experiences as both an external intermediary (R1 university science outreach research coordinator) and internal intermediary (district science strategist) are the focus of Part III. Reflecting on Supposition 5, my experience as an external intermediary showed me that the teachers I worked with did not have a clear understanding of reform-based science goals, and needed more time together to share resources and reflect upon shared classroom problems (see vignettes in *An Inquiry Into Inquiry*). In facilitating a single experience for just a few teachers as an external intermediary, I felt that by providing consistent support for teachers as an internal intermediary, the goals of reform-based science education might be better achieved.

As I moved towards a leadership position as a district science strategist, I felt I was in a better position to act as an intermediary for change. Previous investigations suggest that professional support from an internal intermediary can be effective in building capacity of teachers who are not situated in a reform-based science education mindset (Farley-Ripple & Grajeda, 2020; Malin et al., 2020; Whitworth et al., 2017). My experiences as a district science strategist illustrated how I navigated micro systems, cultures, and policies to help to build capacity for reform-based instruction of teachers across three middle schools (see vignettes, *Professional Professional Development, Put Me In, Coach!, Too Many Cooks in The Kitchen,* and *Keeping up Appearances*). Reflecting on Supposition 5 and 6, as an internal intermediary in the role of district science strategist, employing transformational leadership strategies and models within my control, I was able to build capacity of some individuals but I was unable to effect deep and sustained cultural changed in the district (see Abbott et al., 2023 and vignettes *Strategic Support From Inbetween, Great Expectations, Good Intentions, Rather Mediocre Execution,* and *The Revolving Door of Reform*). However, since building capacity takes time and consistency, neither of which were luxuries afforded in my context as a result of high teacher and leader turnover rate, among other variables described in the vignettes, I was unable to maintain and sustain this capacity to effect deep cultural change.

In sum, I discovered that while intermediaries can build capacity for reform-based science, these efforts can be counteracted by the lack of evaluative power they hold in conjunction with the multiple competing variables that exert influence over the values and work of teachers, coaches, and administrators. Additionally, I found that while employing leadership frameworks, models, and theories were useful to inform, support, and align my work as an internal intermediary in a school district, they were limited in their efficacy as the work I did took place alongside competing initiatives and structures that had stronger influence in directing the values and work of the stakeholders I supported. The main findings that emerged from Part III: *It's A Matter of Perspective*, to be discussed in Chapter Five: Discussion (see *Leading From Inbetween*) include:

- Misalignment between stakeholders prevents progress toward successful implementation of reform-based science
- Leading from inbetween can align can build capacity of systems
- Strategically employing leadership frameworks, models, and theories can build system-wide capacity.

Chapter Four: Final Summary

Throughout Chapter Four: *Data*, I have provided examples across three different countries (Canada, England, United States) through three different roles (teacher, leader, researcher) of great expectations for reform-based science education being set and informed by good intentions. I found that, while each context had subtle differences regarding the variables endemic to each national or school culture, the common theme permeating all these experiences was that reform-based science was not often enacted robustly as outlined in the government policies of educational standards.

Reflecting on Supposition 7: *Autoethnography is a valuable method for exploring enactment of reform-based science education*, engaging in autoethnography to unpack and examine my experiences in science education has been helpful to make sense of my experiences, to consider the similarities and differences between national and professional cultures, and to provide speculative insight into the broader sociocultural phenomenon of reform-based science education implementation and enactment. I find myself left with even bigger questions of whether the goals of reform-based science education are too ambitious to be achieved and further, if the outcomes can even be assessed. Through this autoethnographic research I also found that I turned inwards asking myself: Did I set my personal goals too high? Should I have internalized these goals as much as I have? Can reform-based science education help change our society for the better, or have all of my efforts been misplaced and in vain? Chapter Five: *Discussion* and Chapter Six: *Conclusion* offer reflective insights into my autoethnographic data and possible implications to consider stemming from my research of culture through the self in secondary science education systems.

CHAPTER FIVE: DISCUSSION

Insights from Experiences in Science Education

To investigate my research question: *What insights can be gained from autoethnographic exploration of my experiences with reform-based science education systems in Canada, England, and the United States?*, I used an analytic layered approach to autoethnography to study the phenomenon of this research; my experiences implementing and enacting reform-based science as a participant observer while researching, teaching, and leading in secondary science education in three countries (Canada, England, and the United States) over ten years. Chapter Five is organized into abstracted themes that emerged from the analysis of the narrative vignettes in Chapter Four: classroom infrastructure, instructional policy, and leading from inbetween, which align with the relational framework presented in Figure 2.5.

In the first part of Chapter 5, I explore the theme of classroom infrastructure from Chapter 4 *Part I: Tending the Garden*, which illustrates the numerous variables influencing science education implementation and enactment and the impact that science outreach, technicians, and materials have in supporting instruction aligned to reform-based science aims. In the second part, I explore the theme of instructional policy that emerged from Chapter 4 *Part II: Mind the Gap,* which illustrates the impact of the presence or absence of instructional support on widening or closing the gaps between classroom experiences and the reform vision for science education at the teacher, leader, system, and research level. In the final section, I explore the theme of leading from inbetween that emerged from *Part III: It's a Matter of Perspective*, which details the role of intermediaries and leadership frameworks in developing culture and building system-wide capacity for reform-based science. Taken together, the themes presented in

Chapter Five provide insights that may better support enactment of reform-based science education.

Classroom Infrastructure

Classroom infrastructure is essential for supporting and guiding reform-based science instruction (Fensham, 2009; Karakus, 2021; Penuel, 2019; Powell & Anderson, 2002). Penuel (2019) defines infrastructure to include standards, curriculum, assessments, professional development, instructional techniques, policies, schedules, instructional supports, school routines, and performance evaluations. To this definition I add science-specific components such as materials, equipment, laboratory space, technical supports, and technicians. Further, infrastructure can expand beyond this material definition to be thought of as a "fundamentally relational concept" that "emerges for people in practice, connected to activities and structures" (Star & Ruhleder, 1996, p. 113). The following section will provide an analysis of the theme of classroom infrastructure in relation to these elements and features, as they relate to my experiences as a participant observer implementing and enacting reform-based science education.

Because insufficient classroom infrastructure is frequently cited as a significant barrier to enacting reform-based classroom science (e.g., Bencze & Hodson, 1999; Roehrig & Luft, 2004), infrastructure availability and use was explored. From recounted observations of use/misuse and recounted conversations with peers, my experiences suggested that reform-based science was not being robustly enacted. I found that despite its importance, effective classroom infrastructure for reform-based science education is a luxury not always provided. And even when it is provided, it isn't necessarily visible, appreciated, or fully understood. The following subthemes will provide insight into the role that infrastructure plays in supporting and creating the conditions necessary for enacting reform-based science education, and what follows when effective conditions and infrastructure are not provided.

Too Many Variables

Many variables impact the goings-on of teaching and learning in a science classroom within a single school, let alone between schools, and across countries. Despite the different classrooms I experienced in three countries, I found several common themes reappear: lack of time, an overstuffed set of standards to cover, competing school and/or district initiatives, and teacher feelings of being overworked and underpaid. These themes were common across countries (Canada, England, and the United States) and professional context (teaching, researching, and leading) (see vignettes: *Isolating Variables; Overstuffed, Underpaid, Overworked*). My experiences suggest that these variables are temporally persistent and are spatially ubiquitous. While there were particularities regarding the prominence of variables in particular locations, they were present in all contexts. For example, in Alberta and Nova Scotia, Canada, the lack of science technicians and quality teaching resources were observed as the prominent variables preventing hands-on reform-based science from occurring regularly (see vignettes *Teacher Technicians, Hiding in Plain Sight*), and corroborated by research (Beyer et al., 2009; Gatsby Foundation, 2017a; Roehrig & Luft, 2004). In Devon, England, I found that the cultural focus on standardized assessments and content-based student achievement were prominent variables hindering reform-based pedagogical culture (see vignettes *A Thespian Affair, What'd You Get on The Test*). These experiences corroborated previous research showing the power of assessments over instructional decisions (K. Anderson, 2012; Fensham & Rennie, 2013). Unique to Arizona, United States, low teacher pay, high teacher turnover, non-existent hiring pools, and low PCK were the most prominent variables that impacted science instruction (see vignettes *Put me in Coach, Professional Professional Development*), corroborated by Harris & Rooks (2010).

Teacher Pedagogical Content Knowledge is Low, Teacher Education isn't Helping

Pedagogical content knowledge (PCK) is demonstrated by teachers through their understanding of how to make the subject matter (e.g., science) best accessible to students, relying on knowledge of student misconceptions in addition to subject and concept-specific teaching approaches and strategies (Shulman, 1986). PCK can primarily be observed through peer-peer professional learning community conversations and instructional strategies and practice enacted in the science classroom. For reform-based science instruction, high PCK requires mastery of management of inquiry and knowledge of how to engage students in scientific skills and processes (Harris & Rooks, 2010; Hodson & Bencze, 1998; Lawson, 2000).

In all three countries, I observed different manifestations of low teacher PCK (see vignettes *Two Courses Isn't Enough, Step into my Classroom, If You Can't Do, Teach*). Low pedagogical content knowledge is a well-documented variable that impacts classroom instruction (Abrahams & Millar, 2008; Falk et al., 2008; Farber, 2003; Lederman, 1992; Taber, 2006), yet my narratives demonstrate that it remains a significant variable of concern that is temporally persistent and spatially ubiquitous.

As previous research has demonstrated, low PCK is hardly the fault of the teacher (Bencze & Hodson, 1999; Bowen, 2005; Volkmann et al., 2005; Waight & Abd-El-Khalick, 2011). Considering most teachers' educational pasts, which are primarily experienced as traditional (non-reform-based science education) sage-on-the-stage, non-inquiry, teacher-centered practices reinforced from K-12 throughout their university education, it is "absurd to expect teachers to create the necessary experiences for students to develop these abilities if they themselves have not had similar experiences" (Bencze & Hodson, 1999, p. 525). I further argue that it is the lack of these experiences and PCK that makes it equally absurd to expect educational system constituents, including teachers, to enact reform-based science.

