DISSERTATION

TEACHERS' AND RESEARCHERS' BELIEFS OF LEARNING AND THE USE OF LEARNING PROGRESSIONS

Submitted by

Francis Neely Clapp

School of Education

In partial fulfillment of the requirements

For the Degree of Doctor of Philosophy

Colorado State University

Fort Collins, Colorado

Spring 2017

Doctoral Committee:

Advisor: Meena Balgopal

James Graham
Russell Korte
Andrea Weinberg

ABSTRACT

TEACHERS' AND RESEARCHERS' BELIEFS OF LEARNING AND THE USE OF LEARNING PROGRESSIONS

In the last decade, science education reform in the United States has emphasized the exploration of cognitive learning pathways, which are theories on how a person learns a particular science subject matter. These theories are based, in part, by Piagetian developmental theory. One such model, called Learning Progressions (LP), has become prominent within science education reform. Science education researchers design LPs which in turn are used by science educators to sequence their curricula. The new national science standards released in April 2013 (Next Generation Science Standards) are, in part, grounded in the LP model. Understanding how teachers apply and use LPs, therefore, is valuable because professional development programs are likely to use this model, given the federal attention LP have received in science education reform.

I sought to identify the beliefs and discourse that both LP developers and intended LP implementers have around student learning, teaching, and learning progressions. However, studies measuring beliefs or perspectives of LP-focused projects are absent in published works. A qualitative research is therefore warranted to explore this rather uncharted research area. Research questions were examined through the use of an instrumental case study. A case study approach was selected over other methodologies, as the research problem is, in part, bound within a clearly identifiable case (a professional development experience centering on a single LP model). One of the broadest definitions of a case study is noted by Becker (1968), who stated that goals of case studies are "to arrive at a comprehensive understanding of the groups under

study" and to develop "general theoretical statements about regularities in social structure and process." (p.233). Based on Merriam (1985) the general consensus in the case study literature is that the assumptions underlying this method are common to naturalistic inquiry with research conducted primarily in the field with little control of variables. Beyond this similarity, different researchers have varying definitions to case studies. Merriam's (1985) provided a summary of the delineations and varying types of case studies. Merriam divided the various case study methods by their functions, with a marked divide between theory building and non-theory building methods. Non-theory building case studies are generally descriptive, and interpretive methods that apply theory to a case or context allow researchers to better understand the phenomena observed (Lijphart, 1971; Merriam, 1985). Conversely, theory building case studies focus on hypothesis generation, theory confirming, theory informing, or theory refuting (Lijphart, 1971; Merriam, 1985). Though there are many definitions and methods labeled as 'case studies,' for the purpose of this study, Yin's (1981) definition of a case study will be used. Yin (1981) defined a case study as a method to examine "(a) a contemporary phenomenon in its real-life context, especially when (b) the boundaries between phenomenon and context are not clearly evident" (p. 59). My study seeks to apply theory and study phenomena in their context, as I will examine teachers' practice in context of their respective classrooms.

This study focuses on the lived experiences of both teacher and research stakeholders within the study. Specifically, I interviewed teachers who participated in a year-long teacher-in-residence (TiR) program. In addition, researchers/content experts who conceptualized the LP were also interviewed. Because the TiR experience was a form of professional development, I propose to study the impact that it had on participants' perceptions of the LP and any teacher-reported changes in their respective classrooms. However, because beliefs influence the language

that we use to describe phenomena (such as learning and teaching), it is informative to also describe patterns in how LP developers explain learning and teaching. Subsequently, the results of this study will inform literature on both science teacher professional development and LPs theory to practice.

Keywords: Learning Progressions, Cognitive Learning Pathways. Researcher Beliefs, Teacher Beliefs, Teacher Systemic Reform Model, Teachers in Residence

ACKNOWLEDGEMENTS

I would first like to express my gratitude to my advisor, Professor Meena Balgopal, for her tenacity, patience, and support in my somewhat convoluted path towards a PhD. Dr. Balgopal has always been staunch supporter and has helped me not only academically, but more importantly given me life lessons on humility and introspection. She has been one of the strongest advocates I have had in life and a buttress to the many occasions I doubted myself. I have been very lucky that she “stuck with it” with me. Sufficed to say, my opportunities in writing this acknowledgement would have be slim had it not been for her leadership, council, and coaching. Thank you, Meena, for help getting me here.

I would like to thank Dr. Jim Graham for giving me the amazing opportunity to be financially supported during my PhD program, teaching me five-ish programming languages, and always bluntly pushing me to get those “four signatures” I need to graduate. Special thanks goes to Kirsten Holfelder and Greg Newman who always supported my graduate studies and helped assist me in juggling the duties of the project with my own research agenda. Special thanks also goes to Dr. Weinberg who was willing to participate in my final defense committee at the last moment and to Dr. Gene Gloeckner for giving the opportunity to assistant teach a graduate course and in navigating the political arena of academia.

I would like to thank my mother who always gently and warmly pushes me to succeed in my own path through life. To my father who helps me laugh at things I sometimes want to cry about. Finally, thank you, Sarah Badding, for sharing the PhD experience with me and supporting the early and middle stages of my dissertation path.

Thank you all.

TABLE OF CONTENTS

Chapter 1

INTRODUCTION

Over the last decade science education research and policy have undergone several reforms to address the lack of science literacy among American K-12 students (National Research Council [NRC], 1996, 2001, 2007, 2012, 2013). Being scientifically literate is defined as having the competency in science practices and core ideas that enable one to make scientifically sound decisions about the world in which they live (NRC, 2012). One pursuit in science education reform is research that studies the progress of students' reasoning patterns within scientific subject-matter domains. The theoretical framework for these studies on how a person learns has been researched in earnest since the early 1960's.

However, there are variations and continued debates on the beliefs of both learning and teaching (Gess-Newsome, 1999; Zeidler, 2002). More recently, the differing viewpoints on how students learn have crossed into "cognitive learning pathways," (CLPs) which are models that attempt to demarcate and make assumptions about how learners come to understand science (NRC, 2007; Corcoran, Mosher, & Rogat, 2009; Duschl, Maeng, & Sezen, 2011; NRC, 2012). Learning Progressions (LPs) have been well-explored within scientific domains with models being established for evolution, carbon cycling, and water cycling. Some of these pathways are both linear and hierarchical in nature. Researchers assume that people must learn certain concepts before others and that learning is progressive (Gotwals & Songer, 2013; Lawson, Alkhoury, Benford, Clark, & Falconer 2000; Mohan, Chen, & Anderson, 2009).

Research has also supported and refuted the concept of LP models which have been examined extensively in the past decade (Alonzo, 2011; Corcoran, Mosher, & Rogat, 2009; Duschl, Maeng, & Sezen, 2011; Gotwals & Songer, 2013; Metz, 2009; Mohan, Chen, &

Anderson, 2009; Shavelson & Kurpius, 2012). The LP model proposes a link between cognitive development and science content specific subject matter (Gotwals & Songer, 2013; Lawson, Alkhoury, Benford, Clark, & Falconer 2000; Mohan, Chen, & Anderson, 2009). Therefore, according to Ducan and Helmo-Silver (2009), LP models hold the promise of creating a generalizable model that could potentially align curriculum, instruction, and assessment. This, in turn, has encouraged researchers to engage in both exploratory and confirmatory research around LP models. Concurrently, studies exist that are critical of the LP model, arguing against the models' theories about how people make meaning of concepts and learn, citing support in branches of psychology that support learning as distinct, individualistic, and non-generalizable (Metz, 2009; Shavelson & Kurpius, 2012).

Although LP research has primarily focused on better understanding how learning occurs, more recent efforts have moved towards teaching K-12 educators about LPs to help them apply developmentally appropriate assessments. The current theoretical and empirical research on LPs has gathered the attention of national science education organizations such as the American Association for the Advancement of Science (AAAS), the National Research Council (NRC), and the National Science Teachers Association (NSTA). The inclusion of LPs in recent American core science reform documents, namely *The Next Generation Science Standards* (NGSS), *Taking Science to School*, and *How People Learn*, is noteworthy. The same national science education reform documents that promote LPs also set forth the charge for effective professional development for science instructors. Regardless that LPs are indoctrinated in the national science education reform, a lack of focus and substantiated research exists regarding professional development and teacher practice implementing Learning Progressions (Shavelson & Kurpius, 2012).

Starting in the 1980's, Clark & Peterson (1986), Gess-Newsome (1999), and Thompson (1984) studied teacher decision-making on instruction and concluded that teacher belief structures play a major role in a teacher's decision-making in curriculum and instructional tasks. They posited that beliefs, in turn, drive a teacher's behavior and practice. The researchers divided teacher beliefs into two domains: (1) the contextual factors of structure and culture - such as National, State, and local science education reform policies, as well as the district and school culture; and (2) the teachers' personal contextual factors – such as their demographics, content knowledge, and beliefs about students and how students learn. In 2002, Woodbury and Gess-Newsome (2002) constructed the Teacher-Centered Systemic Reform (TCSR) model to explain how contextual factors of a teacher's beliefs drive his/her teaching practices. Making sense of teacher beliefs and their context is critical for teacher educators who design professional development programs because it helps explain how teacher practices are likely to change (or not).

Importance of This Study

Because LP models are increasingly used for advancing research, national standards, and education reform, reassessing these models to validate the currency of approach and validity of methodologies becomes necessary (NRC, 2007; Corcoran, Mosher, & Rogat, 2009; Duschl, Maeng & Sezen, 2011; NRC, 2012). However, no studies, to my knowledge, exist that critically support the justification of LPs over other CLPs. A few studies refute or caution the notion of Learning Progressions as an accurate cognitive model (Metz, 2009; Shavelson & Kurpius, 2012). Shavelson and Kurpius (2012) argue that LPs lack convergent validity and are still at the stage of conjecture. Other studies, such as Metz's (2009) argue that there is a problematic disconnection between LP assumptions about the learner and current psychological theories. Beyond the theoretical validation of cognitive learning pathway models, little research exists on how teachers are informed through professional development on LPs. Specifically, clear linkages between LPs and teacher beliefs have not been established. Therefore, regardless of what CLPs model professional development leaders follow, it is necessary to evaluate the impact of teacher professional development regarding the CLPs to track the impact that it has on student learning outcomes. Because teachers' beliefs play a significant role in driving their pedagogical and assessment choices (Nespor, 1987; Pajares, 1992; Richardson, 1996; Woodbury & Gess-Newsome, 2002; Wallace, 2004), investigations of how teachers interpret LPs and whether or not this construct impacts their teaching practices are informative to science education reform efforts. Therefore, there is a call for more research to critically assess the linkages between CLPs, professional development, and teacher beliefs (Shavelson & Kurpius, 2012).

Research Questions

My dissertation study investigates the relationship between two stakeholders' (LP developers and intended LP users) perspectives about learning and teaching. As LP developers write about how students learn, teachers may hold similar or different views on how students learn, which may affect the implementation and sustainability of LPs (Thompson, 1984; Clark & Perterson, 1986; Nespor, 1987; Pajares, 1992; Richardson, 1996; Woodbury & Gess-Newsome, 2002; Wallace, 2004). Therefore, this study is organized around the following research questions:

1. What are LP researchers' beliefs of how students learn, how to best support learning, and their intentions for the role that LPs can play in supporting learning?
2. What are teachers' beliefs of how students learn, how to best support learning, and the role that LPs can play in supporting learning?
3. What beliefs and intentions do LP developers and intended LP implementers have that are aligned and not aligned?

Definition of Terms

Cognitive Learning Pathways (CLPs) – Piagetian framed models that attempt to align predictive, linear, and hierarchical learner cognition with content matter and instruction.

Epistemology – a branch of philosophy that is concerned with how knowledge can be acquired and the extent to which knowledge can be acquired.

Learning Progressions (LP) – A predictive step-like model of student reasoning within a particular area of science subject matter (Smith, Wiser, Anderson, & Krajcik, 2006, p. 1).

Ontology – A branch of metaphysics that questions and determines the nature of existence.

Science Literacy –Having competency in science practices and core ideas that will enable an individual to make scientifically informed decisions about the world in which they live (NRC, 2012; NGSS Lead States, 2013).

Stakeholder - A person or group that has an investment, interest, or role in something.

Teacher-In-Residence (TiR) – A teacher who participates in a year-long fellowship. In this dissertation study TiR were paid through a National Science Foundation Math and Science Partnership grant awarded to CSU – Teachers assisted with education research and conducting professional development programs for other teachers.

Study Delimitations

The study is delimited by participants of a National Science Foundation funded project led by a lead researcher at a tier one university as well as other partnering tier one universities. The project spanned within the United States. Participants (high school and middle school science teachers) were recruited from California, Colorado, Maryland, and Michigan). A "sister project," funded off another NSF grant-funded project focused more on teacher support. The NSF project in focus attempted to build upon assessments of the LP models from the previous sister NSF project that can more easily be used by teachers. In the NSF project, I was a graduate research assistant working as an assessment technician. My primary advisor Professor Meena Balgopal who was not part of either of these projects. My dissertation study specifically focuses on the eight TiRs who participated in either the NSF projects on LPs.

Positionality Statement

This statement serves as background on how my own beliefs and experiences have shaped my perceptions on how people learn as well as how those perceptions have influenced my view of instruction, educational reform, and research. This statement also serves to expose my choice of methodology and my bias.

As a former high school teacher, outdoor guide, researcher for the NSF sponsored project, and current middle school teacher, I have learned every student brings a unique set of perspectives and experiences to the classroom. As an instructor, I believe students can bring fundamentally different perceptions, ideas, and understanding of how the universe turns, along with culturally situated language use. Therefore, student knowledge is based on a weaving of prior experiences coupled with present exposures of events. From these experiences I believe connecting to students' backgrounds is essential to instruction.

However, the science subject matter I teach is generally based on the belief that the universe is stable and generalizable. Science as a type of knowledge and philosophy is based in part on observable phenomena in which predictable patterns can be found. These patterns in turn are governed by natural laws, laws which can be discovered by systematic observation and experimentation. Another postulate of science is that reality is equally experienced by all observers. It is these beliefs of science compound my teaching in that I teach content material based on beliefs that differ from how I believe learning occurs. I attempt to mitigate the incongruence of these belief systems by commonly taking a more post-positivist stance on the universe, in that reality is a singular event that can only be known imperfectly through individuals differing perceptions and bias. However, I also admit to changing positions and holding a more constructivist belief system in which the view of science has commonalities that are partially shared between individuals amongst realities that are individualistic. In all, I can only confirm that my beliefs are still in flux, but currently switch back and forth between these main assumptions.

In the context of this study, my perspective is that research should inform practice. Having participated in professional development programs in the past I know that there can be a divide between theory and the classroom. Professional development in LPs may have similar divides. The focus of this study is to better identify what beliefs informed the development of LP models and whether these beliefs are shared by teachers who participated in the NSF sponsored project. As my teaching philosophy is centered on the notion that an instructor must be able to understand a student's background to convey knowledge, so then must a researcher have the empathy to understand a teacher to convey theory. I chose to study my peers, practicing secondary science teachers, because I believe that my position as another practitioner of science will allow me insight into the concerns and needs of teachers. Conversely, as researcher I am also able to navigate the context of theory and research. Having these two positions gives me personal insight in both contexts of research producers and research consumers. I do not consider my position as restrictive; rather, I believe that my position will afford me more sensitivity to uncover both teacher and researcher beliefs about student learning.

Chapter 2

LITERATURE REVIEW

Historical Perspective

The lack of science literacy among K-12 students in the past 20 years in the United States has become a major concern in science education (Corcoran, Mosher, & Rogat, 2009; NRC, 2001, 2007, 2013). There are numerous definitions of science literacy within research, but for the purposes of this study, 'science literacy' will be defined as having competency in science practices and core ideas that will enable students to make scientifically sound decisions about the world in which they live (NRC, 2012; NGSS, 2013). While broad, this definition encompasses the majority of national and research views on the topic (Jenkins, 1990; NRC, 1996; Laugksch, 2000; NRC 2000, 2007, 2012, 2013). National and international assessments validate that there is a large disparity in K-12 student science literacy rates among individual state benchmarks in the United States and among other countries (Programme for International Student Assessment, 2010; National Center for Education Statistics, 2011; American College Testing, 2012). Only thirty percent of eighth graders performed at or above "proficient" on the most recent 2009 National Assessment of Educational Progress (NAEP) assessment (NAEP, 2011). The same trend can be seen at grades 4 and 12, by which relatively few students reached grade-specific science proficiency (NAEP, 2011). Similarly, less than one in three high school graduates met the College Readiness Benchmark in Science (American College Testing, 2012). These national indicators are consistent with international findings of the lack of science literacy in the United States. Out of 70 countries, the 10th graders in the United States ranked 14th in reading, 17th in science and 25th in mathematics, according to the Programme for International Student Assessment (PISA, 2010). Thus, most American youth in public schools do not have the content knowledge or skills in science to meet national benchmarks or to compete with other countries on international assessments.

The lack of science literacy among American youth is a critical issue that the country is facing. To underline the relevance of this issue, The National Science Board (2012) reported that there is an aging science and engineering workforce that is drawing into retirement, thereby creating gaps in science occupations that must be filled by the next generation. *The Economic Impact of the Achievement Gap in America's Schools* report from McKinsey and Company (2009) highlighted the significant and negative correlation between educational benchmark disparities and national Gross Domestic Product (Auguste, Hancock, & Laboissière, 2009). Therefore, science reform initiatives at the National and State level have been pushed in an attempt to address the lack of science literacy among United States' youth.