What continuously fails to be acknowledged by post-secondary teacher education programs and government professional requirements alike, is that "teachers' views are built up over a long period and are burnished in the furnace of everyday practice" and thus "challenges must be vigorous and explicit if change is to occur" (Bencze & Hodson, 1999, p. 531). If teachers are to be expected to teach reform-based science standards, post-secondary educational institutions tasked with educating teachers should "think about mapping backward from a particular vision of instruction to the conditions needed to support such a vision" (Sykes & Wilson, 2016, p.904). I believe that, as it stands, pre-service teacher programs are largely insufficient to develop teachers' skills and understanding for effective enactment of reform-based science.

Teachers must be better equipped to understand reform shifts by experiencing, firsthand, the reform-based science discussed in the aims (Gatsby Foundation, 2017a). Yet, over twenty-five years of reforms and change there has been little progress towards achieving a well-educated and sufficiently equipped professional workforce for enacting reform-based science. One should hope that teacher preparation programs engage teachers in reform-based science experiences that reflect the aim of the science standards they teach. But, as evidenced by my own experiences and those shared by others, this does appear to be the predominant experience of teachers (Karras et al., 2015).

In any case, it is evident that the culture of education systems remains disparate to the needs of reform-based science education – from those tasked with delivering it to those tasked with educating educators. The words of Nietzsche on the state of educational systems over 150 years ago still ring true: “various external measures seemed necessary and some crucial ones were successfully applied to the modern form of the gymnasium, with lasting effects – but the single most important thing failed to happen: consecrating the teachers themselves to this new spirit” (Nietzsche, 1872/2016, p. 33). For me, the spirit that Nietzche states must be consecrated amongst teachers is the culture for reform-based science. However, as history and present day have shown, this has not yet happened on a large scale. Perhaps it could, but only if the educational institutions tasked with educating and supporting teachers were committed to “mapping backward from a particular vision of instruction to the conditions needed to support such a vision” (Sykes & Wilson, 2016, p.904).

Science Outreach is Positive, but Neither Equitable nor Scalable

Science outreach programs are developed by intermediaries of various origins (e.g., universities, student groups, companies, school districts) to provide engaging learning opportunities otherwise unavailable for students to experience within the canonical science classroom (Honig, 2004). Examples of outreach programming include opportunities for students to experience authentic encounters with scientific practices, processes, equipment, and/or scientists themselves with the end goal of increasing attitudes and interest in science (Grantmakers for Education, 2019; Honig, 2004; Laursen et al., 2007; Malin et al., 2020). These experiences provide students a glimpse into the goings on of science research (Fensham, 2009) and the opportunity to use authentic scientific tools and equipment (Waight & Abd-El-Khalick, 2011), something that students would not otherwise be privy to. Outreach opportunities also provide an extension or practical application of some theoretical concepts learned in the classroom.

My cultural experiences as a learner, teacher, and outreach coordinator corroborate how powerful these opportunities can be in developing awareness, attitudes, and beliefs in students for science that extends beyond the classroom. While outreach is positive, it takes time, know-how, and insight on a teacher's behalf to discover, establish, and maintain connections with outreach opportunities (see vignette *Insider Connections*). Some opportunities book up quickly, others are only possible to find if you have an insider connection, and some are challenging to coordinate due to location or complexity (Friedman, 2012). Moreover, the planning and coordination processes of preparing trips for outreach experiences are time-consuming and nuanced—requiring ample paperwork, calendaring, academic permissions, health and safety evaluations, transportation, and parental permission forms, all done outside working hours for teachers (Friedman, 2012). Considering the extra unpaid time and energy required to be invested to offer these experiences to students, it makes sense why few teachers tend to organize these experiences (see vignette *If You Caused Change, But It Wasn't Maintained, Did it Matter?*). Similar barriers have been identified by science outreach organizations and scientists offering school opportunities (Andrews et al., 2005; Woitowich et al., 2022).

Science outreach, while well intended, is inherently inequitable (see vignette *Science Outreach is Out of Reach)*. From my own teaching experiences, I limited outreach opportunities to higher-level academic classes or students, solely because of the logistical constraints such as transport, time, appropriateness for age, and interest. Science outreach fills gaps, but mainstream ‘ordinary’ science education is a sieve, and plugging one hole occasionally isn't enough, nor is it accessible for everyone. This lack of equity is concerning, given the premise of outreach programs, which are designed to fill voids that cannot be filled by the schools or districts themselves (Fensham, 2009; Honig, 2004). Outreach is a great example of a change made in response to support the needs of schools. However, for myriad reasons, outreach does not contribute to progress, but rather, a short-lived, ad-hoc bandage of change, to which only a privileged few have access.

Standardized Assessments Detract from Reform Efforts

School culture, routines, and practices are focused on ensuring what is taught on standardized tests is taught in science class. I have observed this phenomenon at a local, state/provincial, and national levels, all of which I believe in some form or another is driven by the pressure to achieve well on the OECD PISA. The PISA compares educational rankings of OECD countries on a standardized international assessment (see vignette *What’d You Get on the Test*). This is problematic because standardized assessments do not map to reform-based science education goals and instead predominantly focus on standards focused on content-based facts and surface-level scientific skills (Abrahams & Millar, 2008; Hume & Coll, 2010; Phillips & Norris, 2009).

The educational goals and aims identified in government educational standards and policies remain largely misaligned with the nature and purpose of standardized assessments. Consider the following government educational aims and goals for students to: develop critical sense and wonder, critically addressing science-related issues, mutual respect, stewardship, and collaboration (Alberta Education, 2014); experience the nature and processes of science, understand the uses and implications of science, and develop scientific attitudes (UK Department for Education, 2013); make sense of phenomena of natural world, sustain natural curiosity, thinking critically, and working collaboratively (Arizona Department of Education, 2018). The nature of, and the importance placed on, standardized assessments have been cited as contributing factors to impacting teachers' attitudes towards content, and away from authentic science learning experiences (Black, 2001; Fensham & Rennie, 2013; Harlen & Crick, 2003). I observed this phenomenon impact enactment of reform-based science education and dominate informal and professional (PLC) conversations about science instruction in Canada, England, and the United States in the cultural spheres of teaching, researching, and leading (see vignette *What'd You Get on the Test*).

My observations reaffirm the negative impact standardized assessments have on enactment of reform-based science occurring across Canada, England, and the United States. Evidently, the cultural spirit of standardized assessment is well and alive in educational systems, as it pervades every level of educational constituents and in one way or another, drives the work they do. The strength of the common spirit for assessment starkly contrasts the absence of a common spirit for reform-based science education.

Technicians Increase Hands-on Opportunities

Science technicians are school staff tasked with preparing, cleaning, and maintaining science materials and equipment. Science technician or technical support personnel in a school has been shown to increase access to science opportunities for students (Edelson, 2001; Gatsby Foundation, 2017a; Harlen & Crick, 2003; Waight & Abd-El-Khalick, 2011). Because teachers have limited time to prepare experiments or hands-on activities between classes for students, the absence of a technician can severely limit hands-on opportunities provided to students (Galton & MacBeath, 2008; Gatsby Foundation, 2017b). The presence or absence of technicians was one of the main differences I observed between the English and the North American approach to science education, with the former resulting in increased hands-on experiences for students. However, the presence of technicians did not necessarily correlate with reform-based science enactment, as it encompasses much more than just ‘hands-on’ experiences.

In Alberta and Nova Scotia, Canada, some science experiment resources were available, but no science technicians, thus requiring the teachers to be their own technicians (without being provided additional prep time) (see vignette *Teacher Technicians*). I observed that the science resources were left unused, unclean, and/or in a state of disrepair, which were kept hidden away in closets or cupboards in several classrooms (see vignette *Hiding in Plain Sight*). As a result, students (my own included) were not regularly doing hands-on or experimental science. In Devon, England, science technicians organized, ordered, maintained, prepared, cleaned, and delivered science items to teachers. I went from doing a few experiments a year in Alberta to at least two hands-on experiments or modeling activities a week for each class of students in England (see vignettes *Practical, Practical Work* and *There’s Always Room for Dessert*). However, I found that even with the presence of technicians, due to other confounding variables (e.g., overstuffed curriculum and standardized assessment culture), I was unable to provide reform-based science experiences regularly to my students (see vignette *A Thespian Affair*). In Arizona, United States, science kits were designed to make science more accessible to teachers in the absence of science lab configurations or science technicians (see vignette *Kit Culture Couture*). The kits made it easy so that teachers to offer a subset of activities that were easy to prepare and clean up that were linked directly to the curriculum. However, the activities were limited in complexity and scope and were mostly ‘cook book’ or confirmation-style hands-on activities with little connection to the scientific practices outlined in reform-based aims. Admittedly, despite everything being in one place, there were less hands-on learning opportunities with this model, not to mention the issues of expense and maintenance of the science kits (see vignette *You Get What You Pay For*).

Ultimately, my observations corroborate previous research to show that technicians are essential for providing a service to teachers and students: access to hands-on experimental learning experiences as they increase both the quality and the frequency of hands-on and inquiry-based learning opportunities. Undoubtedly, increased access to hands-on experiences increases student enthusiasm for, and interest in, science education (Gatsby Foundation, 2017a). However, as I experienced in England, the presence of technicians does not necessarily correlate with or guarantee enactment of reform-based science education. My findings provided insight into three different national cultures regarding approaches to hands-on science experiences (Canada: materials, no technicians; England: materials and technicians; the United States: science kits, no technicians). In the case of England, I observed technicians positively correlate with increased hands-on experiences. This was a positive example whereby the culture for hands-on experiences permeated the culture of constituents at all levels of the educational system (e.g., national, school, classroom). Taken as a whole, regardless of the presence or absence of science technicians, each different approach to hands-on science experiences did not correlate with enactment of reform-based science experiences for students.

High-quality Instructional Materials are Necessary, But Not Sufficient

Curriculum is designed as an instructional material to support teachers in delivering the mandated state, national, or provincial standards or programs of studies. In all three countries, the curriculum I experienced and observed in action was different: in Canada the curriculum was a textbook, in England the curriculum was PowerPoint slides and assessments, in the United States the curriculum included student notebooks, PowerPoint slides, assessments, and science kits. Each curriculum had its shortcomings, some have more than others.

The neoliberal selling and purchasing process of curriculum was ever present, with some marked differences between countries (see vignette *Neoliberalization of Science Education*). In some instances, to be a curriculum provider, you must be given official curriculum status by the creator of the standards (e.g., subject to government regulation as observed in Canada and the UK). In other countries, companies sell alignment to standards in the neoliberal free-for-all company cash grab (e.g., with no governmental regulation as observed in the United States). The dreaded classroom textbook is still alive in Canada (from one of two provincially approved textbook companies), perpetuating note copying, rote memorization, sage on-stage pedagogy, and cookbook experiments (Phillips & Norris, 2009). In England, the government-approved curriculum (two to choose from) focuses on assessing and monitoring student understanding of each scientific standard, aligned with the focus on standardized assessments. In Arizona, there are endless curricula to choose from; some come with physical materials (if you can afford them), some come with no physical materials.

The potential impact of a high-quality and well-designed curriculum aligned to government standards that seek to achieve the aims and goals outlined in the standards is significant (Bencze & Hodson, 1999; Cervetti et al., 2006; Powell & Anderson, 2002). For example, a research-informed, standards-aligned curriculum (Amplify Education, 2019a,b; Harris et al., 2022) that is literacy-rich and focused on not just exposing students, but entrenching them in science and engineering practices has great promise. The Amplify Science curriculum centers student learning on a scientific phenomenon that they investigate through a series of embedded problem-solving tasks rich in embedded opportunities for student-student discourse, sense-making, writing, and modeling, all while taking on the role of a scientist or engineer (Amplify Education, 2019a,b; Harris et al., 2022). Unlike any other curriculum I experienced in any other country, this thoughtfully designed curriculum is of high quality, nuanced, and complex. Admittedly, the complex and nuanced elements can make it challenging for teachers to use as intended, especially considering the prevalence of low teacher PCK. From my experiences supporting over 40 middle school teachers as a district Science Strategist, I observed that a good curriculum is only as good as its user's interpretation and understanding, couched within the "interplay between what a curriculum statement says and the various interpretations and emphases afforded it by supporting materials, agencies, and schools" (Hume & Coll, 2010, p. 45) (see vignette *If They Can't Fish, Give Them Fishes*).

Taken as a whole, my findings related to classroom infrastructure present two implications of pedagogical and epistemological nature (Hammond & Brandt, 2004). First, in my experiences, I found that the ontological and epistemological presuppositions of science and reform-based science education were not widely embodied by leaders, teachers, or students of science. Second, the pedagogical implications of my findings suggest that in my experience, few teachers regularly practice reform-based science education pedagogy.

In conclusion, classroom infrastructure is an essential element of science education systems to support enactment of reform-based science education. In every country I experienced different combinations and manifestations of infrastructure. However, I found that regardless of the quality of curriculum, experimental resources, outreach opportunities, or technical support personnel, reform-based science education was not being enacted robustly in the classroom. This speaks to the deeply rooted culture of each of these systems. In all three countries, over a decade of experiences as a participant observer, I failed to experience the spirit for, and culture of, reform-based science enactment.

Synthesizing my experiences in the field and reading literature, focused strictly on classroom infrastructure, I have crafted a hypothetical recipe for fostering reform-based science "*in vitro*", assuming the unrealistic conditions of a closed-system. To make this hypothetical recipe, I combined all the affirming and barrier-reducing variables and negated the confounding variables I experienced. My imagined ideal ingredient list for sufficient classroom infrastructure to realize reform-based science education would look something like this:

- Research-informed science standards focused on scientific practices (e.g., National Research Council, 2013), as I experienced in the U.S.
- High-quality standards-aligned curriculum (e.g., Harris et al., 2022), as I experienced in Arizona, U.S.
- Science technicians and experimental materials (e.g., Gatsby Foundation, 2017a), as I experienced in Devon, England.
- Healthy science outreach connections (e.g., Honig, 2004), as I experienced in Alberta, Canada.
- Strong PLC culture and professionalism between teachers (e.g., Gatsby Foundation, 2017a), as I experienced in Devon, England.

- Healthy professional competition and expectations (Gatsby Foundation, 2017a); not observed.
- Teachers with high pedagogical content knowledge for reform-based science (Gatsby Foundation, 2017a); not observed.
- Authentic performance-based assessments that assess attitudes and understanding of the processes and practices of science (Fensham & Rennie, 2013); not observed.

While this 'recipe' is helpful to consider, it must be supported by instructional policy to be realized. The following section will explore the role of instructional policy in supporting infrastructure implementation and classroom enactment efforts to build a culture that fosters, supports, and encourages systems that provide reform-based science education experiences.

Instructional Policy

Instructional policy (e.g., allocation of funds and resources to support science instruction) is created to provide the necessary infrastructure (e.g., curriculum, instructional resources, science materials, professional development) to realize educational policy (e.g., government mandated science standards). Alignment between these three elements is imperative to not only implement, but also enact reform-based science.

Educational policy such as government-mandated science standards (e.g., Alberta Education, 2014; Arizona Department of Education, 2018; UK Department for Education, 2013) identify what is to be taught to students. An important feature of educational policy is that it "articulates discrete learning goals for students but not specific curricular or pedagogical choices for teachers" (Cohen et al., 2020, p.2). Instructional policy, distinct from educational policy, plays an essential role in influencing how one teaches, thereby supporting the realization of educational policy by efforts to "exert and direct influence on instructional practice in educational settings, or to offer guidance on the use of new curricular materials (Sykes & Wilson, 2016, p. 852).

Instructional policy can exist at various levels (e.g., school, district, and government) and should be primarily concerned with developing communities, instruments, and institutions to guide and direct (instructional) practice, but also implementation strategies and processes that balance capability building with accountability (Fensham, 2009; Roehrig et al., 2007; Sykes & Wilson, 2016). While the value of an instructional policy is apparent in theory, the practical execution is rife with challenges in relation to how it is interpreted, planned, and executed in alignment with other policies and values of constituents at each level of implementation and enactment (Abbott et al., 2023; Cohen et al., 2020; Pak et al., 2020; Roehrig et al., 2007). In the following section I outline the importance of instructional policy for enactment of reform-based science by referencing candid insight of examples and non-examples from my autoethnographic data supported by research.

Striking a Balance Between Pressure and Support

To influence instruction, support through instructional policy must be provided on multiple fronts while striking a balance between pressure and support (Sykes & Wilson, 2016). Good instructional policy intrinsically establishes the conditions necessary to enact the policy (Fensham, 2009). However, the politics and values underpinning a system influence what that support looks like in the spheres of implementation and enactment (Ball et al., 2012) across the various levels of agency at the national, state/provincial, district, and school level (Sykes & Wilson, 2016).

I experienced many examples of instructional policy that provided infrastructure in addition to the directives for infrastructure use to support enactment of reform-based science education. Each country shared commonalities – each country had some form of instructional policy for providing science resources – but also had context-dependent nuanced differences relating to the how/what/why and politics of designating funding for instructional supports (e.g., coaching, pedagogical routines), clear expectations and school routines for accountability (e.g., regular administrator classroom walkthroughs, rigorous PLCs), allocated and protected time for professional development (at the site and/or district level), protected time and expectations for professional learning communities (at the site and/or district level), and allocation of funds for instruments and personnel (e.g., science materials, equipment, personnel).

In Canada, I experienced the outcome of effective instructional policies in place to protect teacher autonomy, provide funding for science education outreach, and provide funding for laboratory instruments and materials (see vignettes *Hiding in Plain Sight* and *Insider Connections*). However effective those policies were, they could not overcome the absence of instructional policies for evaluation and accountability, high quality instructional materials, regular required professional development, or science technicians/personnel to maintain and support with science materials (see vignettes *Teacher Technicians* and *Chinese Takeout*). The result of this imbalance between support and pressure is best visualized by the vignette *Hiding in Plain Sight* – where policy existed to fund the purchasing of science lab materials, but none to ensure the materials were used.

In England, I experienced the outcome of effective instructional policies at the national and school level to provide funding for laboratory materials and technicians to service and support the use of materials (see vignettes *Practical Practicals* and *There's Always Room for*

Dessert). At the school level, I experienced examples of instructional policies that robustly drove evaluation of instructional efficacy and accountability for enactment of school-based instructional expectations. The result was a highly professional environment with high pedagogical expectations – resulting from regular data-driven professional learning community (PLC) meetings, school grading policies and accountability checks, and regular classroom walkthroughs. England offered an interesting case study into an alignment of layers of instructional policy between the school, county, and country. However, this alignment was not focused on the tenets of reform-based science, but rather on student achievement for standardized assessments (see vignettes *A Thespian Affair* and *What'd You Get on the Test?*).

In the United States, I experienced positive examples of instructional policy at the district and state level for funding instructional support personnel (due to Title-1 funding). Since academic coaches can build instructional and pedagogical capacity of teachers (Darling-Hammond et al., 2017), the district employed school-based academic coaches, district level content strategists, and interventionists (see vignette *Put Me in Coach!).* High-quality, standards-aligned instructional resources provide teachers and students with meaningful teaching and learning experiences (Beyer et al., 2009; Fullan, 2008; Roehrig & Luft, 2004). Thus, the district purchased a high-quality curriculum and instructional resources aligned to reform-based science standards (see vignettes *If They Can't Fish, Give them Fish* and *Kit Culture Couture).* Considering the impact of high-quality professional development to deepen teachers' awareness and development of content and pedagogical content knowledge (Darling-Hammond et al., 2017; Loucks-Horsley et al., 2010; Penuel et al., 2007), regular high-quality professional development opportunities were provided (see vignette *Professional Professional Development*).

These instructional policies at the state and district level resulted in a significant amount of high-quality instructional support, resources, and materials available to educators (Abbott et al., 2023). However, the utility and accessibility of the provided infrastructure was complicated by confounding variables such as high teacher turnover, low teacher pay, and small/non-existent hiring pools. Further, the district's overzealous implementation of multiple instructional programs, change initiatives, and school improvement models resulted in "opaque and contradictory" demands that competed for time and energy of teachers, coaches, and administrators, resulting in at times, superficial or fabricated practices (Ball et al., 2012) (see vignettes *Revolving Door of Reform* and *Keeping up Appearances*).

Across my experiences teaching, researching, and leading in three countries, I observed combinations of infrastructure and instructional policy that either hindered or promoted enactment of reform-based science. Ultimately, I observed that no matter how effective any one element of infrastructure or instructional policy was in promoting reform-based science, the efficacy was impacted by the presence or absence of any one variable (see the previous section, *Classroom Infrastructure)* or lack of policy alignment within and between layers of implementation and enactment. What remains absent are the instructional policies for science education at the school, district, and state levels that work synergistically together to intrinsically establish the conditions for enactment of policy through emergent interactions with infrastructure (Fensham, 2009) that strikes a balance between pressure and support. The following sections will discuss the implications of these findings for accountability measures and policy change timelines.