Science education reform. Current science education reform within the United States started with the American Association for the Advancement of Science (AAAS) initiative in 1985, the same year Halley's Comet passed near Earth. During this time, the same children who are in the early years of schooling will potentially see the return of Halley's Comet as it passes again near Earth in 2061. Concerned with how science education can prepare students to make scientifically informed decisions in their everyday life, Project 2061 was initiated (AAAS, 1985; AAAS, 1989). In 1989, one of the initial publications from Project 2061, *Science for All Americans*, defined science literacy and laid a foundation of principles for effective science teaching and learning (AAAS, 1989). The definition AAAS (1989) proposed for science literacy was:

> "being familiar with the natural world and respecting its unity; being aware of some of the important ways in which mathematics, technology, and the sciences depend upon one another; understanding some of the key concepts and principles of science; having a capacity for scientific ways of thinking; knowing that science, mathematics, and technology are human enterprises, and knowing what that implies about their strengths

> and limitations; and being able to use scientific knowledge and ways of thinking for personal and social purposes. (pp. xvii - xviii)"

From research publication to science reform policy, one approach policymakers have taken to address the lack of science literacy of American K-12 students is to advocate, develop, and reform the national science education standards (NRC, 1996, 2001, 2007; Corcoran, Mosher, & Rogat, 2009; Next Generation Science Standards, 2013). While intended to establish a universal state-wide standard, the national science standards may or may not inform state academic standards. For example, Colorado has not officially "adopted" the NGSS, but there are districts that are piloting these standards (Colorado Department of Education, 2013). The National Research Council's *Taking Science to School* (2007) concluded that the United States science standards are contributing to a "mile wide and an inch deep" problem. In other words, previous standards included the paradigm of having broad science content but lack depth and emphasis in the practice of science. In 2009, the Carnegie Corporation of New York's Institute for Advanced Study Commission on Mathematics and Science Education released a report *The Opportunity Equation: Transforming Mathematics and Science Education for Citizenship and the Global Economy*, recommending new national science curricular and practice standards emphasizing the importance of the practice of science inquiry over the memorization of key facts. More recently, the shift towards a stronger emphasis on science inquiry or practices can be seen in the new iteration of the National Science standards framework, which establishes the guiding principles of the *Next Generation of Science Standards* or NGSS (2013). These newer iterations of national science education standards express a more limited number of core science content materials while subsequently emphasizing student engagement in scientific investigations and argumentations than what was shown in previous standards (NRC, 2012; NGSS Lead States, 2013).

Theoretical Perspective

Throughout recent history continued discussions have attempted to address the basic beliefs about learning (Gess-Newsome, 1999b; Zeidler, 2002). A variety of differing perspectives emerged in investigating this field of research. On one extreme, researchers contend that nature and the nature of knowledge is objective, tangible, and singular; while on the other extreme, researchers state that nature and the nature of knowledge is subjective, based on experience, and essentially personal in nature (Burrell & Morgan, 1979; Gess-Newsome, 1999b; Zeidler, 2002).

In some cases, the varying of beliefs of learning and possible conflicts between beliefs of learning has not been fully described in the science education literature (Gess-Newsome, 1999b; Zeidler, 2002). Conflicts in the beliefs of learning have also become prevalent in the National Research Council's *Taking Science to School*, which informs science education instructional practice for K-8 programs. The NRC (2007) expresses incompatibilities with how students learn without explicitly mediating these conflicts. Zeidler (2002) asserted that in the process of seeking common ground towards the goal of effective science instruction, the varying beliefs of how students learn is impeded by the inability to mutually agree on incremental changes to ontological, epistemological, or methodological beliefs. In this divide the social scientists express varying and sometimes conflicting beliefs on learning (Figure 1). Zeidler (2002) implored science education researchers to be aware of this potential divide when developing teacher education courses on instructional strategies. She argued that science educators must be cognizant that there are multiple worldviews and these undoubtedly influence instructional choices that each person makes.

In many cases LP journal articles reference a blended discussion of learning, describing both paradigms that Zeidler presents (Maeng & Sezen, 2011; Gotwals & Songer, 2013; Mohan, Chen, & Anderson, 2009). However, because journal articles may not always reflect the exact perceptions of the authors, interpreting the theoretical stance of LP developers must proceed with caution.

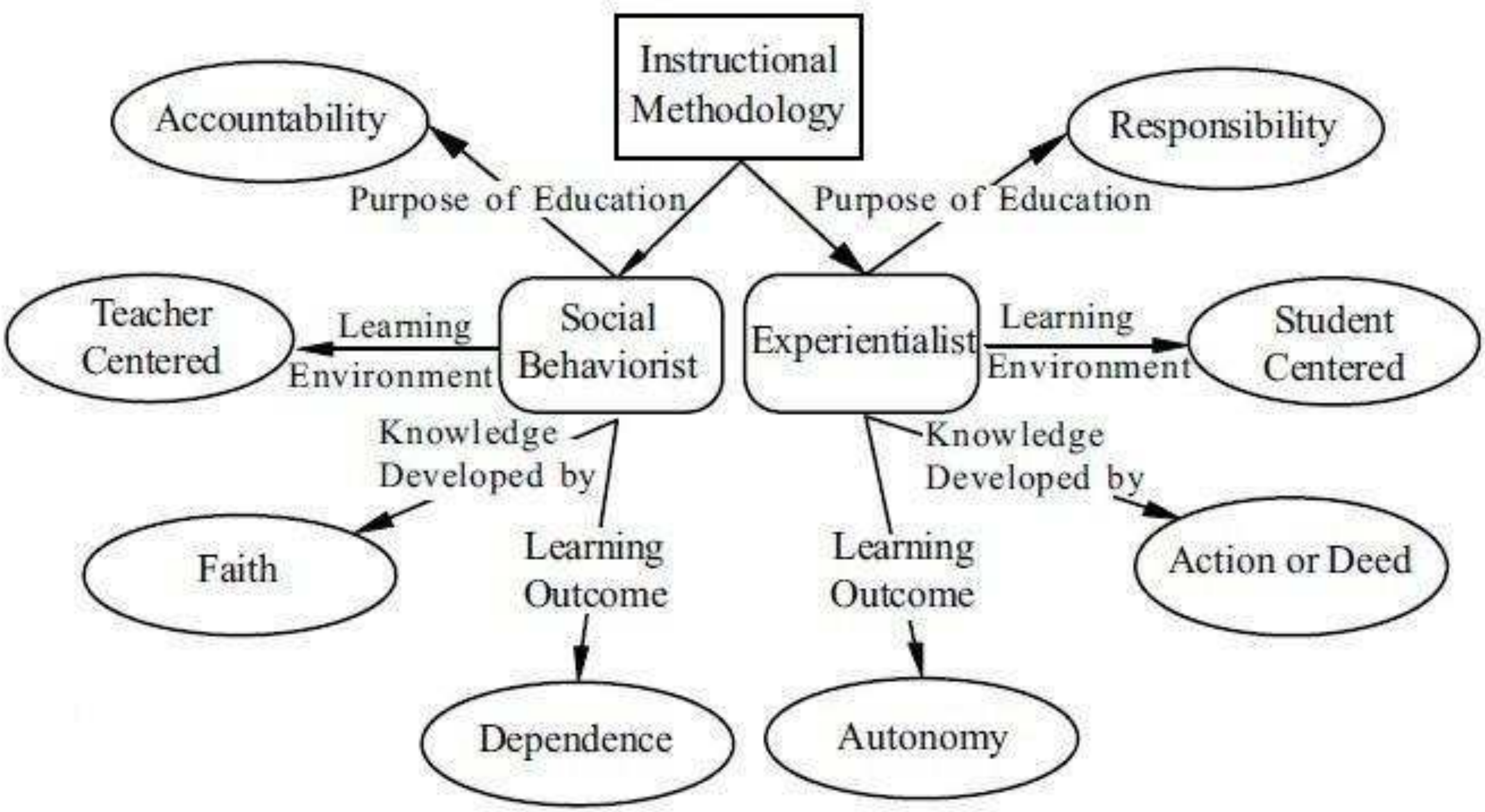

Figure 1. Zeidler's (2002) model of how beliefs about learning can classify science educators as either social behaviorists or Experientialists.

Developmental Theory

At the heart of beliefs about learning are different concepts of how the mind develops knowledge. There has been a continuing debate regarding whether the mind develops in a predictive general unified fashion or in a specific and individualistic manner (Case, 1992; Fischer & Silvern, 1985; Flavell, 1982, 1985, 1992). Developmental psychologist Jean Piaget postulated that a child goes through four general stage-like cognitive development levels (Inhelder & Piaget, 1958). Piaget and Inhelder (1958) characterize human cognitive development in terms of four stages. The first two stages, "sensory-motor" and "preoperational," are generally completed before a child reaches 3rd grade. The subsequent stages, "concrete thought" and "formal thought," generally occur in students in secondary and postsecondary schools (Inhelder & Piaget, 1958). "Concrete thought'' is denoted by individuals who can apply classifications and generalizations on phenomena based on observable criteria, conservation laws, and serial ordering. "Formal thought" is denoted by more complex reasoning patterns including abstract concepts and the ability to establish experimental designs (Inhelder & Piaget, 1958; Karplus & Butt, 1977). Piaget and Karplus assert that individuals can be identified and categorized by the reasoning patterns that they use within any stage of development. Many current researchers have adopted a Neo-Piagetian view that there is a more general continuum of cognitive development (Case, 1997, 1992; Flavell, 1994; Fischer & Farrar, 1987; Metz, 2009). They caution that students may not neatly fall within one developmental category and could exhibit behaviors reflecting multiple stages of development (Inhelder & Piaget, 1958; Inhelder & Piaget, 1964; Karplus & Butts, 1977; Metz, 2009; Gotwals & Songer, 2013).

Regardless of philosophical dispositions, researchers have supported the use of developmental theory to better explain how people learn (Alonzo, 2011; NRC, 2000; Bybee, 2013; Corcoran et al., 2009; Duschl, Maeng, & Sezen, 2011; Gotwals & Songer, 2013; Mohan, Chen, & Anderson, 2009). Developmental theory has been particularly important for framing studies on subject matter learning. Previous studies by David Ausubel (1963), Robert Gagne (1965), Jerome Bruner (1966), and Robert Glaser (1963) are early examples of models that trace and predict student learning within a certain science topic or science subject matter.

More recently, the Piagetian cognitive framework has been both explicitly and/or implicitly used in various content specific assessment models, including both Learning Progression models and Lawson's science concept construction models (Alonzo, 2011; Corcoran et al., 2009; Duschl, Maeng, & Sezen, 2011; Gotwals & Songer, 2013; Lawson et al., 2000; Mohan, Chen, & Anderson, 2009). Within the last decade, this same framework has also become more strongly rooted in our national science education reform. The NRC's *How People Learn* (2000) provides a summary of past cognitive research for understanding conceptual changes in students and discusses implications of learning regarding what we teach, how we teach it, and how we assess it (NRC, 2000). In part, it is this publication by the National Research Council (NRC) that influenced both the NRC's 2007 *Taking Science to School*, the 2012 National Science Standards Framework, and the Next Generation Science Standards (NRC, 2012; NGSS Lead States, 2013). Therefore, the imbedded beliefs of Piagetian developmental theory are contained within our National Science education reform standards and practice.

However, the extent to which we can create predictive cognitive pathway models at various science content resolutions is still debated (Case, 1997, 1992; Flavell, 1994; Fischer & Farrar, 1987; Metz, 2009). In particular Metz (2009) argued that Learning Progressions are based on older cognitive development theories that adhere to a more Piagetian 'stage-like' development of student cognitive growth, which does not reflect the more current psychological development research theories. Metz (2009) also questioned the validity of the assertion that one model can capture the various learning pathways of student cognitive growth across all contexts. This debate can be seen as a conflict in the original incompatible beliefs of the behaviorists and constructivists camps, as asserted by Zeidler (2002).

Cognitive learning pathways and science reform. While the discussion of cognitive developmental theory is still in debate within academia, national policies and standards have more strongly embraced the beliefs of Piagetian Developmental Theory (NRC 2000, 2007, 2012, 2013). One of the explicit goals of the *National Science Education Standards* and the more recent *Next Generation Science Standards* (NGSS Lead States, 2013) is to establish high levels of science literacy in citizens in the United States. Embedded within these standards and policies is notions that learning can occur in a systematic and predictive manner (NRC 2000, 2007, 2012, 2013).A specific example of this is shown in *The Next Generation Science Standards* (NGSS Lead States, 2013) and underlying framework (NRC, 2012) which conceptualize learning as a "trajectory" whereby a student's competence levels might "progress" across grades: "Each discussion describes the practice, articulates the major competencies that students should have by the end of 12th grade ("Goals") and sketches how their competence levels might progress across the preceding grades ("Progression")." (NRC, 2012, p. 49). This notion has ties to Piagetian Developmental Theory (NRC, 2012).

Other national science education reform policies have supported these notions and give justification to the use of a Piagetian cognitive framework to inform curriculum, assessment, and teacher practices (NRC, 2000; Duschl, Maeng, & Sezen, 2011; Gotwals & Songer, 2013; Lawson et al., 2000; Mohan, Chen, & Anderson, 2009). *The Next Generation Science Standards* (NGSS Lead States, 2013) themselves are framed by "Disciplinary Core Ideas" which are logically sequenced science content that students should be able to know by the end of grades 2, 5, 8, and 12. The notion of "Disciplinary Core Ideas" is based on the major goal for students to build and apply science ideas in a coherent manner or progression within each grade. Students would provide information to be used as feedback to modify the teaching and learning activities in which they are engaged" (NGSS, p.7). Bridging formative assessment with science education guidelines and policy, the NRC postulates in *How People Learn* (2000) that effective learning communities are best promoted by four interdependent environmental conditions: learner-centered, knowledge-centered, assessment-centered, and community-centered. Of the four environmental conditions, the assessment-centered environments, which is the focus of cognitive learning pathways - consists of frequent formal and informal opportunities for students to be assessed (NRC, 2000). Through frequent formative assessments, students have opportunities to revise, reflect, and improve their thinking and understanding of a scientific topic. In turn, the teacher can better guide students to think more deeply about science-related issues (NRC, 2000).

The NRC (2007, 2013) asserted the need for better alignment among assessment, curriculum, and instruction grounded in common core beliefs about cognition and learning within the subject domain (NRC, 2007). These beliefs about cognition and learning have informed the development of cognitive learning pathways which are models based in part on developmental theory that attempt to make predictive, linear, and hierarchical cognitive pathways on how a learner understands a particular science concept. In this regard, cognitive learning pathways attempt to provide a tool in which to satisfy the charges set forth in the United States recent science reform policies to better align assessment, curriculum, and instruction (NRC 2007, 2013).

Learning progressions. One cognitive learning pathway that has become prominent in the recent education reform policies is the "Learning Progression" model. Learning Progressions (LPs) are descriptors of increasingly complex ways of understanding within a given topic (NRC, 2007). LPs are "successively more sophisticated ways of reasoning within content domains that follow one another as students learn" (Smith et al., 2008, p.1). Generally, an LP model will be designed to use student force responses on formative and summative assessments that in turn can be used by an instructor to guide instruction (Corcoran et al., 2009, Duncan & Hmelo-Silver, 2009; Mohan et al., 2009; Smith et al., 2006). LPs of student learning are relatively new and still warrant more empirical validation (Corcoran et al., 2009; Duschl, Maeng, & Sezen, 2011; Duncan & Hmelo-Silver, 2009; Shavelson & Kurpius, 2012). LPs share strong similarities with older behaviorist constructs, which emphasize assessing and strengthening student's knowledge over time. Examples of previous models that share similarities with LPs would be Bruner's (1960) spiral curriculum, Brown and Campione's (1994) development corridors, and Carpenter and Lehrer's cognitively guided instruction (1999).

However, LPs as a conceptual model have become more popular within the field of assessment, notably due to the works of Kennedy, Brown, Draney, and Wilson (2005). Kennedy (2005) and colleagues studied progress variables that provided a common basis for interpreting students responses to formative and summative assessment measuring student progress over time. The study's data came from thirteen California middle schools in the 2003-2004 school year. The study concluded that progress variables can be used to guide the development of assessment activities that, in turn, can inform teacher practice.

As a pedagogical tool, LPs can inform formative assessment, during which an instructor can gauge students' levels of understanding within a particular science topic (Corcoran et al., 2009). Therefore, LPs serve multiple functions. One of these functions is the potential to monitor students' written display of understanding within a particular science topic. Another function is to provide a pedagogical framework for teachers to align curriculum to cognitive development levels (Corcoran et al., 2009, Duncan & Hmelo-Silver, 2009; Mohan et al., 2009; Smith et al., 2006).

Concurrently, there has been a strong push from national initiatives to create stronger linkages between science curriculum, instruction, and assessment, giving greater reason and justification to develop LPs. Specifically, the LP model has become embedded in policy and standards from three noteworthy US national science education initiatives: *Systems for State Science Assessments* (NRC, 2005), *Taking Science to School* (NRC, 2007), and NAGB's revision of *National Assessment of Educational Progress* (NAEP) Science Framework (NAGB, 2008; Corcoran et al., 2009; Duschl, Maeng, & Sezen, 2011). *Taking Science to School* (NRC, 2007) emphasizes the importance of well-grounded Learning Progressions as a tool to align assessment, curriculum, and instruction. Duncan and Hmelo-Silver (2009) agreed that LPs can promote dialogue among science education researchers and curriculum developers in joint science education reform efforts.

The rising prevalence of the LP models within both research and policy has generated controversy, as research groups question the validity and grounding of LP in empirical evidence (Metz, 2009; Shavelson & Kurpius, 2012). Even proponents of LP caution their widespread use and argue that most Learning Progression models are early in development with little supporting student data. These claims are based more on conjecture than strong empirical support (Shavelson & Kurpius, 2012; Duncan & Hemlo-Silver, 2009; Duschl, Maeg, & Sezen, 2011).

Moreover, the driving educational reform policies explicitly state the limitations of LPs and their inability to capture all the varying cultural learning histories of students (NRC, 2007).

> "Finally, no single Learning Progression will be ideal for all children, since they have different instructional histories, bring different personal and cultural resources to the process of learning science, and learn in different social and material environments. The best Learning Progressions are those that make effective use of the resources available to different children and in different environments. This is the challenge that we are farthest from responding to effectively with the current research base…we would like to describe children's knowledge and practice in ways that help us to see the continuities—and the discontinuities—between the reasoning of children of different ages. Inevitably, these descriptions must fail in some way; no organizational scheme can fully capture the organization of a child's knowledge or its connections. (p. 222)"

The research atmosphere surrounding the topic of Learning Progressions can be best summarized by Duschl, Maeg, and Sezen's (2011) notion of Kuhn's "crisis" activity associated with the emergence of a new paradigm. During the initial stages when a new theoretical framework is proposed, conflicting perspectives arise and compete until the community settles on a new paradigm. Ziedler (2002) noted these conflicts stem in part from the presently insurmountable differences in epistemological beliefs of behaviorists and constructivists within science education research.