Policy Change Takes Time, Sometimes

Implementing new policies requires structures and policies to inherently establish the conditions necessary for enactment (Fensham, 2009; Roehrig et al., 2007; Sykes & Wilson, 2016). Creating the systemic and instructional policies necessary to establish conditions requires knowledge of stakeholders' everyday barriers, challenges, and needs (Karakus, 2021; Lawson, 2000; Pak et al., 2020). Unfortunately for the stakeholders involved, these challenges do not integrate into the neat and tidy policies that are designed for the educational systems to which they belong, and thus as policies in practice are "revised as well as sometimes dispensed with or simply just forgotten." (Ball et al., 2012, p.4).

Policy development is inherently political and is "typically written in relation to the best of all possible schools, schools that only exist in the fevered imaginations of politicians, civil servants and advisers and in relation to fantastical contexts" (Ball et al., 2012, p.3). In a certain sense, educational systems are doomed from the beginning because the policy developed to direct and mandate instructional practice, is not designed with the 'ordinary' school in mind, and as if "science (education) occurred within a vacuum" (Fensham, 2009, p. 1078). My experiences suggested to me that reform-based science is largely not being enacted in classrooms. However, I did observe policies and initiatives being enacted better in some places than others, and I was curious why that might be the case. In this section I explore examples of how policy change takes time, sometimes.

My experiences observing educational policy changes over a decade in three countries provides an interesting perspective on the systems underpinning the classrooms I have been in or around. I have experienced time points in vastly different policy implementation timelines - from a seamless transition between two national science standards and curriculum change (England) to a decade-long incomplete transition to new provincial standards (Alberta) (see vignettes *Timing is Everything*, *The Revolving Door of Reform*, and *30 Years Later, Why is Inquiry Still Not Used in Classrooms?*). The variables impacting change were relatively similar: competing initiatives, lack of time, focus on standardized assessments, and low teacher PCK (C. Anderson et al., 2018; Fensham & Rennie, 2013; Galton & MacBeath, 2008; Harris & Rooks, 2010; Karakus, 2021). The stark contrast I observed between implementation timelines in three countries was corroborated by the assertion of Ball (1998) that policy is "received and interpreted depending on the political architectures, national infrastructures, national ideologies and business cultures." (p.126). Inevitably, the meso- and micro-cultures of districts and schools also impacted system responsiveness and professionalism toward change (Pak et al., 2020; Roehrig et al., 2007; Sykes & Wilson, 2016).

From my experiences, I observed teachers in every country responding in similar ways to change: the rolling of eyes, defiantly challenging the incoming new initiative, creation of a temporary façade to appease administrators, and/or simply ignoring the very existence of it (Personal Observations and Communications, 2013-2023) used to inform vignettes in Chapter Four). Ball et al., (2012) corroborate this phenomenon as they note that schools may " 'fabricate' a response that is incorporated into school documentation for purposes of accountability and audit" or teachers may "superficially map the new policy on to current practices" (Ball et al., 2012, p.10). The example of the Title-1 school district in the United States identified in the vignette *The Revolving Door of Reform* exemplifies "superficial continuity within profound change" (Ball et al., 2012, p.10), in which there is much change, but without progress or deep continuity, resulting in frustration and confusion. In contrast, the example of the English school identified in the vignettes *Timing is Everything* and *A Thespian Affair*, exemplifies superficial change within profound continuity.

It is no wonder teachers are tired of hearing the never-ending spew of the revolving door of reform or the latest educational fashion fads (Bower, 1996; Furtak & Penuel, 2019; Roehrig et al., 2007). Book studies, buzzwords, TED Talks, and school initiatives burgeoning from new educational studies inundate schools, classrooms, and the general media every year. And every year, teachers' beliefs and values are challenged. This constant exposure to change works against new change initiatives, as teachers have become habituated to change, simply ignoring it or stubbornly bearing down on past practice. Because "teachers' views are built up over a long period and are burnished in the furnace of everyday practice" the proposed change must be explicit if change is to occur (Bencze & Hodson, 1999. p. 531).

Across educational systems, I observed the effects of change without progress. For educational system-wide change in response to science education standards, the nature and the time needed to enact the change depended on the local and national cultural contexts in which it was embedded. In Alberta, Canada, I experienced that the change to be made was incremental, yet took place at a snail's pace, if at all (see vignette *Hiding in Plain Sight* and *30 Years Later, Why is Inquiry Still Not Used in Classrooms?*). In Devon, England, I experienced moderate changes for the content and assessments to occur rather swiftly and seamlessly (see vignette *Timing is Everything*). In Arizona, U.S., I experienced substantial shifts to instruction that were required for pedagogy, attitudes, and beliefs, the process of which remains underfoot (see vignettes *The Revolving Door of Reform* and *30 Years Later, Why is Inquiry Still Not Used in Classrooms?*). Overall, I observed that the culture within educational systems and the larger political and economic contexts in which a policy is situated, impacted the speed with which the change was enacted once it was implemented.

Culturally speaking in a broader sense, the English are considered a relatively compliant and unified people (Orwell, 1946/2014), which may also have contributed to the swift uptake of the new standards and curriculum. This cultural difference starkly contrasts the Canadian and American cultural values of autonomy, independence, and freedom, particularly in a regional (i.e., state or provincial) sense. In Canada, there are no national standards and provinces have complete autonomy. In the U.S., despite the significant research and financial investment to create quality national standards (National Research Council, 2013), states have autonomy over their own educational standards (Arizona Department of Education, 2018). I experienced and observed a lag in schools in the U.S. and Canada before efforts were put into changing instructional practice. For example, the school district I worked in Arizona implemented new standards in 2020, seven years after the new national standards and 2 years after the state standards were disseminated. In Alberta, the schools I taught at largely disregarded the STS, skills and attitudes elements of the standards published in 2014 (a minor revision from the last major revision of standards in 2003 and 2009). Regardless of the country, the culture, or the many variables that are prone to impacting policy change, change is implemented in education systems. However, from my experiences, policy changes that enable reform-based science practices to be enacted in classrooms as a rule rather than an exception remains to be seen.

Accountability Measures for Maintaining and Sustaining Change are Absent from the Educational Landscape

An essential aspect of instructional policy, in theory, is that it offers guidance, support, and accountability for material or policy use. However, classroom infrastructure and instructional supports do not guarantee the use of resources nor enactment of policy in the classroom. Working in and around science education systems in three countries over a decade, I observed many different versions of infrastructure, instructional supports, and policies. While I observed several change initiatives implemented in these systems, finding examples of enactment of reform-based science was rare.

Accountability can be a powerful tool to impact practice, though it may not necessarily do so in ways that are always productive for reform-based instruction. Sykes and Wilson (2016) identify that an “excess of external accountability has been matched with insufficient attention to capacity building” (p. 860), which is particularly true for my own experiences where accountability focused on student achievement on standardized assessments or school/district initiatives, for the purpose of an “audit, rather than to effect pedagogic or organisational change” (Ball et al., 2012, p.10). The result of which can often present as a “superficial mapping” of a policy onto current practices and “fabrications” in response to accountability efforts (p.10) (see vignette *Keeping up Appearances*).

In contrast, the absence of accountability is the principal reason why purchased science resources are left untouched, why, after three decades, inquiry is (still) not used in the classroom, and why the impact of funding is only as good as long as it is flowing (Cohen et al., 2020; Fensham, 2009; Karakus, 2021; Lawson, 2000; Sykes & Wilson, 2016). However, accountability measures cost money, and funding for reinforcement, maintenance, and sustainment are not easily affordable luxuries. The reasons why the two polar ends of the accountability spectrum are problematic are outlined in the following section.

Because beliefs, attitudes, and skills take ample time, trust, and effort to build for each stakeholder within a system (Bencze & Hodson, 1999; Bowen, 2005), change that persists to make progress, takes time. Across my experiences, three elements kept surfacing that prevented constituents and systems from embracing and pursuing change: time, consistency, and continued funding (Fensham, 2009; Roehrig et al., 2007; Sykes & Wilson, 2016). The exhaustion, tension, and frustration resulting from the absence of these elements can be felt through the vignettes *The Revolving Door of Reform, Overstuffed, Underpaid, Overworked, Isolating Variables,* and *Hiding in Plain Sight*.

Despite the importance of ample time, funding, and consistency to support and sustain reform-based efforts, they are not common standard luxuries of educational systems. This is perhaps because accountability for evaluating the quality and frequency of infrastructure used to support reform-based science efforts are also absent (see vignettes *Hiding in Plain sight, The Revolving Door of Reform,* and *If You Caused Change, But it Wasn't Maintained, Did it Matter?*). Ultimately what I found was that absence of time, consistency, and continued funding for maintaining and sustaining change initiatives persist as central challenges to creating and maintaining the conditions to foster the space and time for lasting change (progress) to take root. I found time and again that there was money to buy flashy new books, resources, materials, and consultancy time, but little or no funding to evaluate how they impacted instructional practice and institutional culture.

Changes to school or district administration can also reset the clock on change initiatives, or thwart them all together (Fensham, 2009; Karakus, 2021; Sykes & Wilson, 2016). The culture for reform-based science is not anchored strongly enough in districts and schools to persist through a lack of funding or changing leaders. In my experiences, I regularly observed inconsistent or misaligned visions between teachers, administrators, district leaders, and/or government education ministers (see vignettes *Lost, and Found, in Translation*, *Critical Conversations*, and *Looking at Science Education with Rose Coloured Glasses*). This created a rather challenging environment to promote and support reform-based science enactment not only in my own classroom, but in those of others, and the schools in which I worked with or in (see vignettes *An Experiment*, *Step Into My Classroom*, and *If You Caused Change, but it Wasn't Maintained, did it Matter?*).

I have experienced a similar phenomenon regarding a lack of accountability for maintaining and sustaining research and outreach interventions. I observed that once the money, support, and/or personnel leave a system, an educational system has a natural tendency to revert back to its homeostatic pre-intervention state (Ball, 2008; Fensham, 2009; Honig, 2004; Roehrig et al., 2007) – see vignettes *The Revolving Door of Reform* and *If You Caused Change, but it Wasn't Maintained, did it Matter?*. Yet, despite the rather limited and ephemeral nature of these interventions and supports, there remains ample interest, funding, and support that exists for trying new things in science education research, outreach, and the neoliberal world of science education resources (Grantmakers for Education, 2019; Honig, 2004; Inside Philanthropy, 2020).