Teacher beliefs and practice. Teacher practice is guided by constructs which lie within the domain of social cognitive theory (Bandura, 1994, 1997. 2003). One such construct is the self-efficacy theory pioneered by Bandura (1994) which asserts that teacher beliefs drive behaviors, which in turn drives teaching practices (Bandura, 1994, 1997, 2003; Richardson, 1996). Self-efficacy is the belief in the ability to successfully complete a task under specific conditions (Bandura, 1994, 1997). Bandura theorizes that belief in the ability to complete a task (self-efficacy) is necessary and fundamental for completing a desired action. Several studies have proposed links between self-efficacy to a teacher's epistemology, or beliefs about how a student learns (Schraw, Crippen, & Hartley, 2006; Yilmaz-Tuzun & Topcu, 2008). Parallel to these notions, is another growing body of research that further connects teacher beliefs, including self-efficacy to instructional choices and practices (Nespor, 1987; Pajares, 1992; Richardson, 1996; Wallace. 2004). Nespor (1987) asserted that teachers rely on their belief structures rather than their content knowledge when teaching. Similarly, Pajares (1992) concluded that beliefs strongly guide an individual's decision-making regarding instruction. In summary, these theories support the notion that a teacher's self-efficacy is linked to his or her epistemology and, therefore, linked to behavior which, in turn, impacts instructional practices (Bandura, 1994, 1997, 2003; Richardson, 1996; Woodbury & Gess-Newsome, 2002; Crippen, & Hartley, 2006). In an effort to align teacher beliefs and practices, Woodbury and Gess-Newsome (2002) developed the Teacher-Centered Systemic Reform (TCSR) model. This model combines three overarching frameworks: (a) the general context of reform, (b) the personal contexts of a teacher's beliefs, and (c) the structural contexts of a teacher's beliefs to help frame research on science teacher practice. Under the TCSR model, teachers' beliefs are built upon personal and structural contexts (Woodbury & Gess-Newsome, 2002). Personal contexts include: (a) constructed knowledge of the subject matter, (b) feelings, (c) subjective evaluations, and (d) presumptions about how students learn. Structural contexts include the science culture surrounding the teacher, which is shaped by national, state, district, school, and classroom influences (Nespor, 1987; Woodbury & Gess-Newsome, 2002). Within the TCSR model, a teacher continually interacts and compromises between their personal context beliefs and their structural context beliefs and the results of these compromises are ultimately disclosed throughout a teacher's practice. Teacher actions represent only one façade of a teacher's structural beliefs system. What a teacher actually acts upon in the classroom is just one representation of their beliefs (Woodbury & Gess-Newsome, 2002; Figure 2). The TCSR model importantly connects teachers' knowledge and beliefs about how a student learns to his or her instructional practice (Fennema et al., 1996; Peterson, Fennema, & Carpenter, 1991; Woodbury, 1997; Woodbury, 2004). More broadly, the TCSR model creates a dynamic, multifaceted model of the interactions that shape teacher practice and, ultimately, educational reform.

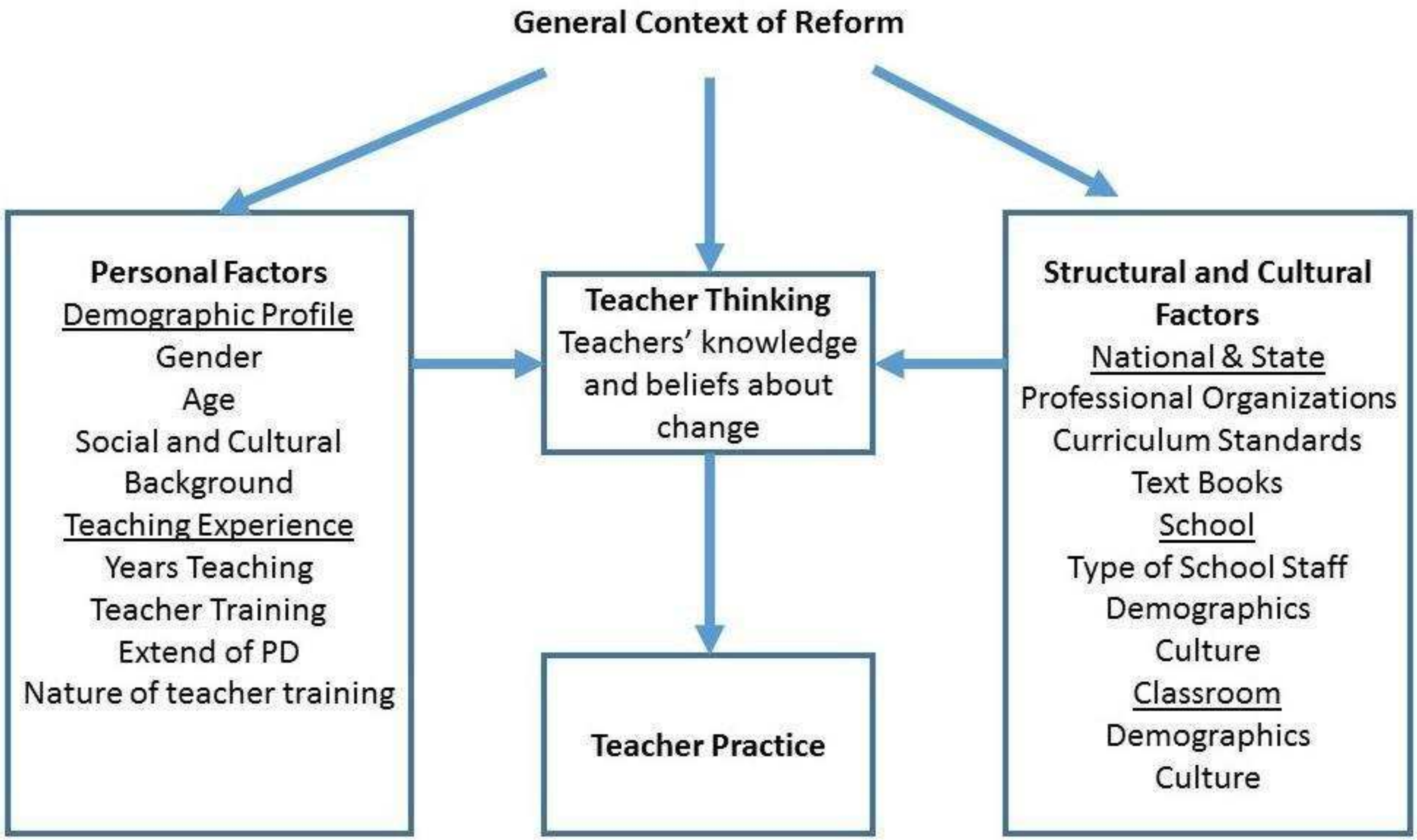

Figure 2. The Teacher-Centered Systemic Reform Model (Woodbury & Gess-Newsome, 2002).

Recent empirical evidence suggests that teachers can also have varying beliefs about learning (Woolley & Woolley, 2004). Pajare (1992), Richerson (1996), Wallace (2004), and Woodbury and Gess-Newsome (2002) argued the importance of researching teacher actions as well as their beliefs in order to understand the influences that guide teacher practice. However, little research has tackled the impact of possible conflicts between LPs beliefs on how learning occurs and teacher beliefs on how learning occurs. The question that emerges for me is that if such conflicts arise, how then is this reconciled in a teacher's thought process and subsequent teacher practice?

Proposed Theoretical Model

In light of what is known about teacher beliefs and practice in school contexts and the current science education reform efforts to develop and test LPs, I have simplified the TCSR model and nested it within the larger context of cognitive learning pathways (Woodbury, 2002). Because the implementation of assessments developed as parts of LP models may either challenge or support teachers' ideas about learning, this construct impacts the personal contextual factor (Figure 3). However, because LPs are embedded in current science education reform documents, they also impact structural and other contextual factors.

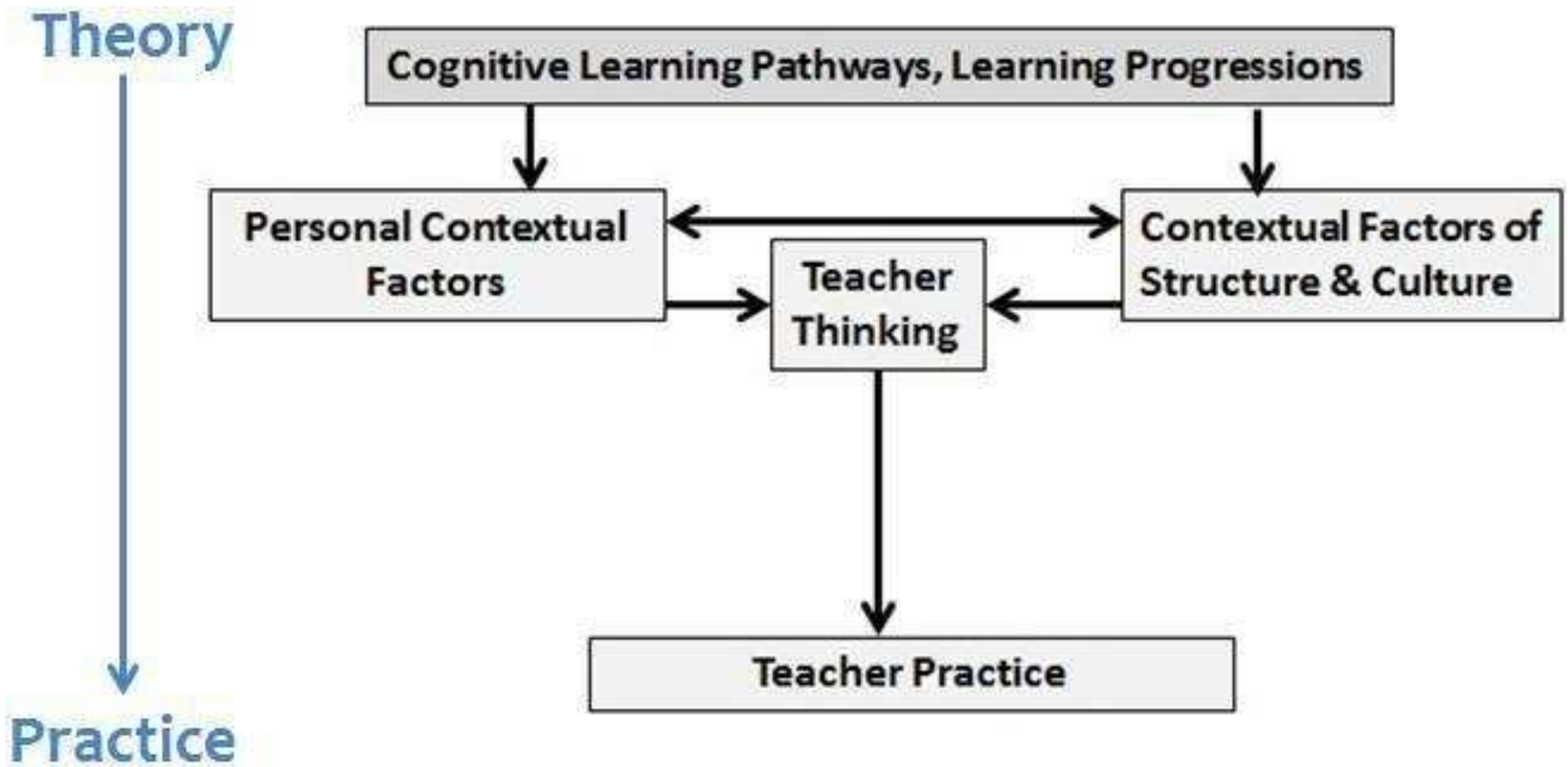

Figure 3. The Teacher-Centered Systemic Reform Model with the addition of learning pathways as influencing a science teacher's personal and structural cultural contexts.

Therefore, I intended to investigate the relationship between LP developers and teacher perspectives about learning and teaching, as it impacts teacher practice. As Woodbury and Gess-Newsome (2002) explained, the TCSR model provides a template for analyzing the observed effects of a particular reform effort, which in this case is the implementation of LPs. To accurately understand the effect of this reform, it becomes important to identify and measure the various contextual factors that may influence teacher beliefs about the reform effort. The TCSR model provided a framework that can inform researchers as they collect data to evaluate theory as it is translated to practice.

Chapter 3

METHODS

Research Design and Rationale

The current dissertation study uses a multiple methods design to answer questions about the rationale used to develop LPs and how LPs inform teachers' practice. I am interested in beliefs on how people learn as held by LP developers, and those teachers who have participated in LP professional development experiences. These two stakeholders may hold similar or different beliefs on how students learn, which in turn may affect the implementation and sustainability of the LP model, an argument established previously in professional development literature (Thompson, 1984; Clark & Perterson, 1986; Nespor, 1987; Pajares, 1992; Richardson, 1996; Woodbury & Gess-Newsome, 2002; Wallace, 2004). The ultimate goal then of my study is to describe the relationship between two stakeholders' (LP developers and intended LP users) beliefs about learning and teaching.

This dissertation study is organized around these three research questions:

1. What are LP researchers' beliefs of how students learn, how to best support learning, and their intentions for the role that LPs can play in supporting learning?
2. What are teachers' beliefs of how students learn, to best support learning, and the role that LPs can play in supporting learning?
3. What beliefs and intentions do LP developers and intended LP implementers have that are aligned and not aligned?

As LP models are one attempt to promote and satisfy recent national science education reform, this study seeks to provide insight on how LPs are interpreted and translated into practice. As LP models are still in relative infancy, using an instrumental case study method is an appropriate approach to illuminate important characteristics, such as the belief systems of researchers and teachers regarding the LP model.

The intent of this study was to gain insight into the beliefs that researchers and teachers have on learning and instruction and how these, in turn, may affect the implementation of LPs. In this regard, Stake (1995) suggested that an instrumental case study is informative when the "case" may play a secondary role to the phenomena presented. In this case, the LP model may be of less importance than the beliefs of learning and teaching that researchers and teachers may have.

In my study, each research question was examined in a similar, methodical manner. To answer the first research question, I conducted a thematic analysis of interviews, which allowed me to interpret how LP developers describe how people learn about carbon cycling, how to support learning (through teaching) about carbon cycling, and their intentions on how the LP can be used by teachers. To answer the second research question, I examined teacher perceptions after collecting interview data and conducting thematic analysis of transcripts. The third research question allowed me to compare holistically the findings from the first two research questions and, in the process, describe whether there was alignment or nonalignment of how LP developers and intended LP implementers used language to describe learning and teaching about carbon. All data analyses were grounded in Yin's (1981) and Stake's (1995) instrumental case study methodology and thematic analysis was employed to organize and interpret transcript data (Table 1). This study does not attempt to generalize the results to other LP-professional development programs; rather, provide insight into the relationship between LP models and teachers' perceptions about how students learn content in a particular context.

Table 1.

Research Questions, Data Analysis, and Types of Data Collected to Answer Research Questions (RQ)

Research Question	Data Analysis	Type of Data
1. What are LP researchers' beliefs of how students learn, how to best support learning, and their intentions for the role that LPs can play in supporting learning?	Thematic Analysis	Interviews, published peer-reviewed articles, grant proposals
2. What are teachers' beliefs of how students learn, to best support learning, and the role that LPs can play in supporting learning?	Thematic Analysis	Interviews, instructional materials used to teach LPs, assessments
3. What beliefs and intentions do LP developers and intended LP implementers have that are aligned and not aligned?	Thematic Analysis	Interviews, and teacher- or researcher-produced artifacts used for RQs 1 and 2.

Participants and Site

An LP model was developed as part of a multi-institution National Science Foundation (NSF)-funded grant. The NSF-sponsored project goal was to assess 6th through 12th grade students and teachers on their understanding of environmental science constructs. Participants were recruited from the following Long Term Ecological Research (LTER) network sites: the Santa Barbara Coastal (SBC) LTER in California, the Shortgrass Steppe (SGS) LTER in Colorado, the Kellogg Biological Station (KBS) LTER in Michigan, and the Baltimore Ecosystem Study (BES) LTER in Maryland. The project's goals, as defined by three science content areas (strands), were: *carbon*, *water*, *culture*, and *biodiversity*. Each strand developed its own LP. The NSFsponsored project LP was developed by a group of researchers, the majority of whom are content experts in environmental science and ecology at research institutions (universities and one center for ecological study) across the U.S. The current dissertation study centered solely on the *Carbon* learning progression.

Carbon learning progression. My dissertation study focused on the "Carbon Strand's" development of and intended implementation of the *Carbon* LP model (Mohan et al., 2009). LP researchers working on the carbon LP worked to describe predictive pathways of 8th-12th grade students' understanding of carbon-transforming processes in socio-ecological systems across multiple spatial scales. However, the researchers drew on elementary students' (grades 4-7) accounts of carbon cycling processes, as well, to help them construct a more comprehensive LP for secondary students. This involved an iterative process of gathering formative student assessment data, conducting student interviews, and then developing teaching materials based on the LP model (Mohan et. al., 2009). Science content in the *Carbon* LP centers on processes that include: (a) creating organic carbon (photosynthesis), (b) transformation of organic carbon (biosynthesis, digestion, food webs, and carbon sequestration), and (c) oxidizing organic carbon (cellular respiration and combustion) (Mohan et al., 2009). The *Carbon* LP framework describes students' learning in terms of four levels of achievement.

> *Our Lower Anchor—Level 1—describes the reasoning typical of upper elementary middle school students in our samples.*
>
> *Two intermediate levels— Levels 2 and 3—describe the reasoning we see in most current middle school and high school students.*
>
> *The Upper Anchor—Level 4—describes the reasoning we hope to see in environmentally literate high school graduates* (researcher participant and colleagues, 2010, p. 4).

Each level of achievement is determined by the students' language choice/use and description of carbon transforming processes. At level 1, students describe carbon cycling in terms of "actors" and "enablers," anthropomorphizing how carbon transforms from inorganic to organic forms. Level 2 and Level 3 student responses include notions of "actors" and "enablers" but also attempt to trace matter and energy through different biological and environmental scales. Level 4 student responses remove language use of "actors" and "enablers" by directly discussing components of energy inputs and outputs along with directly traces the transformation of energy and matter through the carbon cycle. Level 4 student responses include the factors of socio-ecological systems that play a role in the carbon cycling process (Table 2).

Table 2.