A quick look through broader impact sections of science research grants, philanthropic funding agendas, or outreach resources (see vignettes *Insider connections* and *Outreach is out of reach*), suggests there is ample funding for new ideas and things, but not much in the way of evaluating previous efforts, improving existing resources, or inventorying past and present efforts within existing systems. Sustaining, maintaining, repairing, and cleaning are not buzzwords easily found in science education literature, philanthropic funding agendas, or science outreach. Yet, it is these very processes that create the conditions necessary for change initiatives to take root in existing systems and become an integrated element of the system (Fensham, 2009). The pervasive culture in education to throw out the old to bring in the new, without first trying to troubleshoot why the old didn't work in the first place, continues to be pervasive across systems, widening the gap between intended and enacted reform.

In sum, the vignettes I referenced throughout this chapter provide insight into the interplay and goings-on of school systems and educators as they navigate the variables and infrastructure that support or hinder instructional practices. When taking the positive elements of instructional policy I experienced across three countries, I identified three overarching features of effective instructional policy that must be coordinated simultaneously:

- A balance between pressure and support – the more balanced, the more the more deeply rooted change becomes in practice;
- Alignment of constituents at all levels tasked with implementing and enacting the change – the more aligned, the more swiftly the change takes place;
- Accountability measures for sustaining and maintaining – the more robust, the increased longevity and spread of influence of the change.

Regardless of environment or variable, efforts are needed to bridge the space between practice and policy to address and coordinate these elements. The following section will explore the relevance and importance of doing this work in the third space through leading from inbetween.

Leading From Inbetween

Educational leadership is commonly considered a visible enterprise. Taken together leadership, policy, and research are well-bounded and typically understood as discrete entities that interact to direct and exert influence over practice. The goings-on of the actors in each sphere are well studied and documented. How is it possible then, that one could lead from inbetween these spheres through situational awareness, translation of knowledge, leveraging insider insight, and leading by example alongside stakeholders to identify problems of practice and offer context-specific solutions? The following section will explore the value of leading from inbetween, what leading from inbetween can look like, and how the approach can offer support for both implementation and enactment of reform-based science education.

Misalignment Prevents Progress Toward Enactment of Reform-based Science

For a multitude of reasons, the why, what, and how of reform-based science education lacks alignment between stakeholders, ultimately resulting in a substantial gap between the "reform visions and historical/current instructional realities" (Sykes & Wilson, 2016, p.901). In three countries, I experienced many examples of misalignment between educational stakeholders but also between the products of policy, research, and practice. Misalignments are readily visible in science classrooms, the arena for enactment of reform-based science (see vignette *Great Expectations, Good Intentions, Mediocre Execution*). I observed this phenomenon in many classrooms, my own included.

More commonly than not, I observed that the typical classroom showcased traditional teacher-centered pedagogy filled with fact-based memorization note-taking, sprinkled with cookbook recipe hands-on activities (Lawson, 2000; Roehrig et al., 2007). Student-student discourse, critical thinking, problem-solving, design, scientific literacy, and debate that are centerpieces to reform-based science were sparse (Phillips & Norris, 2009 and Sykes & Wilson, 2016). These observations have been supported over the past decade-and-a half by previous researchers in Australia (Fensham, 2009), the United States (Roehrig et al., 2007 and Sykes & Wilson, 2016), and Canada (Phillips & Norris, 2009). My findings support those of Roehrig et al. (2007) in their observation that "although cases of individual teachers or groups of teachers being successful in implementing reform-based teaching exist in the literature … we do not see significant impact of the proposed science education reforms across the United States" (p. 884). Over 15 years later, I have seen this similar trend across the three countries I worked in, whereby I observed and experienced more non-examples than examples of reform-based science, and thus a lack of a widespread impact of reform-based science initiatives. Taken together, I believe that despite much change, robust progress for enactment of reform-based science fails to be made – a theme that, at least for my own experiences and those of the researchers previously listed, transcends space and time (see vignettes *30 Years Later, Why is Inquiry Still Not Used in Classrooms?, Hiding in Plain Sight* and *If You Caused Change, But it Wasn't Maintained, Did it Matter?*).

Evidently, despite changes and variations in infrastructure, instructional policy, and leadership, teachers' pedagogical approaches continue to be misaligned with the science education reform vision or pedagogical content knowledge needed to teach reform-based science (Fensham, 2009; Karakus, 2021; Penuel & Furtak, 2019; Sykes & Wilson, 2016). Misalignments are perpetuated by the learning experiences of teachers in secondary science and as pre-service teachers (Akerson et al., 2006; Roth et al., 1998; see vignette *Two Courses isn't Enough*) and later in in-service professional development (Karakus, 2021; Penuel et al., 2007; Roehrig et al., 2007; see vignette *Put me in, Coach!*). Misalignments between teacher pedagogical content knowledge and reform-based science pedagogical expectations are further exacerbated and left unattended by the reform-based science standards themselves, which, while clearly articulate discrete learning goals for students, leave the pedagogical recommendations and tools to help teachers facilitate the learning “to the imagination” (Cohen et al., 2020, p. 2). Further, instructional policy that could support the development of the type of ambitious, adventurous and student-centered instruction required to effectively teach reform-based science is largely absent (Sykes & Wilson, 2016).

Not surprisingly, misalignments are also present at the policy and leadership level. Sufficient and aligned instructional policies to ensure the conditions necessary to achieve reform-based science aims are, at best, incomplete (Cohen et al., 2020; Hung et al., 2010; Karakus, 2021; Pak et al., 2020; Sykes & Wilson, 2016). For example, government, district, and school leadership continue to focus on fact-based standardized assessment scores to measure successful science teaching and learning (K. Anderson, 2012; Fensham & Rennie, 2013; see vignette *What’d you get on the test?*), leaving reform-based science outcomes unevaluated.

To further complicate matters, the undercurrent of conversation in science education research is unclear on what to constitutes reform-based science and to what extent it should mirror scientific practices (Furtak & Penuel, 2019; Southerland & Settlage, 2019). This lack of clarity is mirrored by educational constituents in the field (e.g., philanthropic granting agencies, administrators, teachers, curriculum companies), who have varied understandings and priorities about which elements of reform-based science should be promoted and how to achieve them (see vignettes *Lost, and Found, in Translation, A Case of Mistaken Identity* and *Chinese Takeout*). Commonly used descriptors of tenets of reform-based science education (e.g., hands-on, minds-on, phenomenon-driven, and inquiry-based) have a slightly different connotation and manifestation in classroom outcomes (Furtak & Penuel, 2019; Osborne, 2019; see vignette *A Case of Mistaken Identity*). The debate about what classroom science can and should look like, and what to call it, is exacerbated when neoliberal, economic, and political agendas collide (Ball, 2008; Fensham, 2009; Nietzsche, 1872/2016). I have experienced these tensions, confusions, and frustrations navigating the varied agendas and values of the systems that are in place to support instruction – instructional policy, philanthropy, and outreach—the very tools designed to fill gaps school systems they themselves cannot fill. This is evidenced in the different translations of language used about science education: education researchers are primarily concerned (nuanced debates aside) with reform-based or inquiry-based science; philanthropic foundations are interested in funding hands-on or technology and engineering "STEAM" opportunities (Inside Philanthropy, 2020; see vignette *Two Scientists Looking for Inquiry*); classroom teachers and students relish hands-on experiences (Gatsby Foundation, 2017b; see vignette *There's Always Room for Dessert*); and administrators and government measure success by, and focus on, standardized assessment scores (Fensham & Rennie, 2013; see vignette *What'd You Get on The Te*st*?*). This chorus of various interpretations and values of the what, how, and why of reform-based science contributes to misalignment between educational constituents within and between the spheres of research, policy and practice. Taken together, my experiences, corroborated by research underscore the importance of, and the need for, individuals operating from inbetween who can speak multiple languages to traverse different professional cultures to access the everyday experiences of stakeholders, understand multiple viewpoints, and simultaneously translate understandings between stakeholders to bring stakeholder understanding for reform-based science into system-wide alignment.

Leading From Inbetween Can Align and Build the Capacity of Systems

Inbetween is an amorphic, dynamic, and ephemeral concept – it fills the spaces, created intentionally or not, between people and objects (Brighenti, 2013; Giesen, 2012; Ollila & Yström, 2020). In science education, I found myself drawn to the inbetween.

The concept of 'inbetween' is not new to education, as evidenced by the small but burgeoning field of intermediaries, external individuals or organizations well-positioned to "operate between policymakers and implementers to affect changes in roles and practices for both parties" (Honig, 2004, p. 6). Knowledge brokers are a distinct subset of intermediaries, defined as an individual who assumes a whole system perspective to conduct their work, which takes place "in-between people, departments, processes, or organizations" (Cooper et al., 2020, p. 90). Knowledge brokers "explore the relationships or lack thereof between diverse stakeholders in different areas of a system" (Cooper et al., 2020, p. 92) by partnering, engaging, translating, and building the capacity of stakeholders and the systems in which they operate (Cooper et al., 2020; Meyer, 2010; Oldham & Mclean, 1997). The primary focus of knowledge brokers' work is to bring alignment between stakeholders of educational systems (Malin et al., 2020; McWhorter et al., 2020).

In line with current definitions, knowledge brokering is limited chiefly to external intermediaries (e.g., outside agencies or consultants) – with internal "school-based" knowledge brokers having thus far been an "often overlooked type of knowledge broker" (Farley-Ripple & Grajeda, 2020). The following section expand on the work of Farley-Ripple and Grajeda (2020) to define knowledge brokering to include internal intermediaries working between constituents within educational systems such as coordinators, strategists, consultants, and coaches (Whitworth et al., 2017). Internal intermediaries are exceptionally positioned inbetween stakeholders to “drive the process of social communication” (Giesen, 2012, p.789) and foster a place where “hidden agency can become present” (Ollila & Yström, 2020, p.209).

Through the lens of a district science strategist tasked with building system-wide capacity for reform-based science, I will describe the role, work, challenges, and potential impact of an internal intermediary/knowledge broker. It is worthy to note that formal positions for internal knowledge brokers are geographically limited, with my only experience of them taking place in Arizona of the United States. Despite being notorious for low education funding and poor instructional policies, the U.S. provides an excellent example of research-informed instructional policy at the state and district level for providing funding for internal knowledge brokers (Corcoran et al., 2001; Murphy & Hallinger, 1988; Spillane et al., 2002).

As an internal knowledge broker at the district level, my role as a science strategist (also referred to as a consultant or coordinator (Whitworth et al., 2017)) focused on identifying and supporting the professional realities, priorities, beliefs, capacities, and problems of educators to strategically bring alignment between stakeholders of educational systems (Malin et al., 2020; McWhorter et al., 2020). I worked “in-between people, departments, and processes” (Cooper et al., 2020, p. 90) within the school district to translate, coordinate, and align perspectives, understandings, and systems (Meyer, 2010) between district directors, district content strategists, school administrators, academic coaches, and teachers (see vignette *Strategic Support from Inbetween*). As a knowledge broker, I assumed a “whole system perspective to explore the relationships (or lack thereof) between diverse stakeholders at different areas of the system” (Cooper et al., 2020, p. 92) to identify the priorities and problems of practice on an individual and system level (McWhorter et al., 2020). Effective internal knowledge brokering takes time and must be conducted strategically to build authentic relationships and mutual understandings of constituents to align the systems and processes in which they operate (Hung et al., 2010). The following sections will identify the system needs that knowledge brokers can fulfill, their challenges, and their work's benefits.

Learning, navigating, and traversing the cultural boundaries of stakeholders was at the heart of what I did as an internal knowledge broker in the role of district science strategist/coordinator (see vignette *Strategic Support From Inbetween*). Fluency in many subcultural languages and the ability to wear many hats were assets when embarking on expeditions into each cultural sphere I supported (Whitworth et al., 2017). I interpreted, translated, and communicated information between stakeholders while holding multiple subcultural languages in my mind, all the while providing the appropriate translation and information that was most relevant to each stakeholder. From this, I used the brokered information to address and resolve misconceptions to bring system constituents into greater alignment—practically and ideologically (see vignette *Lost, and Found, in Translation*). The goal of my work among, with, and between stakeholders was to alleviate dissonance to ameliorate the disconnect between research and practice at the school and district level (Farley-Ripple & Grajeda, 2020).

A central feature of knowledge brokerage is the brokerage of research between stakeholders. In my role as a strategist, I provided wrap-around support that had internal and external coherence (Abbott et al., 2023; R. Anderson et al., 2014; see vignette *Strategic Support from Inbetween*) using the following research-informed strategies: development of aligned, coherent, strategic implementation and enactment plans (Firestone et al., 2005; Hung et al., 2010; Maass et al., 2019); developed team and community relationships in-person and online (Baier Wideman & Hale, 2020); build capacity of teacher professional learning communities (PLCs)

(Dogan et al., 2016; Lakshmanan et al., 2011); teacher instructional planning supports (e.g. pacing guides and recommendations) (Schneider & Krajcik, 2002); curricular sense-making support (Domina et al., 2015); maintenance and sustaining of science materials/kits (Waight & Abd-El-Khalick, 2011); differentiated professional development for teachers, coaches, and administrators (Darling-Hammond et al., 2017; Loucks-Horsley et al., 2010; Roehrig, 2023;Whitworth et al., 2017); coaching and model classroom lessons (R. Anderson et al., 2014); conducted authentic needs assessments to identify barriers and challenges (Karakus, 2021; Lawson, 2000; Whitworth et al., 2017); reviewed, analyzed, and communicated student achievement data (K. Anderson, 2012; Whitworth et al., 2017); organized family and community science engagement opportunities after school hours; collaborated with teacher leaders (Abbott et al., 2023); and conducted classroom walkthroughs with look-fors aligned to reform-based science (Cohen et al., 2020; Roehrig et al., 2007).

The many responsibilities and interactions required of an effective science strategist (coordinator) means they have the access to probe every nook and cranny of a science education system. They are, indeed, "uniquely situated within their organizations" to "make important contributions to the capacity for research use in school decision-making" (Farley-Ripple & Grajeda, 2020, p.81). While the ideal positioning and multiple responsibilities promise a high impact on science instruction and educational systems, this long list is constrained by time considering internal intermediaries "carry more responsibility than is realistic for one single person" (Whitworth et al., 2017, p. 932). Shifting funds from external intermediaries, a "motley collection of organizations" (Honig, 2004, p. 66) that can produce "crowded, complex, and varied efforts" (Malin et al., 2020, p. 14), to internal intermediaries to lessen their context-dependent and embedded workload could benefit educational systems.

My findings show that internal knowledge brokers who lead from inbetween bring novel value to educational systems' functionality and growth (Malin & Brown, 2020; Whitworth et al., 2017) that is tailored to the needs, culture, and individuals of that system. Thus, educational systems would benefit from creating in-house non-canonical science-specific leadership positions (e.g., strategists, coordinators, or specialists), tasked with leveraging existing resources, personnel, and relationships to strengthen systems from the inside out. Ultimately, change that impacts student learning, instruction, and educational systems take time and consistency (Ball et al., 2012; Bowen, 2005; Fullan, 2008), something which few schools and districts have the luxury of. Bringing internal knowledge brokers such as strategists (coordinators) into the fold of the wider field of knowledge brokering would provide visibility to their work, and ideally, increased demand to align and build capacity of constituents and systems from within.

Taken together, infrastructure, instructional policy, and internal intermediaries are essential elements to support implementation and enactment of reform-based science. However, without a robust, dynamic, strategic, coherent, and ambitious system-wide framework, no amount of infrastructure or support can overcome or compensate for this shortcoming.

Summary

To conclude Chapter Five, engaging in autoethnography as method and methodology enabled me to access data that is otherwise hidden using traditional methods, to answer the research question; *What insights can be gained from autoethnographic exploration of my experiences with reform-based science education systems in Canada, England, and the United States?* Much of my data corroborated findings of previous studies that dotted the academic landscape over the past twenty-five years; however, novel insight gained from employing noncanonical research methods were uncovered. Notable findings relating to classroom infrastructure, instructional policy, and leadership include:

1. The value of engaging in autoethnographic methods to acquire otherwise hidden data unattainable by canonical education research methods.
2. First-hand candid accounts of the frustrations, confusion, and exhaustion experienced by stakeholders navigating multiple school and district initiatives to attempt enactment.
3. Similarities and differences between science education levels and national systems.
4. The critical role that inbetweeners play in leadership and brokering of research-informed knowledge between stakeholders; and the argument for the field of knowledge brokers to be expanded to include internal brokers (e.g., strategists and coordinators).
5. Evidence of temporal persistence and spatial ubiquity (across Canada, England, and the United States) of themes impacting science education enactment.

This research considered the variables impacting science education, bringing them to a confluence and investigated not as separate entities, but together in relation to one another and the whole. Most extant research investigates one element almost as though it is '*in vitro*' in a closed environment, isolated from the chaos of the everyday, from the perspective of a non-participant observer. While my own research relied on these studies as a foundation from which to conduct my actions in science education, my own research probed deeper and farther into the raw underbelly and the interstitial inbetween spaces of science education systems. As a participant observer, I was able to access candid insight to science education systems, '*in vivo*', in living, breathing educational environments. My research dug deep into the messiness of the mangle of the practice of science education and its constituents, beyond the reach of canonical research methods

CHAPTER SIX: CONCLUSION

At the beginning of this study, I asked the question: *What insights can be gained from autoethnographic exploration of my experiences with reform-based science education systems in Canada, England, and the United States?* Stemming from childhood memories of meagre science experiences and ignited by my experiences in natural science research, my quest to realize reform-based science education in classrooms took me on a journey through experiences teaching, leading, and researching reform-based science education in three countries, over the course of a decade.

In this final chapter, I share overarching insights and considerations that stakeholders of science education might find valuable, if their own experiences resonate with my own. In the following, I organize my considerations into three broad themes: (1) Prioritize progress over change; (2) Build the beliefs and attitudes of educators for reform-based science; (3) Re-evaluate educational systems from inbetween. Implications of these findings and some final thoughts are provided to conclude this work.

Overarching Insights and Considerations

Insight: Change Ebbs and Flows Without Progress

Working in three different countries, I have experienced several examples in which change incentives, initiatives, and implementation have not yielded significant progress toward classroom enactment of reform-based science as defined in government educational policies. Despite the revolving nature of change found throughout different aspects of science education systems, I observed little evidence of permanent progress made in the past decade, and even longer, considering many issues I experienced had been cited in literature dating back ten to over twenty-five years. Preservice science teacher education continues to be insufficient to prepare future educators to achieve reform-based science aims (Akerson et al., 2006; Lederman, 1992). Science classroom infrastructure remains largely unused (Lawson, 2000; Roehrig & Luft, 2004). Lecture-style instruction remains a dominant staple in classrooms (Harris & Rooks, 2010; Hume & Coll, 2010; Lawson, 2000). Standardized assessments that focus on facts instead of process continue to dominate school and classroom culture (Black, 2001; Fensham & Rennie, 2013; Harlen & Crick, 2003). Science outreach continues to attempt to fill gaps but remains inaccessible to most students (Andrews et al., 2005; Friedman, 2012). Instructional policy to sustain and maintain change or to measure enactment remains insufficient (Ball et al., 2012; Fensham, 2009). Change initiative timelines are impatient and vague, lasting only as long as the attention span or term of the leaders or the time spent by researchers in an educational system. I too, am guilty of perpetuating this ephemeral nature of education, as I have stayed in an educational system for only one, three, or four years at a time—a small slice of time in the history of each institution. It might be the case that I happened to leave before a change took root. But, it might also be the case that regardless of my presence, the educational systems of which I was a part of, were doomed to repeat history—as evidenced by artifacts and conversations from peers that suggest had been done years and decades prior to my arrival.

In sum, my experience over the past decade in three countries in science education considered within the historical literature of science education research over the past 25 years, leads me to believe that science education is caught in a self-perpetuating system for change without progress. Science education research continues to create answers and solutions to problems through new models, theories, and frameworks. Some of this research eventually trickles into government and instructional policy. Over time, these policies are implemented in schools and districts, eventually manifesting as classroom infrastructure with the expectation that this infrastructure results in classroom instruction aligned with reform-based science government standards. Teachers adapt, revise, discard, or ignore these reform-based standards, focusing instruction on what is assessed and therefore what is socio-politically valued. From research and classroom observations, enactment problems and barriers are identified, prompting new science education research studies, thus perpetuating the change cycle, without any substantial progress towards the reform-based vision of science education.