The Four Levels of Coding in the Carbon Strand LP Model (Mohan e al., 2009)

Level	Enablers or Inputs	Actors and Settings or Systems	Results: Purposes or Products
Level 1: Lower anchor, elementary starting point	Needs or enablers	Abilities or powers of actors Settings for events	Achieving purposes or goals of actors
Level 2: Principle based, elementary goal	Different kinds of enablers: - Materials (solid, liquid, gas) - Energy sources - conditions	Abilities of actors plus internal structure (organs, cells) and movement of materials and energy through settings and actors	Material products - gas-gas cycles - growth as matter moving into bodies Energy products
Level 3: Principle based, middle school goal	Material inputs, distinguishing organic from inorganic materials Forms of energy, including chemical energy (C-C and C-H bonds)	Movement of materials through systems at multiple scales Living systems made of organic materials	Changes in matter obeying conservation laws Transformation and degradation of energy
Level 4: Upper anchor, high school goal	Material inputs with specific chemical identities Energy inputs	Movement of atoms in molecules through systems at atomic-molecular to large scale scio-ecological systems	Material products tracing atoms between inorganic and organic forms Transformation and degradation of energy

A central theme in the LP model is linking these processes to global climate change as a human-induced imbalance that causes higher inorganic carbon to be emitted into the atmosphere (Mohan e al., 2009). Duschl, Maeng, and Sesen's (2011) review of LPs described the *Carbon* LP model as an effective example of a learning progression that is a cognitive learning pathway generally accepted within the science education research community (Alonzo, 2011; Duschl, Maeng & Sezen, 2011). The *Carbon* LP was chosen for this study, as it was the most researched and cited of the four strands at the time of my study.

LP teaching experiments. After the development of the LP model, the researchers designed instructional materials with the intention of helping students move towards level 3 and 4 responses on assessments. The building of instructional tools followed specific principles: (i) conservation of matter, (ii) conservation of energy, (iii) entropy, and (iv) scale. The instructional tools were built into instructional interventions that were repeated across multiple lessons. An example of a lesson is one that directs the student to use digital balances to measure the change of mass of a cup of crickets over a period of 1-2 days without feeding the crickets. The students are meant to discover that the mass decreases over time, and in this manner, students explore where the mass has gone (Figure 4; Mohan, et al., 2009).

Example of Digital Balance Activity

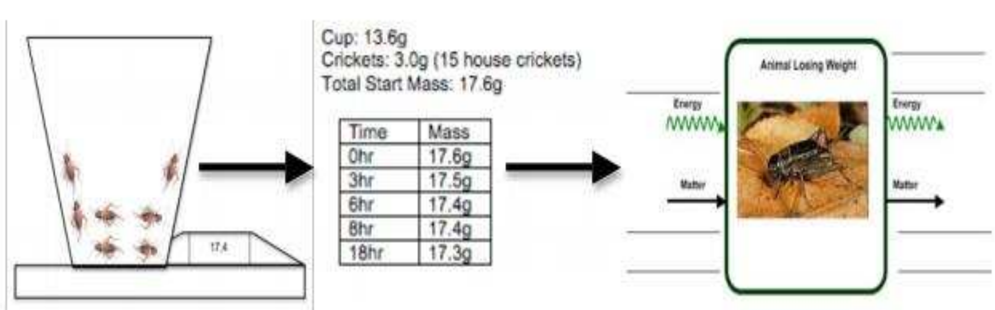

Figure 4. A diagram of the digital balance activity developed for the carbon strand LP.

Another lesson developed for the *Carbon* LP revolves around the hierarchy of scales, whereby students use the powers of ten to reason through carbon cycling processes at different scales. The powers of ten concept refers to exponential thinking. The Eames brothers (Ray and Charles) created a film to help viewers visualize scale from the subatomic to the cosmic levels (http://sciencenetlinks.com/tools/powers-of-ten/). To support the Carbon LP, researchers ensured that the Powers of Ten concept was built into several classroom activities, including one when the students can watch the Eames Brother's Powers of Ten DVD (Mohan, et al., 2009). The teacher uses a three foot by four-foot wall chart to locate carbon transforming processes using the powers of ten (Figure 5) (Mohan, et al., 2009).

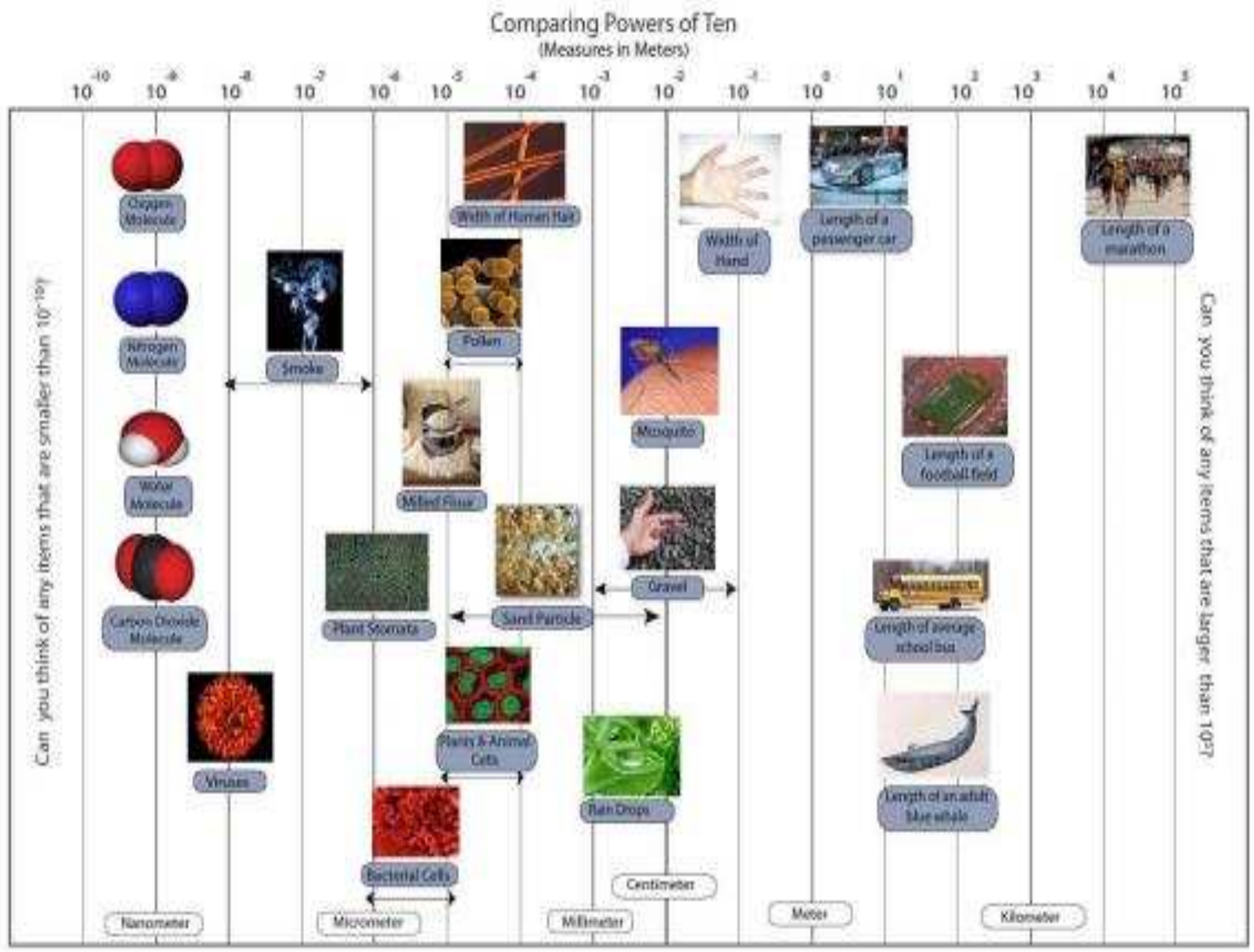

Figure 5. Powers of Ten classroom chart.

The *Carbon* LP research group developed presentations that incorporated the powers of ten concept to explain the different scales of carbon transforming processes. One example includes asking students to examine a flame in three different scales (Figure 6; Mohan et al., 2009).

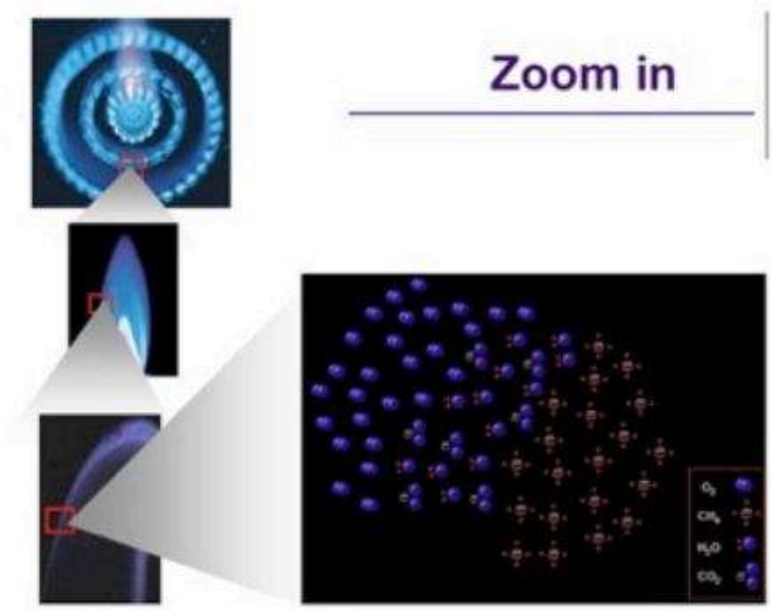

Figure 6. Powers of Ten presentation on different scales on a flame.

The chemical change that shows a flame as the combustion of methane is then examined by students (Figure 7). With these instructional materials, the intent is for students to discuss why a flame is a mixture of gases at the atomic-molecular level. Hence, the development of the Carbon LP informed the curricular material development.

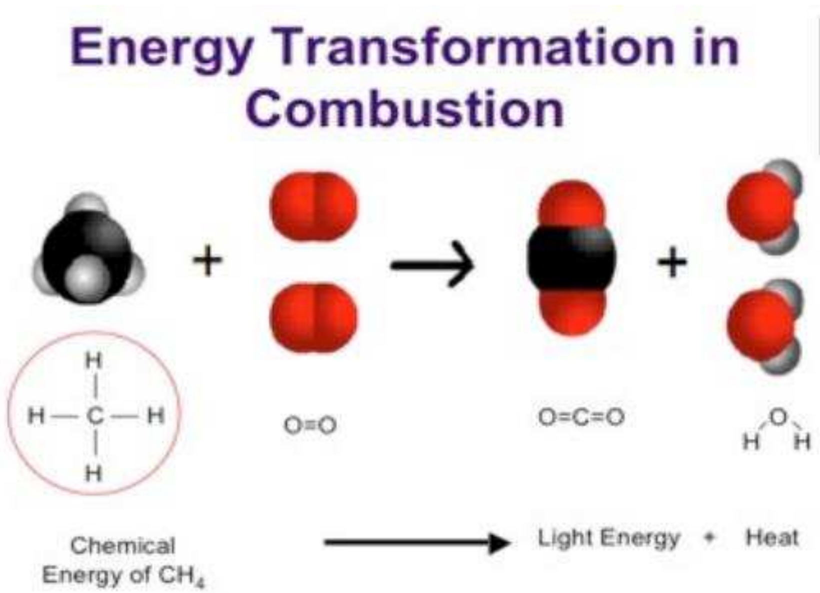

Figure 7. Powers of Ten presentation example on the combustion of methane.

Researchers. The researchers for this study include the majority of the principle investigators of the original NSF-sponsored grant, along with key researchers associated with the LTER Network. Most of the researcher participants hold leadership positions within their respective academic departments and/or are in senior tenured positions within a research university. Collectively, the five researcher participants had over 140 years of experience in the academic research at the time of this study.

Individual Researcher Narratives. The following are brief descriptions of each of the participating researchers in this study. Each of the researchers were given a pseudonym. David – is a senior tenured professor at a tier one state university and has over 38 years' experience in academia. David's college background includes post-secondary degrees in the natural sciences, while he is currently investigating topics in science education. Josh – is a department head and has over 30 years of teaching in experiential education and post-secondary education. In his 30 years of teaching, he also has 8 years teaching within the K-12 system. Ethan – is a department head within his program and has over 40 years teaching - including leadership roles in teaching professional development courses to new and veteran science teachers. Jacob – holds a tenured leadership position within a tier one state university and has a 30 years of teaching experience. Jacob's formal post-secondary education is in the natural sciences. Samantha – was a researcher on the NSF sponsored project and has a background in science education.

Teachers. The Teaching-in-Residence (TiR) component of the project was a strategy to provide intense professional development training to in-service teachers. The TiRs are involved in research activities but were primarily charged with bridging research to practice. In this NSF-sponsored project, the TiRs were expected to implement LP-informed curriculum and assessment into their respective classrooms and to be an ambassador for these models. The TiR component is based on the project group's prior research, which identified an alternative approach to teaching – one that emphasized core scientific principles and how to teach those principles using conceptual change models (Hollon, Roth, & Anderson 1991; Smith, Blakeslee & Anderson, 1993: Kang & Anderson, 2009; Windschitl, 2004; Windschitl, Thompson, & Braaten, 2008). The NSF sponsored project's professional development instruction model included key strategies of (a) building formative assessments and tools for teaching practice, (b) teaching science content and discourse appropriate for students' level of achievement, and (c) engaging students in modeling science practices. These key strategies informed the project's four-tiered design approach:

1. Engage teachers to use scientific models and principles to explain as well as predict carbon-transforming processes at multiple spatial scales as well as promote in classroom scientific discourse and augmentation based on evidence.
2. Introduce and guide teachers to use the project's LP framework and underlying assessments.

3. Introduce teachers to formative assessment tools and suggest ways in which they can change instructional practices based on students' performance on formative assessments.
4. Train teachers to use tools for reasoning, modeling, and scaffolding student learning of environmental science literacy content and practice.

Based on the NSF sponsored project's accepted proposal and professional development (PD) documents, the TiRs were tasked with various roles throughout the five-year span of the project. Each of the participating research sites' TiR program could accommodate up to two teachers per year with a stipend of up to $50,000. TiRs for the first year of the project were tasked with data collection of written instruments and targeted interviews with students to help gather empirical data to refine the project's LP model. Year Two TiRs, which included either continuing or new teachers, were tasked with establishing workshops and discussions on previously collected data that would help them understand the results of the LP assessments and help in the development of teaching materials. The resulting teaching materials used common frameworks based on LP research results and adapted to each research site's local cultures and ecosystems. In Year Three of the project, the TiRs were continually tasked with taking a lead in conducting teacher experiments at each site based on pre- and post-assessment data of student responses. Year Four TiRs guided the revision of teaching materials on LPs as well as assisting in the data analysis of student data to provide empirical validation of the LP. Year Five TiRs assisted in publishing LP frameworks, assessments, and teaching resources. All TiRs also participated in a two-week summer workshop on LPs. Considering the project's professional development model and the expectations of TiRs, an evaluation of the perceptions and beliefs of the TiRs regarding LPs can inform future professional development projects on student learning and their respective sustainability.

The participants of my dissertation study will include five TiRs who all teach in the local school district, Poudre School District (PSD), and who were a part of the LP project's Colorado research site. PSD is located in Fort Collins, Colorado and serves approximately 27,000 students and 1,400 teachers in 50 different schools, making it the 9th largest school district in Colorado. PSD employs a "school choice" program, whereby families can select which schools their children attend, based on space availability. As of Fall 2015, student demographic PSD records show that the student population can be classified as 74.31% Caucasian, 17.93% Hispanic/Latino, and 7.76% other ethnicities. One third of the student population receives free or reduced lunch (FRL) and 7.55% are labeled as English Language Learners (ELL) for whom English is not a first language.

The TiRs included both middle school and high school teachers of which eight participated through the Colorado research site. Of the eight TiRs, five were interviewed for this research. The teachers all identified as Caucasian. The TiRs self-selected into the NSF sponsored project based on a recommendation from their respective school administration. Selected TiR were given a full-year stipend to assist in the NSF sponsored project's various research tasks, which included: formal training on the Project's Carbon Strand research and teaching the Carbon LP to other PSD teachers.

Individual teacher narratives. The following are brief narratives for each of the five TiR participants. Each teacher was given a pseudonym name. Preston – is a veteran middle school and elementary school teacher with over 10 years of instruction within the Poudre School District of Colorado. He also has research experience from Florida International University based on an NSF funded project that incorporated a Research Experience for Teachers (RET) program. He was a TiR for the project for one year. Blake – is a middle school teacher and has been an educator for over 17 years. Before teaching in a K-12 environment, Blake was a civil engineer. He currently is the science department head in his associated school. Ashley – has a background both as a teacher and as a researcher in the field of science. She has taught for over 25 years as a middle school and current high school science teacher, 20 of those years within the Poudre School district. Ashley also extended her TiR grant for two years within the NSF sponsored project. Harper – is a middle school science teacher with 13 years of teaching experience. She has non-traditional teaching experience coming from the private industry as a scientist. Harper was a TiR for one year. Brian – Is a recently retired high school science teacher with over 30 years of experience. Most of Brian's teaching experience was at the same high school within Poudre School district. Brian was a TiR for one year.

LP Developer's Language Use in Describing Learning and Teaching of LPs

Research Question (RQ) One was addressed by conducting interviews with the principle investigators and research developers of LPs on the NSF sponsored project. Interviews were coupled with analyzing the project's written documentation of LPs, published peer-reviewed articles of researchers who were a part of the project, as well as any written products of the project that were intended for teachers. Data from both LP interviews and the written documents were thematically analyzed. The details of both the data collection and data analysis are described in more detail in the following paragraphs.

Data collection. Data were collected through semi-structured interviews with the five former principle investigators (PI) for the NSF-sponsored LP project. I invited each of the five PIs via e-mail or phone to participate in my dissertation study. Each PI also received an e-mail with a voluntary participation letter that informs him/her of the study, their rights as a participant, and contact information (Appendix A). Other PI recipients were blind copied on the recruitment email.