Consideration: Focus on Progress Over Change

I define progress in a reform-based education system as any sustained and holistic enactment of reform-based implementation goals, evidenced by visibility in the everyday student classroom experience. Progress to me would look and sound like the student learning toted in government educational policies being experienced regularly in everyday classrooms: whereby student learning is steeped in the processes, nature, and practices of science through engagement in critical thinking, collaboration, discourse, evidence-based reasoning, discovery, and inquiry. Where students leave their secondary science learning institutions equipped with scientific literacy and the skills to critically engage as citizens that are ready to face the scientific, social, and ecological challenges of the future.

In my experience, though lofty goals exist, there are misguided efforts to commit to these goals because funding only exists to ephemerally implement the new thing, rather than continually enact the old. Progress requires funding that maintains and sustains the goals of reform-based science education. Instead of funding the latest initiatives, frameworks, models, theories, and accompanying resources, we need to consider funding existing programs that align with reform-based science goals. Continuous improvement and innovation are buzzwords of educational systems. The old is abandoned in favor of new, flashier, and fashionable ideas. Where new things bring novelty and enthusiasm, maintaining and sustaining change in systems that are broken only brings expired exhaustion and boredom. This obsession with change diverts effort and funding from maintaining and sustaining existing initiatives and programs. Problematically, these seemingly well-intended new initiatives compete for real estate in the everyday wash of school life, working antagonistically, rather synergistically to achieve change. There is undoubtedly much change, but little in the way of progress.

By funding existing well-aligned programs, leadership can focus on supporting and maintaining enactment instead of just implementation. Change goes hand-in-hand with implementation, but enactment requires an investment in a culture that is expressed in the everyday experiences in school hallways, classrooms, and behind closed doors. Enactment is the accurate measure of the success of change, which over time, is evident through visible progress in the science classroom student experience. Enactment requires an instructional policy that both follows up on and supports the lived expression of implemented change such that the change is sustained and maintained over time. High-quality curricular resources, science technicians, and instructional intermediaries are examples of infrastructure that can support enactment.

Insight: **A Strong Culture for Reform-Based Science is not Prevalent**

The aims of government-created instructional standards are aligned with those of reform-based science education; however, my experiences reveal misalignments between the implementation goals of educational institutions and everyday realities of the classroom. My experiences of classroom instruction, assessments of student learning, and instructional policy suggest that government standards are not yet seen in the everyday of science education. Despite the efforts of education researchers, scientists, intermediaries, and outreach organizations, in my experiences, the spirit of reform-based science is sparse among the teachers and leaders in secondary science and remains absent from evaluations of instruction and standardized student assessments. A similar observation was made over 150 years ago by Nietzsche: “various external measures seemed necessary, and some crucial ones were successfully applied to the modern form of the gymnasium, with lasting effects – but the single most important thing failed to happen: consecrating the teachers themselves to this new spirit” (Nietzsche, 1872/2016, p. 33). Without teacher buy-in (i.e., what Nietzsche refers to as “consecration”) there is little hope that educational reform can lead to lasting effects. Educational systems have failed to effectively develop and sustain a common culture for reform-based science education across teachers, leaders, and researchers alike.

Consideration: **Strengthen the Culture for Reform-Based Science**

I believe that the foundation of healthy educational systems rely on shared attitudes, beliefs, values, and understandings about the ‘what’, ‘how’, and ‘why’ of science education among stakeholders. With its ambitious goals, reform-based science education asks a lot of those tasked with delivering and leading it. Unfortunately, the lofty goals of government policies are not supported with enough instructional or pedagogical support. Although outreach organizations and philanthropic foundations are focused on increasing enthusiasm for science, technological advancement, and preparing the next generation of workers, only the privileged few with access.

If we want a reform-based science education system, I believe we must reevaluate how preservice teachers are educated and how students are evaluated. Most educators have not encountered reform-based science themselves as learners, and preservice teacher education is insufficient to overcome past experiences or prepare teachers to successfully navigate the temptations and barriers that distract from reform-based science aims. If "education is the most powerful weapon which you can use to change the world" (Nelson Mandela), why can we not use education to change the very systems responsible for science education? How can preservice teacher education be made to better align with reform goals? Can we better acquaint science teachers with strategies and pedagogical content knowledge required to achieve reform-based science education goals? I believe that to prepare teachers with the pedagogical content knowledge of 'how' and 'why' to teach reform-based science, preservice science education programs must include additional education research components.

Insight: Reform is Not Enough, A Revolution is Required

Despite 'new' reform-based science educational aims and standards, outdated traditional notions about science education instruction persist. In many ways, these reforms are no different than those Humboldt had championed in the mid-1800s (Thomas, 1973) and Dewey in the early 1900s (Dewey, 1910). The existing systems that control science education and the constituents of these systems lack a common understanding of the aims, outcomes, and ends of education. I believe this is primarily a symptom of myriad and constantly changing variables that meddle with precious time, resources, beliefs, mindsets, and abilities that impact efforts to acknowledge and realize science education reform. The effects of these variables are additive, creating a never-ending evolving ecosystem that stakeholders must navigate both individually and collectively. To my mind, reform-based science education remains a noble cause, though my in-the-field experiences and research reported over the past few decades, we continue to fall short.

The piecemeal, ad-hoc, and step-by-step changes offered to support education constituents to navigate the endless barriers and variables are not enough to achieve reform. I believe that we require a dismantling of the system's components and a reset of the mindsets of constituents so that the education system can be built anew: a revolution forged out of crisis. I am not the first to call for it, but merely echoing the cries of scientists (e.g., Alberts, 2009; Bower, 1996), education researchers (e.g., Fensham, 2009; Phillips & Norris, 2009; Roehrig et al., 2007), educators, and even the OECD who have called for "radical changes to core habits and practices" (2015, p.17).

But what would this post-revolution science education look like? And how would we achieve it? It would require coordinated and committed efforts of all stakeholders, a seemingly impossible task. Yet, I feel it is what is needed if educational systems genuinely want to achieve reform-based science aims. However, if economics and neoliberalism remain the focus of nations, then I believe there is no hope for collective action to occur. Educational systems are subject to the same horrors plaguing our natural ecosystems—they merely provide a necessary commodity that enhances the immediate wealth of a nation, instead of repositories of investment for future use. Despite my seemingly hopeless outlook, several examples of the incredible efforts of individuals can be seen at every level. These efforts are not in vain—there is good and important work being done to navigate and improve existing systems. But these positive examples are not enough to bring about reform. I believe that only a revolution can make this change possible.

But I am not advocating for complacency. Individuals necessarily are the sparks of change. Nearing the end of the writing of this dissertation, I had an opportunity to reconnect with a friend in Berlin, a Syrian political dissident, whom I hadn't seen since we lived there five years prior. This friend had spent 20 years of their life in prison for protesting the Assad regime and now lives in exile in Berlin as a writer in continued protest. Upon confessing my hopelessness about the need for systemic reform, and the unlikeliness that it will ever happen, they stated, "You did not create the system; you just work in it. You cannot change the system, but you can change what is within your reach". Perhaps that is all we can ask of ourselves and each other while echoing and sounding the call for revolution.

Consideration: Work Towards Progress While Waiting for the Revolution

While waiting for the embers of revolution to ignite, where should we put our efforts? I offer the following suggestions:

Put yourself in their place. Education stakeholders are too often siloed in their roles and, consequently, how they view the greater system in relation to their role. Leaders and researchers attempt to demonstrate their badge of 'classroom experience', offering an olive branch to extend to educators in exchange for street cred. Yet, administrators can quickly forget the multiple variables teachers need to navigate in their classrooms, thus losing touch with classroom realities. This lack of awareness of lived everyday experiences of the 'what is' can cause teachers to mistrust administrators and front facades, ultimately leading to missed opportunities for leadership to see their systems as they *really* are. Only by understanding how things are 'on the ground' and in classrooms can they begin to build capacity for change.

Make it an inside job. Gaps have been left in educational systems due to lack of sufficient resources to meet the needs of reform-based science. Intermediaries, outreach organizations, and philanthropic foundations have attempted to fill these gaps. While their aid can be helpful now, once it leaves, the gap remains. By leveraging instructional policy to develop positions for internal intermediaries to support science education from within, rather than outside systems, existing efforts can align systems to bring about internal and external coherence.

Lead from inbetween. This can be done conceptually by any stakeholder or physically by a designated, well-positioned individual. By leading from inbetween, one can not only acquire candid insight, but also translate between stakeholders to broker knowledge. Moreover, it provides a unique opportunity to simultaneously look at the whole system while zooming in on each constituent in relation to the whole. In serving these roles, gaps can be filled in a way that sustains and maintains the system while building the capacity of all stakeholders. To lead from inbetween requires an unfocusing of one's gaze and a stepping back from a siloed view of systems. Any individual can do this, but those found at the fringe and interfaces between siloed roles are exceptionally poised to do this work.

Summary

In this chapter I shared the overarching insights and considerations that were uncovered by my autoethnographic research of experiences occurring over a decade, in three countries, as a teacher, researcher, and leader. While my observations are limited to the classrooms, schools, and districts in which I worked, I believe, they could be helpful if thought of as cross-sections or at the very least, a possible glimpse into the innerworkings and tensions of the social worlds entangled in the educational and national cultures of science education systems. As I identified in

Chapters Two, Five, and Six, science education academic literature over the past twenty-five years has been littered with calls to action, identification of issues, solutions to those issues, and even outcries against policy that continues to push reform agendas without considering local contexts and micro-policies. As I concluded in Chapter Six, my research attempted to demonstrate that while the tenets of reform-based science education are worthwhile, there is, and has been for a very long time, significant barriers and a lack of alignment between all constituents of educational systems, irrespective of temporal or spatial variables. Thus, in light of my findings, the considerations for educational research, leadership, and policy I presented in this chapter include: 1) Prioritize progress over change; (2) Build the beliefs and attitudes of educators for reform-based science; (3) Re-evaluate educational systems from inbetween.

Final Summary

Undertaking this autoethnographic research, I was able to reflect on my experiences over a decade of teaching, researching, and leading reform-based science education in Canada, England, and the United States. I employed an layered analytic approach to autoethnography to offer unique insight into the social worlds, tensions, negotiations, and challenges experienced by stakeholders with respect to infrastructure and fellow stakeholders (Aim 1, see Chapter Four). I explored my narratives for similarities and differences between the national and professional cultures of the science education systems I experienced (Aim 2, see Chapter Five). Finally, from personal experience, corroborated by extant science education research, I offered insight into broader cultural phenomena of reform-based science education implementation and enactment (Aim 3, see Chapter Six). In the event that my own experiences might resonate with others, I offered the following insights in Chapter Five: (1) Classroom infrastructure (such as teacher education, science outreach, technicians, and instructional materials) is essential, but not enough to ensure enactment reform-based science. Further, standardized assessments detract from reform efforts. (2) Instructional policy (such as policy designed to provide instructional supports such as physical materials, technicians, intermediaries, assessments, evaluations, accountability) is essential, but not enough to ensure enactment of reform-based science. (3) Leading from inbetween (such as internal intermediaries) can support the alignment between stakeholders and build capacity of systems, but are not enough to ensure enactment of reform-based science. I used these specific insights to inform the overarching insights of my research that consider infrastructure, policy, and leadership together that may help to build capacity for enactment of reform-based science education: 1) Prioritize progress over change; (2) Build the beliefs and attitudes of educators for reform-based science; and (3) Re-evaluate educational systems from inbetween.

My autoethnographic research uncovered several tensions between what was recommended by science education policy and research, and what was possible in the messy turbulence of the everyday going-ons in classrooms and educational systems. I experienced firsthand, the disparity that exists between the demands that are placed on teachers for delivering the content of reform-based educational systems and the educational and instructional policies and structures that are intended to direct and support. I experienced this chasm widened and sustained by deficient infrastructure and support, as well as the persistent prioritization of standardized assessments, which did not reflect the aims and goals outlined in science education policy. To borrow the words of Perrow (1999), I experienced the interaction of the multiple failures that explained the accident.

Taken together, there are many variables that impact how implemented policies are translated, interpreted, and ultimately, enacted in everyday schools and classrooms. The interplay between stakeholders, infrastructure, and the negotiations that take place in the third space between implementation and enactment are grounded in the historical and situated realities impacted by both micro-level and macro-level policies. Implementing reform-based science is one thing, but the enactment of reform-based science is an entirely different phenomenon. Considering a system from perspectives that have previously been thought of as unproductive boundaries, might represent a way forward. From this vantage point, it might be possible to take these variables into account to assess the progress of reform-based science in educational systems.

It is my hope that this research, which documented and analyzed my experiences of the candid life of educational constituents and systems navigating policy, might increase visibility of internal intermediaries and help bring autoethnography into the fold of the dominant discourse of science education research. The optimistic implication of this research, at its very core, is to bring awareness to the complexities and everyday struggles involved in implementing and enacting reform-based science, with the hope that, maybe one day, reform-based science education can be realized as the norm, rather than an exception in science education classrooms.

Final Thoughts

There are many ways of learning and teaching science, but no one agreed upon way to determine which is best. Nor are what might be considered better ways of learning science (e.g., reform-based approaches) necessarily assessed or positively correlated with achievement on local, government, and international standardized assessments. The metastudies of Hattie and

Yates (2013) and OECD (2016) have shown a negative correlation between achievement on standardized assessments and reform-based science education approaches. Even so, I have observed the status quo continue year after year, decade after decade: Governments continue to roll out educational reforms that promise a future in which students leave secondary science equipped to face the environmental, technological, and social challenges of the future. Local, national, and international politics and economics continue to influence how educational standards are interpreted and taken up in districts, schools, and classrooms. Education researchers continue to concern themselves with the nuances of how best to teach, support, and build capacity for reform-based science. Students continue to experience teacher-centered, fact-based science education experiences as a norm and not the exception.

I believe that if we do not move science education in a new direction, where science is taught as a method of thinking (Dewey, 1910), then we are neither heeding the advice of Humboldt from over 150 years ago that "the making of citizens takes second place to the making of human beings" (Thomas, 1973, p. 224), nor that of Dewey some years later (1938/1997):

> "What avail is it to win prescribed amounts of information, to win the ability to read and write, if in the process, the individual loses their own soul: loses the appreciation of things worthwhile, of the values to which these things are relative; if they lose the desire to apply what they have learned and, above all, loses the ability to extract meaning from their future experiences as they occur?"

Reform-based science education is an answer to Humboldt and Dewey's pleas. Or, at least in its truest form, it could be.

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APPENDIX

Table A1

Summary of goals, themes, and significant elements of educational standards

Alberta, Canada (Alberta Education, 2014)	
Goals: Students will… • Develop scientific literacy • Develop critical sense of wonder and curiosity • Use Science and technology to acquire new knowledge to solve problems • Prepare to critically address science-related issues • Pursue higher level education	
Major themes	**Significant elements**
Science, Technology, Society (STS)	• Nature of Science • Science, Technology, Society • Social and Environmental contexts
Knowledge	• Biology • Chemistry • Physics
Skills	• Initiating and planning • Performing and recording • Analyzing and interpreting • Communication and teamwork
Attitudes	• Interest in science • Mutual respect • Scientific inquiry • Collaboration • Stewardship

England (UK Department for Education, 2013)	
Aims: Students will… • Develop scientific knowledge and conceptual understanding • Develop an understanding of the nature, processes, and methods of science through different types of science enquiries that help them to answer scientific questions about the world around them • Become equipped to understand uses and implications of science, for today and future	
Major themes	**Significant elements**
Working Scientifically	• Scientific attitudes • Experimental skills and investigations • Analysis and evaluation • Measurement
Subject Content	• Biology • Chemistry • Physics

<table>
<tr><th colspan="2">Arizona, United States
(Arizona Department of Education, 2018)</th></tr>
<tr><td colspan="2">Introduction
Sustaining natural curiosity and giving it a scientific foundation must be a high priority.
Scientific thinking enables students to strengthen skills that people use every day: solving problems creatively, thinking critically, working cooperatively in teams, using technology effectively, and valuing lifelong learning.
A fundamental goal of science education is to help students determine how the world works and make sense of phenomena in the natural world.
Students must be able to ask questions, gather information, reason about that information and connect it to scientific principles, theories, or models, and then effectively communicate their understanding and reasoning.</td></tr>
<tr><td>Major themes</td><td>Significant elements</td></tr>
<tr><td>Science and Engineering Practices</td><td>• Ask questions and define problems
• Develop and use models
• Plan and carry out investigations
• Analyze and interpret data
• Use mathematics and computational thinking
• Construct explanations and design solutions
• Engage in argument from evidence
• Obtain, evaluate, and communicate information</td></tr>
<tr><td>Core Ideas for Using Science</td><td>• Phenomena
• Revision of models and theories
• Problem solving and creating products
• Ethical, social, economic, political implications</td></tr>
<tr><td>Core Ideas for Knowing Science</td><td>• Life Science
• Physical Science
• Earth and Space Science</td></tr>
<tr><td>Cross Cutting Concepts</td><td>• Patterns
• Cause and effect
• Structure and function
• Systems and system models
• Stability and change
• Scale, proportion, and quantity
• Energy and matter</td></tr>
</table>

Table A2

Intermediary-produced engaging, hands-on, authentic, and/or inquiry related science teaching resources and/or outreach opportunities

American Intermediary-produced science teaching resources and outreach opportunities
Ask a Biologist
Teacher toolbox https://askabiologist.asu.edu/about/teacher-toolbox
Student games and simulations https://askabiologist.asu.edu/games-and-simulations
Center for Education Through eXploration https://etx.asu.edu/
Immersive field trips
http://vft.asu.edu/VFTPanamaH5/panos/L1MidCanopyMain/L1MidCanopyMain.html
Habitable worlds beyond https://www.habworlds.org/
Inspark https://inspark.education/
Infiniscope https://infiniscope.org/about/
Graduate partners in Science Education @ASU https://gpse.asu.edu/educational-resources/
The Inquiry Project https://inquiryproject.terc.edu/
Problem-Based Learning (PBL) works: https://my.pblworks.org/resources
Science Friday https://www.sciencefriday.com/educate/
Institute for inquiry
https://www.exploratorium.edu/snacks
https://www.exploratorium.edu/education/designing-teaching-learning-tools
https://www.exploratorium.edu/education/ifi/resource-library
Solve it: inquiry driven problems http://schoolsup.org/solve-it
Arc of Inquiry http://www.arkofinquiry.eu/web-based-materials
Siemens Stem Day Hands-on activities: http://www.siemensstemday.com/educators/activities?g=6
Next Generation Science Standards official resources
Teacher Resources https://www.nextgenscience.org/classroom-sample-assessment-tasks
Exemplar Science Lessons and Units https://www.nextgenscience.org/resources/examples-quality-ngss-design
Phenomena for NGSS https://www.ngssphenomena.com/
NGSS-vetted resources
- Stem Teaching tools" http://stemteachingtools.org/tools
- Next Gen 'Story lines' http://www.nextgenstorylines.org/
- Ambitious science teaching tools https://ambitiousscienceteaching.org/tools/
- Open Science Ed https://www.openscied.org/access-the-materials/

Link Engineering
https://www.linkengineering.org/Resources.aspx?resource-type=54_507&grade-level-s-=38_247

National Science Foundation
Classroom resources https://www.nsf.gov/news/classroom/index.jsp

Amgen Foundation – funded resources
Lab Xchange https://labxchange.org/

Lawrence Hall of Science
https://www.howtosmile.org/
https://www.lawrencehallofscience.org/do_science_now/science_apps_and_activities

Generation Genius https://www.generationgenius.com/

US dept of Energy – teaching resources https://science.osti.gov/wdts/K-12-Educators

Understanding Science – University of Berkeley
https://undsci.berkeley.edu/teaching/teachingtools.php
https://undsci.berkeley.edu/resourcelibrary.php

Promise of Place https://promiseofplace.org/curriculum-planning/curricular-resources

Skype a scientist https://www.skypeascientist.com/resources-for-teachers.html

C-Stem
Problem-based, phenomenon driven curriculum
https://www.cstem.org/organizations/curriculum-assistance/curriculum-download-form-page/

HHMI Biointeractive
https://www.biointeractive.org/classroom-resources?f%5B0%5D=grade_levels%3A97
How science works https://www.biointeractive.org/classroom-resources/how-science-works