The interviews with PIs were audio-recorded using a digital recorder and subsequently transcribed for analysis. Because there were only five interviewees there was concern that individual researchers may be identifiable. Therefore, all efforts were made to exclude mention of any personal information that is well-known about each individual. In addition, I excluded any mention of the institution at which the PIs work. During the interview, I explained to the PIs the purpose of the study. Interviews occurred either on the CSU campus or over the phone, depending on the convenience of the participant. Although, all interviews were audio-recorded. The interview questions were based on a modified version of Luft and Roehrig's (2007) "Teacher Belief's Interview (TBI)." TBI questions were modified to reflect the position of the researcher, which differs from a position of a teacher:

1. How do you believe that student learning can be maximized in a classroom?
2. How would you describe the role of a teacher?
3. How do teachers know when their students understand?
4. Pretend you are a K-12 science teacher, how would you decide what to teach and what not to teach?
5. Again, pretend that you are a K-12 science teacher, how would you decide when to move on to a new topic in your classroom?
6. How do students learn science best?
7. How would a teacher know when student learning is occurring in his/her classroom?
8. How can assessments of learning help teachers inform what they teach?

The interviews also included guiding questions regarding how the researcher defines LPs, do LPs support learning, and what was the role of TiRs in the LP project. The interviews allowed time for the interviewee to make additional comments on science teaching or on the NSF sponsored project as a whole. It was anticipated that the entire interview would take about one hour to complete. In actuality the interviews lasted approximately 40 minutes for the shortest duration to over one hour and 20 minutes for the longest duration.

All interviews were digitally audio-taped and stored on my personal computer. The interview questions from the researcher participants were triangulated with documents developed for the NSF sponsored LP project as well as written products made during and after the NSF sponsored LP project. Documents analyzed in this manner included the original NSF sponsored LP proposal and published peer-reviewed articles made as a product of the NSF sponsored LP project.

Data analysis. This study followed Luft and Roehrig's (2007) TBI protocol, which categorizes teachers' beliefs into five domains: traditional, instructive, transitional, responsive and reform-based (Table 3). Traditional and instructive domains define the interviewee's responses as teacher-centered instruction and the knowledge of science as objective, fact-based, and universal. On the other end of the spectrum, responsive and reform-based domains define the interviewee's responses as student-centered beliefs that have the characteristics of science being defined in a cultural and social context that is individualistic. Finally, the transitional domain defines the interviewee's responses in which knowledge of science is still objective, but instruction is dynamic and based on affective but not necessarily the cognitive attributes of students. These domains are similar in nature to previous research on belief systems (Ernest, 1989). Note that the TBI is not designed to compartmentalize a person into discrete belief categories; rather, the TBI was developed to place people's belief systems along a spectrum or continuum of epistemologies.

Table 3.

TBI Categories of Teacher Beliefs (Luft & Roehrig, 2007)

Category	Example	View of Science
Traditional: Focus on information, transmission, structure, or sources	"I am an all knowing sage" "My role is to deliver information"	Science as rule or fact.
Instructive: Focus on providing experiences, teacher-focus, or teacher decision.	"I want to maintain a student's focus to minimize disruptions" "I want to provide students with experiences in laboratory science"	
Transitional: Focus on teacher student relationships, subjective decisions, or affective response.	"I want a good rapport with my students, so I do what they like in science"	Science as consistent, connected, and objective.
Responsive: Focus on collaboration, feedback, or knowledge development.	"I want to set up my classroom so that students can take charge of their own learning"	Science as a dynamic structure in a social and cultural context.
Reform-based: Focus on mediating student knowledge or interactions.	"My role is to provide students with experiences in science which allows me to understand their knowledge and how they are making sense of science."	

I coded each researcher interview. During the process of coding the interviews I created notes that summarize the beliefs of the interviewee and then compared these notes with the TBI categories of teacher beliefs. Each question on the interview was coded in this manner. A second researcher was responsible for coding a 20% overlap of interviews in an effort to determine the level of agreement between the two coded datasets. This helped established an interrater reliability. If sections of the coded datasets were not in agreement, then both the previous coders re-visited the coded section, discussed the discrepancies, and reached agreement. Once the codes were determined and efforts made to increase reliability, the researcher codes and responses were merged to create a belief profile of the interviewee.

A thematic analysis is defined as a method for identifying, analyzing, and describing patterns within data (Braun & Clarke, 2006). While thematic analysis can be similar to other coding methods such as grounded theory, the method itself does not strictly subscribe or require implicit theoretical commitments; rather, the term is used to refer to a wide range of pattern-type analysis of data (Braun & Clarke, 2006). How this method is theoretically bounded is determined by the study's theoretical framework. Thematic analysis can be a realist method reporting experiences, meaning, and the reality of participants, or a constructivist method, examining meaning and experiences as the effects of a range of social discourses (Braun & Clarke, 2006). For the purposes of this study, the thematic analysis will be theoretically framed a within constructivist lens. A thematic analysis method has been selected above other coding methods due to the flexibility it offers in conforming to the study's theoretical groundings, as well as being able to search for themes or patterns across diverse data (written LP development and instructional documentations, interviews, and written classroom artifacts). A theoretical/deductive or "top down" thematic approach will be selected to search for themes or patterns in the data both within the interview data and between the interview and other data sources (Hayes, 1997; Boyatzis, 1998). Braun and Clarke (2006) stated that this method of analysis is particularly useful in investigating an under-researched area, which my study certainly is. Braun and Clarke (2006) described six steps in undergoing a thematic analysis; (Step 1) familiarizing yourself with your data, (Step 2) generating initial codes, (Step 3) searching for themes, (Step 4) reviewing the themes, (Step 5) defining the themes, and (Step 6) reporting the themes found within the data (Table 4).

Table 4.
The Six Steps to a Thematic Analysis (Braun and Clarke, 2006).

Phase	Description of the Process
1. Familiarizing yourself with the data:	Transcribing data (if necessary), reading and re-reading the data, noting down initial ideas.
2. Generating initial codes:	Coding interesting features of the data in a systematic fashion across the entire data set, collating data relevant to each code.
3. Searching for themes:	Collating codes into potential themes, gathering all data relevant to each potential theme.
4. Reviewing themes:	Checking the themes work in relation to the coded extracts (Level 1) and the entire data set (Level 2) generating a thematic 'map' of the analysis.
5. Defining and naming themes:	Ongoing analysis to refine the specifics of each theme, and the overall story the analysis tells; generating clear definitions and names for each theme.
6. Producing the report:	The final opportunity for analysis, Selection of vivid, compelling extract examples, final analysis of selected extracts, relating back of the analysis to the research question and literature, producing a scholarly report of the analysis.

The first step was to immerse oneself in the data so that the researcher is familiar with the expanse and extent of the content. This can include repeatedly re-reading the written documentation of LPs and the transcribed researcher interviews. This should be done before generating initial codes. In the case of my dissertation study, each source of data was read in its entirety before generating initial codes. The second step involved the production of initial codes that identified features in the data that are pertinent to the study. Coded data differs from units of analysis or themes because they are narrower in scope, and subsequently, a sub-unit of themes. Data were coded by using Microsoft's Spreadsheet program with columns indicating the source of the data, the transcribed data, data notes, and rows indicating the data points organized by their source. The third step consisted of analysis of the coded data and organizing the data sets into themes. In my study, themes were 'theory-driven' by both the TCSR model (Woodbury & Gess-Newsome, 2002), the NSF sponsored project's initial PD model, and the study's overarching research question: *What is the relationship between LP developers and intended LP users beliefs about learning and teaching?* The products of the third step included visual representations of sorted codes into themes.

For this study, the visual products are shown and explained in Chapter 4. In the fourth step, I reviewed the produced themes in two sub-sets, by first re-reading each code within a given theme to verify congruence of the theme and then reviewing the theme in relation to the entire dataset. During this process some themes became problematic (e.g., if there is not enough data to support them, or two different themes start to form from the single theme's data) and a judgment was made to either accept or remove problematic themes from the results. Data within each theme was judged by how meaningful they were as a grouping, as well as how each theme was distinct from other themes. During this process, documents of the original NSF sponsored LP proposal and published peer reviewed article made as a product of the NSF sponsored LP project were also analyzed in an effort to triangulate the thematic data with these peripheral resources, which allowed for a more holistic and robust analysis. Once all themes were reviewed, I then continued to Braun and Clarke's (2006) fifth step of defining the formed themes from my study. Defining themes extends beyond just paraphrasing the data contents of each theme, but rather I described the 'essence' of each theme as well as what aspects of the data each theme captures. I did this by going back to each theme's data and organizing them into a coherent and internally consistent account that supports my narrative of the theme. The sixth and final step was to report the themes found, discuss the findings in relation to my research questions, and connect back to the broader field of education research.

Establishing trustworthiness. The researcher interview TBI instrument and protocol are based on previous research that underwent multiple measures of reliability and validity. Furthermore, the TBI has been generally accepted and used in recent education research (Luft & Roehrig, 2007). This gave some degree of instrument reliability. Interrater reliability was established by having 20% of the interview data re-coded by a second researcher to find percent agreements between coded data as well as to discuss any discrepant codes from either of the researchers' results.

To establish a measure of reliability and trustworthiness in analyzing the written documents of the project's LPs, each document was thematically coded by myself and reviewed by a different researcher, following Creswell's (2012) peer debriefing. In this manner, coding was discussed and evaluated in multiple intervals throughout the study. Finally, the interview belief data from the researcher participants was triangulated with the original NSF sponsored grant proposal's theoretical underpinnings as well as peer-reviewed articles authored by the researcher participants on topics that pertained to the LP model in question. The effort of this triangulation was to use multiple varying data sources in determining researcher belief systems.

Teachers (TiRs) Language Use in Describing Learning and Teaching of LPs

Research Question (RQ) Two was addressed by conducting interviews with teachers who were previously TiRs on the NSF-sponsored project. Data from the teacher interviews were coded through the TBI and thematically analyzed following the similar steps taken in analyzing researcher interviews.

Data collection. Data were collected through semi-structured interviews with eight former TiRs who participated in the project at Colorado research site. The process of soliciting the TiRs followed the same methods as described in soliciting the PIs of the NSF sponsored project. Each of the five TiRs was contacted via e-mail or phone to participate in my dissertation study. Each TiR received an e-mail with a voluntary participation letter that informs them of the study, their rights as a participant, and contact information (Appendix A). Although the TiRs know who the other TiRs were, I only blind copied other recipients on the recruitment email.

The teacher interviews followed the TBI instrument and protocols outlined for the LP researcher interviews previously described. However, the TBI questions were directly pulled from Luft and Roehrig's (2007) article, as they were directly designed for teachers.

1. How do you maximize student learning in your classroom?
2. How do you describe your role as a teacher?
3. How do you know when your students understand?
4. In the school setting, how do you decide what to teach and what not to teach?
5. How do you decide when to move on to a new topic in your classroom?
6. How do your students learn science best?
7. How do you know when learning is occurring in your classroom?
8. How can assessments of learning inform how you teach?

While the interview questions for LP researchers and teachers are different in the exact wording, the nature of each question remains the same. The differences among the questions were also kept at a minimum and only used to match the context of the LP researcher which is slightly different than that of a teacher. An example of this difference can be seen in question four for teacher: "In a school setting, how do you decide what to teach and what not to teach?" versus question four for researchers: "Pretend you are a K-12 science teacher, how would you decide what to teach and what not to teach?" The final portion of the interview paralleled that of the LP researcher's interview and included questions regarding how the teacher interviewee defines LP, how are LPs implemented, and what was their role as a TiRs in the LP project. The interviews allowed time for the researcher interviewee to make additional comments on science teaching or on the NSF sponsored project as a whole.

The interviews with teachers were audio-recorded from a digital recorder and transcribed for analysis. Because there are only five interviewees from the same school district, it may be easy for others to identify individual participants based on their demographic data. Therefore, all efforts were made to exclude mention of gender and grade level of participants in the findings section. In addition, I excluded any mention of the schools in which the teachers teach in any narratives used to support any propositions. During the interviews I explained to the TiRs the purpose of the study. Interviews occurred either on the CSU campus or at the school of the participating teacher, depending on the convenience of the participant.

Data analysis. The interviews were coded following Luft and Roehrig's (2007) TBI protocols, as described earlier in the researcher interviews. The teacher grouping of data was then compared with the LP developers' results of researcher interviews and thematically coded researcher documents. Specifically, I looked for meaningful themes between the relationships of teacher's beliefs of how students learn, how LP researchers explain and write about how students learn, and teachers practice using a coding framework informed by the TCSR framework (Woodbury & Gess-Newsome, 2002). Through the thematic coding process, I was able to develop propositions about the relationship between LP developers' perceptions and intended LP implementers' perceptions of learning and the role of LPs in supporting learning. Although the propositions are bounded to the case being studied, the findings allowed me to propose implications for future teacher professional development efforts.

Establishing trustworthiness. The coding of teacher interviews followed Luft and Roehrig's (2007) TBI protocols on inter-rater reliability, as described previously in the researcher interviews. The thematic analysis of the peripheral documentation followed the exact reliability protocol established previously in thematically coded researcher documents. The final coding results were examined by an external auditor who is an expert researcher familiar with case study methodologies in order to minimize bias and increase internal validity.

Chapter 4

FINDINGS

An overarching theme that emerged from the findings of this study is that researcher and teacher stakeholders have similar as well as different beliefs regarding teaching and evidence needed to inform teaching practices. The three research questions guided the investigation of the two stakeholders' beliefs about learning progressions, in particular Luft and Roehrig's (2007) TBI coding scheme helped answer the first two research questions about stakeholders' beliefs about teaching practices in general. Braun and Clarke's (2006) thematic analysis protocol allowed me to analyze stakeholder interviews and describe patterns in participants' perceptions of LPs and how they inform teaching practices. To a greater extent, this type of analysis helped me answer the third research question: What beliefs and intentions do researchers and teachers have that are aligned and not aligned? Following initial coding, patterns, and relationships between codes were expanded leading to the development of propositions. From this analysis, I identified the commonalities of learning beliefs each stakeholder had as well as three major themes revolving around the different tensions of beliefs each stakeholder expressed from the data: (1) Discrepant views about LPs, (2) What evidence counts as assessment (3) Translation of theory to practice. The similarities of view were present in a descriptive manner while the differences in stakeholder beliefs were examined using the theoretical lens described in the TCSR model (Woodbury & Gess-Newsome, 2002; Figure 3).

Researcher Beliefs of Learning and Instruction

Although only five researcher participants were interviewed, those with eight or more years of teaching experience expressed reform-based beliefs about teaching, while those with fewer than eight years expressed traditional-based beliefs (Table 5).

Table 5.

Researcher Beliefs About Student Learning and Teaching

Researcher	Years of K12 Experience	TBI Belief Categories (Teacher-Centered → Student-Centered) Traditional	Instructive	Transitional	Responsive	Reform-Based
Samantha	0	1	3	3	0	0
Jacob	0	3	0	3	1	0
David	4	2	2	3	0	0
Ethan	31#	0	1	4	1	1
Josh	8	0	0	5	1	1

** = number of times a question was coded into one of the five TBI belief categories*
 # = informal/peripheral teaching experiences in a K-12 environment

Researchers with more years of indirect and direct K-12 student experience held student-centered beliefs and implied that the onus of understanding content is on the student. Examples of this category include evidence that teaching is about providing experiences for students to make sense of science as well as modifying instruction based on student perspectives, prior knowledge, and beliefs. Of the five researcher participants, Josh, Ethan, and David had at least some direct or indirect experience with K-12 students. Josh and Ethan had direct teaching experience in a K-12 environment as previous science teachers. During each of their interviews, both Josh and Ethan responded on certain questions that were coded as being either "responsive" or "reformed-based." In response to the interview prompt: "Imagine that you are a K-12 science teacher, how would you decide to move on to a new topic in your classroom?" Josh responded:

> *I certainly look at their (students) development of that understanding, their constructing of that understanding, and their expression, how they communicate their understanding, written or verbal, or fed through demonstration or experiences. I am looking at those as indicators by doing that though I must be prepared to so what if they don't have that understanding that we are working towards. I have be very ready to re-teach it or do another explorer/explain or do another engage…(Josh)*

In his response, Josh described instruction as a two-way relationship during which students construct their own knowledge; and the teacher's role is to provide an experience to help students understand the subject matter. Using the Luft and Roehrig's (2007) coding scheme, this belief was classified as "responsive," having instruction that focuses on collaboration as well as feedback that is more "student-driven."

Another researcher participant, Ethan, has had over 30 years of experience collaborating with K-12 teachers and working as a researcher within K-12 classrooms developing curriculum and professional development for K-12 science literacy. Similar to Josh, Ethan responded in response to another interview prompt, "Pretend you are a middle school or high school science teacher, how would you decide what to teach and what not to teach?" by stating,

> *….presumably I am teaching a subject that has several different types of externally defined canons or standards or curricula, there it might be a state curriculum or district or school level curriculum… and then there is the teacher does know or should now about what big ideas or the important things are to know about the topic and there's what the teacher knows about the students interests and intellectual strengths and needs and what the teacher wants to allow for responsiveness for the student… you have established that you have goals for the students in terms of what are now being called science practices and again even though you are open to the topic you might still want to teach have them through their own investigations you might have your eye on what the big disciplinary ideas are and what the cross cutting concepts are.(Ethan)*

In his response, Ethan explicitly points out that the balance of teaching is to provide experiences which link science standards to student investigations in the classroom. Using the Luft and Roehrig (2007) protocol, Ethan's responses were as coded "Reformed-based" in part because of the explanation of reform goals such as "science practices" intersecting with "disciplinary ideas" and "cross cutting concepts." Not only did Ethan demonstrate his knowledge of the reform documents (in this case, the national Next Generation Science Standards published in 2013), but he demonstrated that he had thought about how teachers can use these documents to inform their teaching practices.

Researchers with fewer years of direct K-12 student experience demonstrated teacher-centered beliefs (Table 6). "Teacher-centered" beliefs are consistent with beliefs that science is based on culturally independent facts and supports a behaviorist view of how students learn. “Teacher-centered” beliefs were identified by examples that participants described that placed the teacher at the center of knowledge whereby information is transmitted from teacher to students. Teachers’ roles in this regard are to deliver the information and not to co-generate knowledge with students (Luft and Roehrig, 2007). Samantha and Jacob had no direct experience in a K-12 teaching environment and only peripheral indirect K-12 experience as researchers on a couple of related, but different, NSF science education grants. Both Samantha and Jacob responded to the TBI questions that were commonly coded as “traditional” and “instructive,” being more focused on the teacher as the center of instruction and science as objective. For example, Jacob stated that: “*in the natural world, I am a scientist so the natural world play out irrespective of what you are looking at.”* He explicitly stated that science is a rule and fact; therefore, supporting a positivistic view of the world and of how the world is studied.

Samantha, although not as explicitly positivistic in her language, espoused beliefs that teachers are in charge of the classroom. In Samantha’s response to a prompt, “describe the role of the teacher” she explained

> *…it is my job to come up with these problems for students to work with. It is my job to structure the problems in such a way that the student can solve progressively more and more difficult and complicated problems. It is my job to assign preparation that they will be willing and able to do. Right. It is my job to motivate the students in order to tackle the work. It is my job to give the feedback. It is my job to help set the culture in the classroom that allows them to talk with each other and they know together. (Samantha)*

Her view of the teacher’s role is to build relationships and establish rigor in the classroom. This was coded as “transitional” because Samantha described the teacher as the focal point of instruction. Although it not clear from her statement how Samantha believes teachers should respond to reform goals, she does explicitly describe empowering students by engaging them in scientific practices and discourse practices. David, a senior researcher with over 38 years of experience also had responses that were generally coded as “transitional”, “instructional”, and “traditional”. David stated in his interview that he had 4 years of K12 teaching experience, but this was prior him being a researcher - essentially meaning that his K12 teaching experience was over 34 years ago. David responses commonly focused on the transmission of information from the teacher to the students, a teacher-centered belief system. Examples of this include: *“The new professionalism tends to make teachers more into performers or drill sergeants.”* I assume that David used the term “drill sergeant” to describe a teacher who expects to engage in rote learning. In another example, David mentioned that learning can occur as “*a sequence of activities that can help students.”* Again, he described teaching from the point of the view of what the teacher is doing or using, rather than <u>how</u> it is helping students to learn.

In this study, researcher participants generally expressed teacher-centered and positivist beliefs about student learning and instruction in contrast to the philosophical underpinnings of the LP model, which was in part developed within a constructivist framework. The categories of “Traditional,” “Instructive,” and “Transitional” are more closely aligned with teacher-centered beliefs (Luft & Roehrig, 2007). In the NSF grant proposal that funded the TiR project, as well as papers that describe the LP model, the researchers did not explicitly mention their ontological or epistemological beliefs (researcher participant and colleagues, 2010). However, a key component of the NSF grant was the use of an existing LP framework created previously by the researchers on the grant (researcher participant and colleagues, 2009). One of the LP framework research articles referenced Gee’s Theory of D/discourse (Gee, 1990), which in turns drew on elements of social constructivist theory (Mackay, 2003). Based on rationale for developing the LP, one might assume that researcher beliefs about teaching practices would be aligned with constructivist teaching practices. It is unclear from both the interviews and the published articles authored by the researchers how the researchers mediated these epistemological incongruences.

Teacher Beliefs of Learning and Instruction

Some teachers demonstrated teacher-centered beliefs, while others demonstrated student-centered beliefs (Table 6). As a group, teachers expressed more student-centered beliefs about student learning and instruction than researchers expressed (Tables 5 and 6).

Table 6.
Teacher Beliefs of Student Learning and Teaching

Teacher	Years of K12 Experience	TBI Belief Categories (Teacher-Centered → Student-Centered) Traditional	Instructive	Transitional	Responsive	Reform-Based
Ashley	25	1	2	3	1	0
Harper	13	2		4	1	0
Brian	30	0	2	4	1	0
Preston	10	0	1	3	2	1
Blake	17	1		2	2	2

** = number of time a question was coded into one of the five TBI belief categories*

Teachers whose instructional experience was primarily in elementary or middle school demonstrated more student-centered beliefs than those whose teaching experience was primarily in high school settings. Both Blake and Preston, who have consistently taught middle school for several years at the time of the study, exemplified this finding. For example, Blake explained,

> *Teaching middle school, you never know what kind of elementary background the kids have . . . You have to be able to support the ones that it is new to and yet continue to challenge the kids that already know it. And that is where it goes back to number 1, maximizing learning is knowing where they are at to start with (Blake)*

In this case, Blake's response describes effective teaching as being able to know the background of students and being able to provide differentiated instruction based on differing students' need, a response coded as "Responsive." Preston's response is similar, focusing on the need to understand students' backgrounds for effective teaching:

> *. . . understanding of a particular topic or subject. So for me that is fairly individualize . . . each [student] individually gain[s] as much as they're capable of doing and that involves a little pushing, pulling, and laughing so that they start to internalize their learning and they want to know more, a lot of inquiry based experiment (Preston)*

Brian gave the most detailed response to the need for instruction to include students' backgrounds, experiences, and ways of learning. In his response, he provided a specific example of his own classroom experience:

> *I think students know what they need to do to learn, especially at high school. At this point they know what works best. I think if you can put it, if the topics are such that students can identify with them with things they are familiar with in their personal lives and their community that they hang out in that helps them learn better. This is the first*

semester of I've taught a geospatial science class and that group of students has a different mindset and a different view on the world. I have had to learn to get down into their level of thinking so that they develop some trust with me. Because if I just did how I taught other classes that wouldn't fly with a group of students who are challenging because they don't fit the mold of other students. I think if you can identify how, if a student can identify what they know is the best way for me to learn and then provide that (Brian)

In the same vein, Ashley responded to a similar question and talked about connecting to the students by creating a "buy-in" to create interest in the subject matter through tapping into the students' interests. She also mentioned the need to create a community and use instructional strategies that revolve around discourse:

. . . more and more I realize the kids won't, they can't learn if there is not a component of like buy-in of learning from everyone So I think I have tried that a lot more this year I have been a lot more successful with getting a, what is not community, but a comradery a community of learning and that is my role is establishing that and trying to maintain that while trying to engaging the kids in the content. (Ashley)

Another aspect of student-centered beliefs is the instructional strategy of providing experiences for students to navigate through collaboration and inquiry. Harper explained that students learn best when they are *"exploring with inquiry, giving them opportunities to experience something and then -- Recently, we did some experiments with on erosion. We looked at water splatter on levy environments."* Her explanation of best teaching practices, which expressed the role of the teacher in providing inquiry experiences was coded as "responsive." In the same response, Harper discussed how students transferred knowledge gathered from a previous experiment to explain the phenomena presented in a new situation, an example of knowledge generation, which was also coded as "responsive:"

> *just kinda all put it together and said oh this makes sense. The other day I gave my students a diagram, a science diagram, of how waterfalls form. They immediately looked at that and they said oh look there is undercutting and then it is weathered and then it's the water is eroding it. Oh I loved this. You know if you have the right vocabulary and they interpret the science diagram without me telling them how it worked. You know and so that is my goal. (Harper)*

In summary, all of the teacher participants had at least one response coded as "responsive" or "reformed based" - codes based on student-centered beliefs. Furthermore, the majority teacher participant codes that were not coded as "responsive" or "reformed based" were coded as "transitional" – focusing on student relationships and affective assessments.

Comparison of Beliefs and Behaviors Between Researchers and Teachers

Using the TCSR framework, I identified similarities and differences that each stakeholder group (teachers and researchers) described (Figures 8a and 8b). Both stakeholders had similar beliefs including: (a) teachers should be facilitators, (b) translation of science education theory to practice is a hard endeavor, (c) the role of citizenship in science instruction, (d) the need for rigor in science instruction, and (e) the need for both cognitive and formative assessments. These five points are in alignment with current science education reform documents, such as the *Framework for K-12 Science Education* (NRC, 2012) that preceded the publication of the *Next Generation Science Standards* (NGSS Lead States, 2013). Despite similarities, there were notable differences between researchers' and teachers' beliefs about teaching and how these should be implemented. These were collapsed into three themes: discrepant views of LPs, what evidence counts as assessment, and the translation of theory to practice. In addition, the two stakeholder groups identified different types of tensions about how beliefs may inform teaching practices.

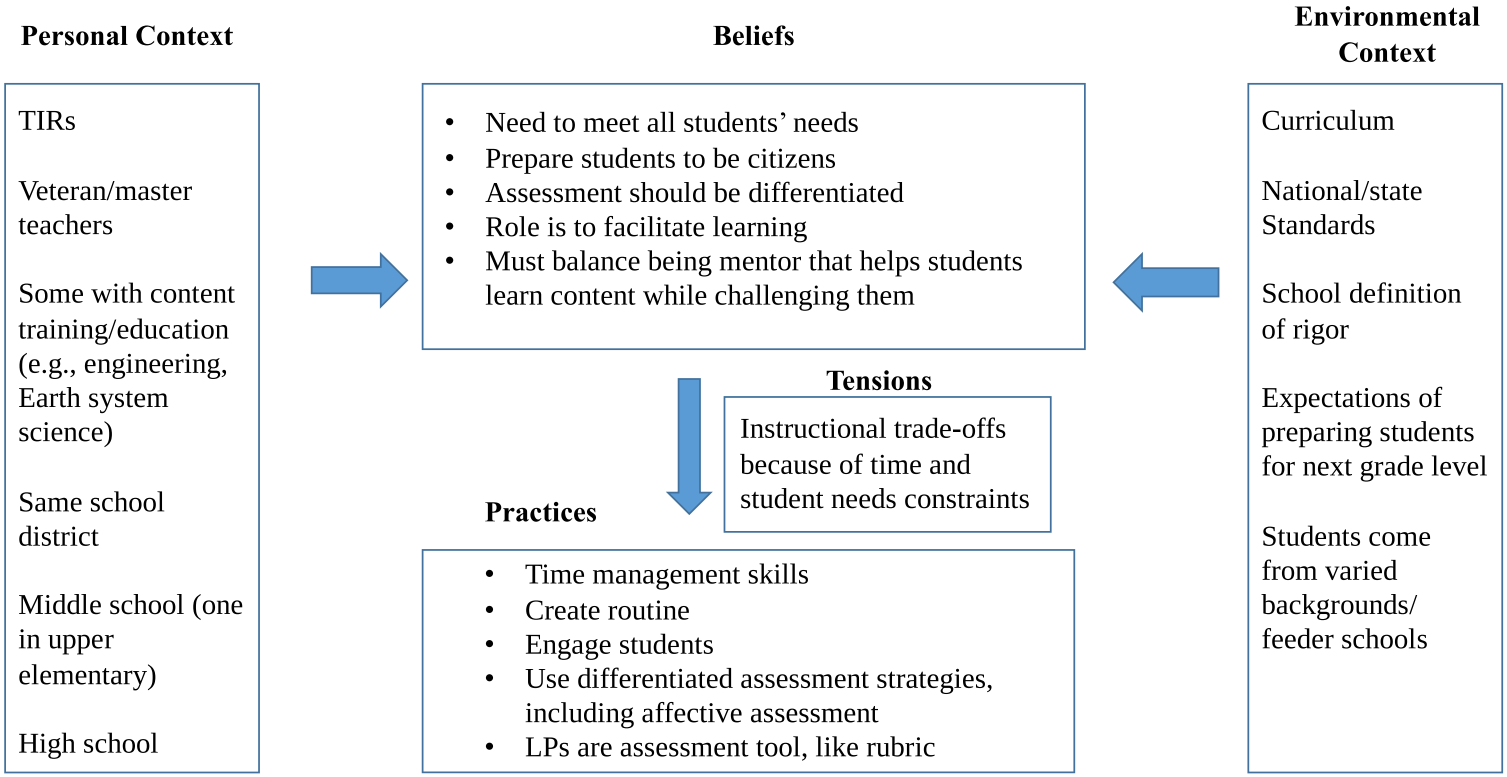

Figure 8. A TCSR model on teachers' personal and environmental context influenced their beliefs about teaching. These beliefs, in turn, influenced their descriptions of instructional practices. Teachers also identified some tensions between their beliefs and practice.

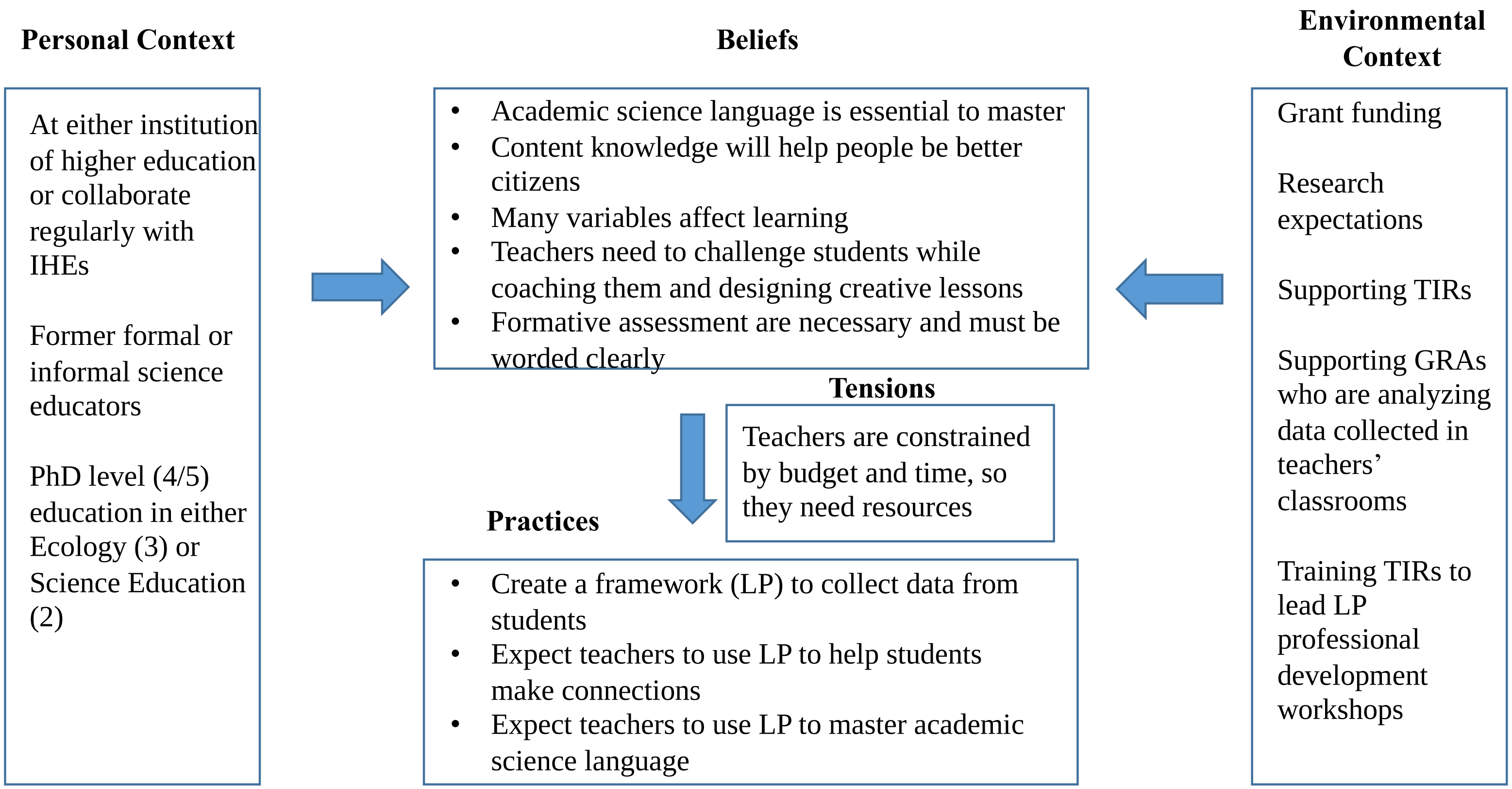

Figure 9. A TCSR model on researchers' personal and environmental context influenced their beliefs about teaching. These beliefs, in turn, influenced their descriptions of instructional practices. Researchers also identified some tensions between their beliefs and practice.

Discrepant views of LPs. Researchers and teachers in this study demonstrated differing views on LPs, including the purpose of LPs and whether they meet all student needs. Researchers generally described LPs as complex instructional models that align student cognition with assessment, science standards, and instruction (Figures 10b). Researchers commonly made claims that LPs can be used as a generalizable model for instruction of science content. Researchers also believed in the importance and use of disciplinary science language to assess student understanding. Conversely, teachers defined LPs either as a simplistic rubric, a formative assessment tool, or a science standard (Figure 8). Most, if not all, teachers gave very brief explanations of LPs, such as "*Oh it is definitely a rubric,*" as Harper explained. This contrasted with researchers' generally more detailed and complex responses of defining LPs. For example, Jacob described LPs as a hierarchical way of learning.

> *It is a description so it is an observation set of a pattern that people have observed in the way in which students learn and it is an increasingly sophisticated way of learning…..we have the description of the forced dynamic narrative to a principle based narrative which we call scientific principle based reasoning. . . Logical narrative to one that becomes that adopts this systems thinking and the cognitive domain so it looks like the content domain is happens first and then you begin to see the cognitive domain develop. It is intimately tied to what we call literacy.*

Similarly, Jacob likened LPs to a learning pathway

> *learning progressions are ideally kind of a description of a pathway of learning about a topic or big idea that spans that kind of range of time and increasing sophistication.*

Another researcher, David, defined it more as an instructional strategy: "*students need a strategy for tracing matter and matter in this case meaning particularly carbon and tracing energy through all these processes of multiple scales."*

Samantha spoke of LPs more as a curricular framework or content standard, "*I thought about as what progressions that students go through in their learning from elementary through high school."* Although David and Samantha described the value of LPs in slightly different ways, they both referenced LPs as a tool to guide curriculum development and instructional practices.

Because researcher participants had varied definitions of LPs, it is likely, therefore, that they presented and defined LPs in equally diverse ways to teachers. In an effort to find a clear definition of LPs, the original NSF (2010) grant proposal that framed this project was examined. The result includes a brief description of LPs taken from the National Research Council's *Taking Science to School* (2010) publication: "*descriptions of the successively more sophisticated ways of thinking about a topic that can follow one another as children learn about and investigate a topic over a broad span of time*" (Committee on Science Learning, 2007, p. 219). Within the grant proposal LPs as a "framework and assessment system," (p.3) are explicitly mentioned but there is no elaboration of the definition of the instructional products. The researcher participants' definition of LPs is conceptual and theoretical. They did not offer specific examples to support each level, nor did they provide detailed descriptions of how a classroom teacher would use LPs to inform his/her teaching.

Finally, researchers explained that LPs are informative to teachers because of their use as a generalizable model (Figure 9). Unlike the researchers, teachers questioned the value of LPs as a tool that meets all of student needs (Figure 8). One teacher, Brian mentioned that they differed with the researcher on what LPs are and how they can be used:

> *This is a criticism that ultimately I have of the learning progressions because I think people progress at different rates so you have to set certain time limits…. I mean that is where we had all these different activities that we did that supposedly moved towards that final goal(LPs) but I don't necessarily agree with the sequence with which things were done in.*

Brian criticized LPs as being unimodal while learning and assessment of students requires a multimodal environment because students learn differently from one another. He explained, "*But sometimes the assessments are not necessarily in a form that every student can identify with. This frustrates me about the standardized testing because standardized tests only are coming at you in one mode."*

Other teachers concurred with this sentiment of LPs and their limitations. Another teacher, Ashley critiqued LPs as formative assessments, and questioned how they can inform what to teach, especially due to the lack of time in the class to remediate some student miss-understandings after studying a learning module: *"…right, well the word there is 'can' vs. 'do' because do they inform how I teach? Not always, because of the 'move-on' mentality, okay versus let's see,* <u>how</u> *can they…*" Blake was also critical of LPs and acknowledged that student results gathered from LP assessments may not be that useful when constrained by class size. "*The challenge with [LPs] in a public setting is that when you teach in, I have 170 kids on my roster, class size of 30, and it is really hard to get authentic experience for every kid.*" Teachers' criticism of LPs may ultimately stem from their personal experiences and environmental contexts that likely influenced their beliefs about teaching (Figure 8). Considering that none of researchers has taught in formal classrooms since the advent of national and state academic standards and current reform policies to promote scientific discourse and practices, it makes sense that researchers' beliefs about teaching differ than teachers' beliefs.

What evidence counts as assessment and translation of theory to practice? Not only did teachers and researchers demonstrate discrepant view of LPs, they also disagreed on how to develop and use assessments of student learning. Researchers discussed the role of cognitive and formative assessments, emphasizing the importance of language as a measure of knowledge (Figure 9). Researchers, unlike teachers, focused on language use (vocabulary) as an effective metric of what students know. For example, Samantha explained *"I think it is probably the language that they are using primarily. The way they communicate it."* A researcher, David shared a similar thought, "*Learning science is like learning a second language, Some of the key characteristics of a second language for the topics."* Therefore, the researchers argued that as students' understanding of disciplinary content is deepens, their use of sophisticated vocabulary should match their understanding. In this way, language can be used as an assessment of what students know and understand.

Contrary to this, teachers did not believe that vocabulary is an important form of assessment of learning outcomes. Rather, these participants mentioned the role of affective or emotive assessments as important informal tools to assess learning or complement other formal forms of assessment. Teachers defined affective assessments as the non-verbal physical expressions that students make when tackling understanding science content. Affective cues indicate students' motivations, interests, levels of engagement, frustration, and "ah ha!" moments. One teacher, Preston, stated that he asks himself "*where is each student at, where is there frustration level, and if I hit that frustration level, then I am going to go on.*" Blake described a light bulb moment for students, "*That is always the ah-ha button. 'Oh my god, we use that much water to water the grass. We are never out on the grass."* Through "ah-ha" moments, this teacher explained that student learning could be discerned. Ashley also described affective assessment, "*I just definitely can see light bulbs sometimes or hear you know or hear a kids go "oh"! You know, definitely."* Teacher participants, therefore, were more likely than Researcher Participants to describe empathic assessment. They were aware of interpreting student learning through emotions, gestures, behaviors, as well as language use. However, they often described the importance of combining the affective informal assessment with other forms of formal assessment, which often involved using content knowledge to solve problems. None of the teachers stressed language or vocabulary use as an important form of assessment.

The two participant groups had different ideas of how to translate research into practice. Teachers also commonly spoke of using affective assessments as a tool informing instruction. Teachers spoke about the external contextual factors that drove their instructional choices, namely high stake tests and state science standards (Figure 8). Teachers subsequently supported their claims about research-informed practice with specific classroom examples that demonstrated that teachers consider how to sequence their instructional activities to support "ah-ha" opportunities. Brian described a laboratory activity along with each step of guidance.

> *Today we did a lab that was helping them learn what are the indicators of chemical change. So, I could tell them about it and they could see it up on the board and I could give them an acronym that describes it and then we try to something where they tactilely touch and manipulate material to be able to move towards that learning target. That is how I would try to maximize student learning.*

Brian described how he introduced content and allowed students to explore the content in different ways – through listening and manipulating. Harper also explained a laboratory activity during which students were able to discuss and observe a scientific phenomenon. The students then answered questions about hypothetical scenarios so they could use the newly learned content.

> *We have looked at infiltration. The hands-on infiltration with some materials that I made. And then I told them I talked to them about what runoff is and what erosion is. You know after we did it I said this is eroding and to you see how this soil has moved from here to here. And if you have a lot of rain where is that soil going to end up? They just kinda all put it together and said oh this makes sense.*

In another instance, Harper further shared that,

> *I gave my students a diagram, a science diagram, of how waterfalls form. They immediately looked at that and they said oh look there is undercutting and then it is weathered and then it's the water is eroding it. Oh I loved this.*

Harper described how the students were able to solve problems and explain phenomenon related to weathering because they had studied the water cycle. Harper never stressed that students demonstrated content knowledge because they used certain vocabulary. Moreover, teachers constructed assessment opportunities that allowed students to be creative in their expression of concepts. These assessments were not focused on vocabulary usage; rather, they enabled students to show what they knew in a multitude of ways, illustrated by Ashley's explanation,

> *I am gonna have them make a product for me that, I do not know if I am going to call it a children's book, but I said this is going to be more you guys teaching me all of this stuff like, So I am going to give you my version of it so you can um create a children's book on*

these different types of weather and then that will be chapter 1. Then they are going to hate me, but then we have to do chapter 2 is going to be energy, so how would you teach about that, and the last one will be climate, so they will do three chapters and it is really a project based piece because they will have to be able to explain it back and not just in a multiple choice tests it has to be more like diagrams and short pieces of content and stuff. (Ashley)

Ashley developed an assessment opportunity for which she could assess student thinking as well as content knowledge. In the following example, the teacher took students outdoors and found an authentic context in which his/her students could explore the concepts being studied (carbon cycling). Although his/her students were not old enough to drive, they were familiar with seeing water and oil spills (from vehicles) in parking lots.

We have taken it into the full progression where they are out measuring evaporation and transpiration and looking at the rooftops and looking at the parking lots. I think the biggest thing for middle schooler when they see that is 'huh, I never thought about water in that way. I never thought about point source solution from the oil spill in the parking lot.' So, I think it goes it is a real life application that leads into 'oh we have got these storm drains and where does that water go and how do we have this fresh water. Why are we taking this highly purified water treated water and we're washing cars with it?' So, kids are really taken into that aspect. (Blake)

In yet one more example, Blake gave students the chance to demonstrate knowledge through diagramming. The shape of the diagram (chains versus webs) allowed the teachers to assess the complexity of student understanding of ecological trophic levels. Therefore, this teacher went beyond simply testing students' knowledge of vocabulary when assessing their knowledge and understanding of concepts.

> *In terms of learning about it, an example of that would be food webs, we start here and some students draw a bunch of stuff on the page, just animals. They do not really connect the dots at all, some make a chain and some actually have some knowledge of what food webs are and can connect multiple parts of the web, and not just the chains. (Blake)*

Unlike the teacher participants, who provided multiple pieces of evidence to support their claims, researcher participants generally focused their interview time discussing the theory behind K-12 instruction or the development of LPs. They gave relatively little evidence or classroom examples to support their propositions about how theory should be put into practice. Teacher and researcher participants used different types of evidence to support their claims about instructional practices and student beliefs. In the case of teacher participants, a majority of the beliefs they voiced were supported through evidence. Researcher participants described the majority of their beliefs without the use of direct evidence or examples from the classroom. In other words, researchers provided lengthy explanations for the *why* and *how* LPs should be adopted in science instruction, but they supported their claims with few authentic examples. The fact that researchers did not describe how LPs are explicitly used in actual classroom practice may allude to why teacher participants gave more simplistic definitions of LPs. Based on the interview data, Teacher participants' definitions of LPs may be the byproduct of them not being immersed in the theoretical constructs of LPs. They also were not given the grant proposals or related research articles to read as they started their TiR experiences. This means that the individuals who were expected to implement the LPs did not have access to the theoretical and conceptual descriptions of the LP literature that the researchers plan to use to develop the

Carbon LP. Teachers did not explicitly mention teaching, or otherwise using LPs in their classroom. In response to prompts about using the carbon LP to inform their teaching, Teacher participants explained that the LP model helped improve their instruction by helping them to consider more broadly what the 'practice' of science means in the secondary science classroom. Teacher participants specifically discussed using instructional strategies that that focused on students following through the methods of science investigations in exploring phenomena. Preston gives an example of this:

> *focus on bringing in the citizenship model into the classroom and teaching students how to think about – have a scientific discussion, thinking like a scientist, claims evidence and reasoning. (Preston)*

Blake discussed using LPs in the classroom when describing how concepts of water have been revised in a middle school curriculum to include an understanding of the local watershed, sources of water, and how water is treated.

> *big idea in water is where does the water go? We look at and its what landing on or what comes down at canard on our properties and you are getting kids using google maps and figuring out land space and ground cover. It really promotes a lot of conversation of about where does it go and how does humanity impact that. We have taken it into the full progression where they are out measuring evaporation and transpiration and looking at the rooftops and looking at the parking lots. (Blake)*

In teaching the processes of water, teachers mentioned the word "progression" but subsequently only described how lessons and instruction revolve around place-based education of water and inquiry units that require students to explore the flow of water. They also referenced emotive formative assessments teachers used while teaching these lessons. None of the teachers mentioned using LP-informed assessments, developing instruction based on the LP process, or any mention of LPs defined by the researcher participants. Teacher participants acknowledged the merit of the LP models but said they rarely implemented them.

Tensions researchers described. In some instances, the researcher participants mentioned that they were not sure how theory can be implemented into practice in K-12 classrooms. David noted that:

> *Rigor meaning that you need to have high levels of understanding of important science and responsiveness meaning that the teacher needs to be a good coach essentially. That is easy to say and hard to pull off. (David)*

Later in the same interview Researcher David repeated the same ideas when responding to a separate question:

> *we have this one group that is focused primarily on responsiveness on understanding students and being responsive to them and another group focused primarily on rigor meaning using specific practices for specific purposes….You need both but actually pulling off both in the classroom is really a hard thing to do and not one we are not accomplishing very often. (David)*

These examples also illustrate that researcher participants, in some cases, acknowledged that theory is hard to translate into practice for teachers. David was clear about this conundrum numerous times throughout his interview, "*….sort of the 30,000 foot view and the work comes when you get into the weeds and have to translate that into what do I do Monday."* Jacob takes this further by specifically mentioning several explicit constraints or barriers that hinder teachers from translating science theory to classroom practice.

I wouldn't say that they (teachers) are shackled but in a way they are definitely constrained. There are things that collectively the community has said these are the things that we think are important and you will follow this curriculum. That sounds kind of harsh and, in reality, that is probably what happens. (Jacob)

Jacob goes on to mention another separate constraint of budget and time, universally applying these constraints to "everybody," presumably meaning everyone in the science education field.

The only thing that constrains them are budgets but everybody has got budgets, budgets and time, money and time, are the only things that constrain you and the rest is to be creative to come up with ways to present materials to challenge students and provide opportunities for them at the same time. (Jacob)

Tensions teachers described. Teachers cited numerous constraints in employing LPs in the classroom, including 1) time and 2) state and district standards. Ashley summed this up well by saying,

Definitely I have my own classroom but my learning objectives are pretty well set in terms of what standards we cover. Yeah, so that is really the Colorado State Standards for 9th and 10th grade physical and earth science combines into one class in one year. It is like a whirlwind though. (Ashley)

Furthermore, several Teacher participants within the project explicitly countered the notion that written cognitive assessment is a gauge of student understanding. Harper explicitly mentioned their refusal to administer multiple choices tests in class, the most common mode of formative assessments in the LP model.

I wasn't going to ever give a multiple -choice test. I wasn't going to hand out vocabulary words ahead of class. I was not going to assign a book reading for kids to learn content *or lecture in front. I was going to give the kids experiences and get them excited about where the learning was going. And get them up to a point where they were participating in their learning rather than being the sponge. (Harper)*

Brian mentioned their epistemological beliefs that students learn differently and written assessments cannot accurately capture the diversity of student understanding on a subject, "*But sometimes the assessments are not necessarily in a form that every student can identify with. This frustrates me about the standardized testing because standardized tests only are coming at you in one mode."* Brian also stated this frequently as a constraint in the decision-making of implementing any type of instructional model.

I was sorta surprised that the researchers thought that what they had created was the end all be all. In other words, it was like you go to do all the steps in this model so that it works the way we think it should work. To bring in a new way to teach about carbon meant that something that I already did in the classroom had to go away. In other words you can't just keep adding on more and more stuff to teach. There are only so many hours in the day.

In conclusion, the combination of differing views of LPs, assessments, and how LPs are translated to practice between researcher and teacher participants shows an incongruent landscape of understanding. In this study, the original message of LPs may have been in partially lost through the process of translating LPs from the context of academia into the context of the K12 environment.

Chapter 5

DISCUSSION

Some researchers argue that, in order for science education reform to be successful, professional development models must take into account the existing belief systems (Van Driel, Beijaard, & Verloop, 2001; Ziegler, 2006). My overarching finding is that researchers and teachers from this study have different beliefs and tensions that guided their instructional practices (or ideas thoughts about instructional practices), both within each group and between each group (Figures 6a and 6b). A cursory search for “Learning Progressions” in the ERIC database on 9/5/2016 revealed that over 671 papers have been published. However, none of the articles identified also contained the keywords, “researcher beliefs” and/or “teacher beliefs.” There were numerous articles that emphasized the importance of considering all stakeholders’ embedded cultures, contexts, and beliefs for sustainable reform but did not include these elements from researchers or did not examine researchers (Gess-Newsome, 1999; Keys & Bryan, 2001; Woodbury & Gess-Newsome, 2002; Tengo et al., 2014). Conversely, published LP research did not explicitly emphasize or mention teacher culture, context, or beliefs (Duncan & Hmelo-Silver, 2009; Alonzo, 2011; Mohan, Chen, & Anderson, 2009). As a whole, this study’s findings explore this new research niche by illuminating the different tensions and patterns of beliefs that a group of collaborating researcher and teachers demonstrated through interviews.

Researcher Participant Beliefs of Learning and Instruction

Researcher participants’ beliefs about teaching, their acknowledgment of tensions that teachers face, and their description of how to resolve these tensions was incongruent with the beliefs of the teachers, who they were trying to support. Researcher beliefs were variable within their own stakeholder group. Researchers tended to lean towards teacher-centered beliefs (Table

6). Researchers described LPs as being generalizable and that student understanding of science content can be predictive of specific science content, such as carbon cycling (Figure 9). However, the same researcher participants quoted constructivist theory, while advocating the use of learning progression theory (researcher and colleagues, 2009). In this regard, it can be interpreted that researcher participants believe that constructivist and LP theories are compatible. Alternatively, another interpretation is that researcher participants are not explicitly aware of or acknowledge the tension in their own beliefs. Although they described tensions that teachers are constrained by budget and time, and need resources, none of the researchers acknowledged that it is challenging for teachers to adhere to constructivist teaching philosophies while employing an LP model that is grounded in teaching tools that teachers believe are positivist.

Most natural and physical science research is framed within the empirical positive traditions, which support behaviorist ways of knowledge transmission. In this case, the observer is independent from the phenomenon being studied (Sullivan, 2002). Sullivan (2002) explained, "*It was of little benefit, for example, to record the thoughts, emotions or reactions of researchers to their subjects, experiments and theories"* (p. 1). If science education researchers initially studied natural science, more often than not rooted in positivist and behaviorist epistemologies (Duschle & Grandy, 2013), it is plausible that these researchers still adhere to positivist research paradigms, even if they for constructivist teaching approaches. Matthews (1993), interestingly, claims that constructivist teaching is actually a variant of empiricist epistemology that can trace its roots to the philosophy that humans made meaning of the world by experiencing it.

Researcher participant beliefs about student learning and instruction also revealed that those with more direct K-12 instruction experiences espoused more student-centered beliefs than those with little to no direct K-12 instruction (Table 4). This finding is important and relevant, considering that researchers are often the drivers of reform efforts in K-12 science education (Bybee, 2013; National Research Council, 2007; National Research Council, 2005). Although current science education reform is heavily framed in constructivist assumptions (NRC, 2000, 2012), the presumptions, experiences, and positionalities of the reform designers is not often explicit in the research (Louden, 1992; De Jong, 2007; Taber, 2009). For example, Pitot (2014) found that reform policy is not always practical when enacted in classrooms. Pitot found that Colorado teachers were asked to create their own district-wide assessment tools to be used in evaluating their own effectiveness as teachers. Teachers in northern Colorado who participated in the study were identified as being highly scientifically literate but their assessment tools did not reflect the same level of expectations of their students. Pitot (2014) concluded that the teachers were aware of their job security and the importance of helping their students demonstrate growth on district assessments, which was, in fact, the opposite of the intent of the state senate bill that resulted in this practice. Ralph and Fennessey (1983), although several decades ago, reminded educational reform researchers to be aware of what research orientations they have that might influence their experimental design. Although researchers' beliefs are not explicitly stated in research studies, they are tacitly included because the theoretical assumptions used to frame studies likely reflect their beliefs.

The TCSR model helped reveal the need for researchers to be more introspective and explicit about their own beliefs, how they mediate the tensions in their beliefs, as well as how they mediate the tensions in the theoretical underpinnings of the LP model. More importantly, this study highlights the reality that although tensions (identified through discrepant beliefs) were recorded, researchers may not always acknowledge that these are important to resolve. If researchers do not need to spend time in the classroom, the tensions are not pressing for them.

The variation in researchers' definitions of LPs coupled with epistemological disparities of LPs may trickle down to teachers' simplistic definition of LPs and their lack of implementing LPs to the fullest extent posed by the researchers. Support for this claim is shown in teacher responses defining LPs as rubrics and using them simply as rubrics (Figure 8). Researchers' perspectives of how to implement reform may be influenced by common epistemological philosophies that do not account for introspection, bias, or inclusion when studying phenomena (Sullivan, 2002). Although, Harding (1998) argued that how science research is conducted is inherently biased based on the perspectives of the researchers. Similarly, Kuhn (1996) reminded researchers that cultural and social contexts cannot be divorced from the scientific endeavor, no matter how much objectivity scientists strive to achieve. Scientific research is socially embedded, either in cultural and political contexts, or in the fact that researchers communicate with one another to exchange ideas (Kuhn, 1996). This study does not suggest what beliefs are correct nor how researchers should mediate their own tensions of beliefs or that the LP model, but suggest that researcher take a more active stance in describing their beliefs and how they mediate the tensions in their beliefs.

Teacher Beliefs of Learning and Instruction

Teacher participants' beliefs about instruction and the tensions involved were also varied. Some held teacher-centered beliefs, while others held more student-centered beliefs (Table 5). Interestingly, middle school teachers tended to have more student-centered beliefs than high school teachers (Table 5). Tsai (2002) found that high school teachers commonly held positivistic belief systems and posited that teachers who hold positivistic views of science and science instruction may be rooted in their experience. Teachers' exposure to science classes, professional development, and science curriculum that reinforce positivistic views on science without giving exposure to other ways of knowing likely influence beliefs about teaching science. If teachers were educated in programs that presented science in positivist ways without science pedagogy courses that simultaneously explored how people learn in constructivist ways, some teachers may have struggled with adopting the LP model and changing their instructional practices. Trumbull and Slack (1991) argued that teachers fail to develop an understanding of constructivist beliefs about teaching and learning, if their science education indoctrination programs/ experiences have been in educational environments that do not embrace constructivist conceptions of learning and teaching. In another example, Spillane and Zeuli (1999) found that mathematics teachers who were committed to their domain-general epistemological beliefs (that knowledge is certain and static, rather than uncertain and dynamic) had problems changing their instructional strategies even learning about teaching reform strategies. Gill et al. (2004) explained that according to the national mathematics standards, knowledge is presented as something that is complex and uncertain, and therefore well aligned with constructivist epistemologies, unlike the domain-specific epistemology that knowledge can be learned passively.

In comparison to researcher participants, teacher participants tended to demonstrate more student-centered beliefs than their academic counterparts (Tables 5 and 6). This correlation can also be triangulated with the similar trend of middle school teacher having more student-centered beliefs than high school teachers (Table 5). Whether there is a link or relationship between working with younger students and having an epistemological orientation deserves further examination. Bryan (2003) described the complexity of “nested beliefs” or tensions in complex sets of beliefs that elementary teachers hold as they navigate potentially competing views of how to teach science: either through didactic approaches comparable to their own learning experiences or constructivist approaches that they learned as in-service teachers. Additionally, Midgley, Anderman, and Hicks (1995), through their survey study, demonstrated that elementary teachers tend to be more task-oriented compared to secondary teachers, who tend to be more performance-oriented. Task oriented instruction focuses on students demonstrating that they know concepts, whereas performance oriented instruction focuses on grade outcomes. The different orientations may be explained by teachers' responses to students' developmental levels but are also likely due to structural characteristics of secondary schools that aim to prepare students to more specialized disciplinary studies.

Many studies emphasize the importance of bearing in mind all stakeholders' beliefs of what is effective reform (Gess-Newsome, 1999; Keys & Bryan, 2001; Woodbury & Gess-Newsome, 2002; Tengo et al., 2014). However, published LP research lacks the explicit mention of teacher beliefs (Alonzo, 2011; Corcoran, Mosher, & Rogat, 2009; Duschl, Maeng, & Sezen, 2011; Gotwals & Songer, 2013; Metz, 2009; Mohan, Chen, & Anderson, 2009; Shavelson & Kurpius, 2012). These findings support both the previously published need to incorporate all stakeholder beliefs and the lack of research incorporating stakeholder beliefs in science education reform (Gess-Newsome, 1999; Keys & Bryan, 2001; Woodbury and Gess-Newsome, 2002; Tengö, Brondizio, Elmqvist, Malmer, & Spierenburg, 2014). If reform policies are to be meaningful, achievable, and sustainable, it behooves researchers and policy makers to identify and acknowledge the beliefs and tensions that teachers face (Woodbury & Gess-Newsome, 2002).

Furthermore, the fact that teachers were not given access to the grant proposal that funded the project and the TiR salaries highlights the divide between theory and practice in this particular project. The researchers may not have thought that providing the proposal to teachers was necessary; the teachers may not have thought to ask to read the proposal. In fact, I did not ask either set of stakeholders about access to this document because it was not obvious to me until I began the data analysis. In retrospect, it is a question worth pursuing because access to knowledge can empower stakeholders and engage them in different levels and types of conversations about teaching, learning, and pedagogy (Basu and Barton, 2010).

Comparison of Researcher and Teacher Beliefs

The most important finding in this study is the fact that researcher participants and teacher participants had different ideas about and tensions around how students learn and how teachers should teach. Teachers were more student-centered and espoused constructivist beliefs while researchers were more teacher-centered and espoused positivistic belief (Tables 5 and 6). Researchers and teachers' beliefs were influenced by different personal, structural, and cultural factors (Figures 8a and 8b). Moreover, teachers described more holistic views of student assessment that include informal affective and emotive assessments (Figure 8). Other researchers have found that reformers and teachers view reform differently. For example, Trachtman and Cooper (2011) found that reformers (in their study, administrators) and teachers approached instructional reform from different angles; they attributed this to different job expectations for mentees (teachers) and mentors (reformers). While researchers explicitly mentioned how hard it is to translate theory to practice, they never provided specific examples or specific solutions that would be meaningful to teachers. Much of the researchers' discourse, therefore, remained theoretical and less practical. In contrast, teachers were able to support most, if not all, of their beliefs in personal experiences and classroom examples. Thus, there appeared to be a "lost in translation" component of this LP reform effort. Teachers interpreted the intentions of the LP model from their epistemological frame, which the researchers did not necessarily share. There are many other examples of struggling science education reform initiatives due to the lack of insight, co-dialog, and collaboration between researchers and teachers (Gess-Newsome, 1999; Keys & Bryan, 2001; Woodbury and Gess-Newsome, 2002; Tengö, Brondizio, Elmqvist, Malmer, & Spierenburg, 2014).

In summary, although there has been a plethora of research about science education reform, research on the belief/viewpoints of researchers or even the viewpoint of teachers has been minimal (Kyle, 1994; Basu and Barton, 2010). Kyle (1994) is quoted to say: "The big advances in understanding about student learning have not been matched by equivalent advances in understanding about teaching. How to teach under real world conditions in such a manner as to foster this kind of learning is not as well understood as learning per se" (p. 36). A possible symptom of this lack of understanding beliefs and viewpoints of all stakeholders on learning is the differences in this study on how teachers and researchers define LPs as well as how they implement them. At a minimal, this study supports previous studies in science education reform and professional development finding trends in the lack of co-development or understanding between reform developers and reform practitioners as a significant barrier in creating sustainable science education reform (Kyle, 1994; Gess-Newsome, 1999; Keys & Bryan, 2001; Woodbury and Gess-Newsome, 2002). Beyond this finding, this study also establishes a small excursion into studying and the importance of studying researcher and teacher beliefs systems on learning.

Conclusion and Implications

It is imperative that science education reform create a two-way collaborative research environment between both the producers of science education reforms and the practitioners of science education. Although this is often the intention of educational reformers, Kennedy (2004) purports that reformers often forget or overlook the complexity of implementing and enacting reform in classrooms. Teachers draw on emotive evidence and often feel isolated in their individual rooms (Kennedy, 2004); and in this sense, are removed from reformers' ideas in ways that are often not recognized. If scientific research traditions strive for objectivity, they do not recognize emotive or affective data, so it is not surprising that these types of data that teachers use in their daily informal assessment strategies were ignored by the researchers in my study.

Validation of different belief systems between stakeholders is generally an explicit requirement for the integration of different knowledge systems (Agrawal, 1995). In other words, teachers hold beliefs, and if reformers hope to change teachers' beliefs, they must recognize that teachers will need to negotiate and then compromise different (potentially conflicting) epistemologies. Tengö et al. (2014) published a multiple evidence-based (MEB) approach model as one way to incorporate stakeholders' belief systems with researcher knowledge systems in a collaborative synergistic way. The goal of the MEB model is to frame reform in ways that develop functioning and sustainable mechanisms to build strongly knit relationships between producers and practitioners. Tengö et al. (2014) designed this model in the context of management of biodiversity and ecosystems in local communities; however, this model is generalizable across different reform domains. The authors postulated that by weaving the diverse knowledge bases of both local and researcher groups an enriched picture is created of the selected problem or issue of concern (Tengö et al., 2014). From this enriched picture, research with the goal of sustainable reform can occur through the integration of knowledge, cross-fertilization of knowledge and the co-production of knowledge (Figure 10).

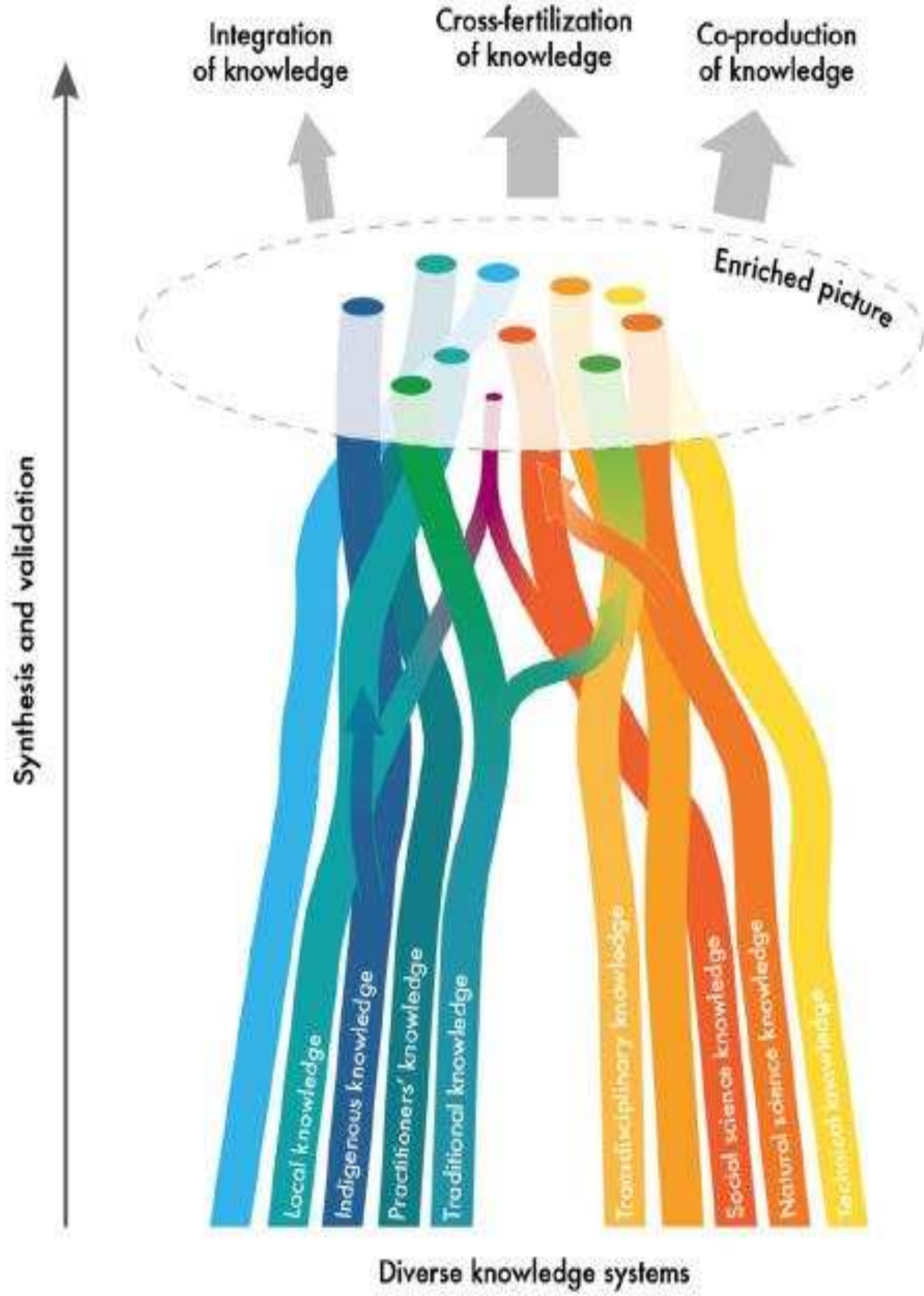

Figure 10. The Multiple Evidence Base (MEB) approach, where diverse knowledge systems contribute to generate an enriched picture of a selected problem or issue of concern. (copied from Tengo et al., 2014).

While abstract, Tengö et al.'s (2014) model may be a relevant model for a discussion of how educational reforms and instructional practitioners can negotiate their different perspectives and epistemologies. Because educational reform efforts are often top down and do not start with increasing teachers' agency (Cuban, 1990), a modified MEB model within the context of K12 science education reform may challenge the common ways of initiating science education reform (Figure 11). In the original MEB model the various stakeholder groups and belief systems are nested as: "indigenous knowledge," "local knowledge," "social science knowledge," "natural science knowledge," and "technical knowledge." In the context of K12 science education reform, the various stakeholder groups and beliefs systems include "researchers' beliefs about learning," "researchers' beliefs about teaching," "administrators' beliefs about learning," "teachers' beliefs about learning," and "teachers' beliefs about teaching" (Figure 11). The over-arching findings indicate that there are tensions in beliefs both within stakeholder groups as well as between stakeholder groups. The modified MEB model offers a way going forward to improve how LPs may be translated from theory to practice. In other words, the modified MEB model offers a pathway which to illuminate and collaborate these diverse belief systems that can be synergistic and create knowledge that can perpetuate sustainable science education reform.

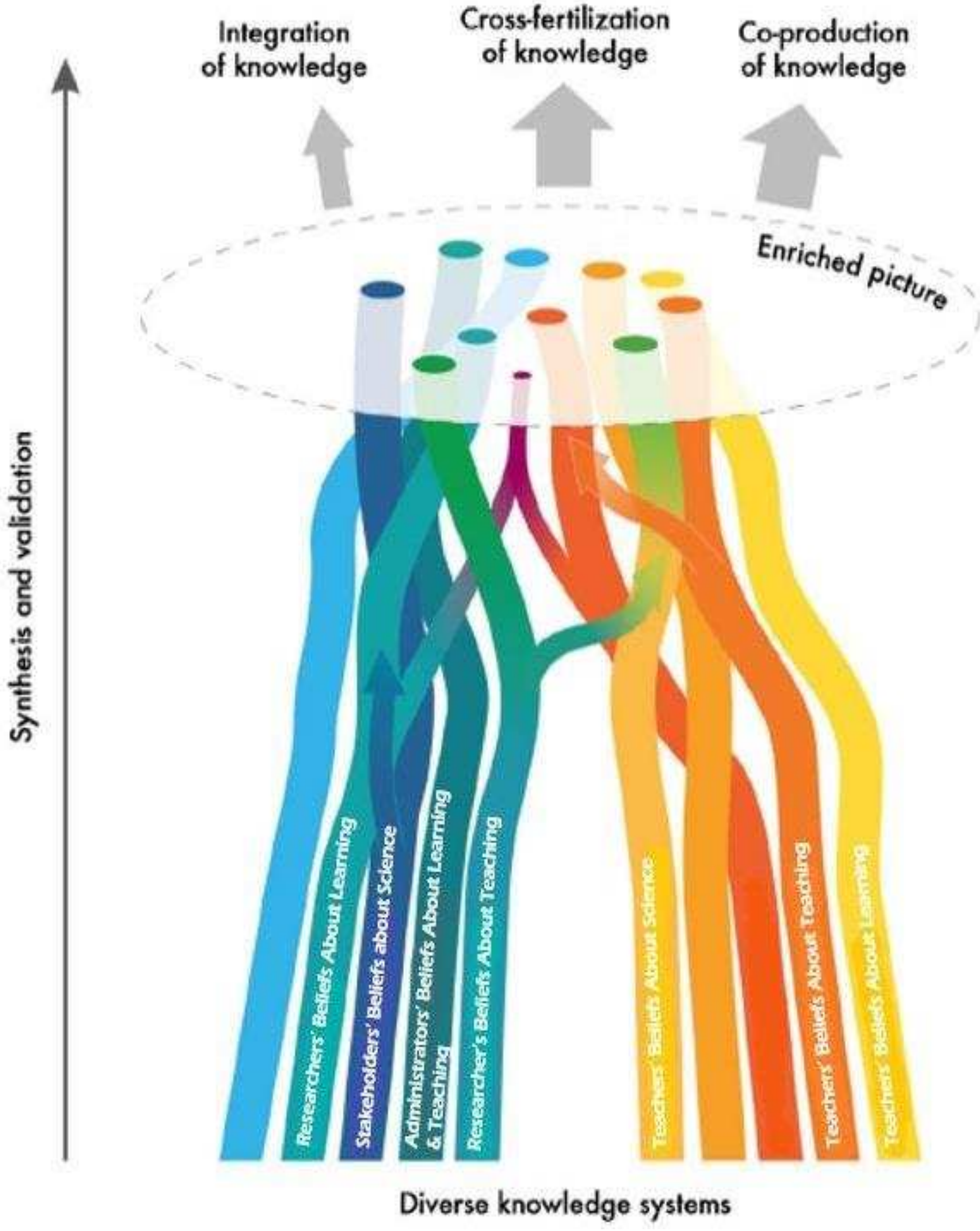

Figure 11. A modified model of the Multiple Evidence Base (MEB) approach model, placed in the context of science education reform (modified from Tengö et al., 2014).

Similar to the MEB model, Reid and colleagues (2009) developed a "continual engagement" model to better integrate knowledge from researchers and practitioners in the context of wildlife conservation in pastoral ecosystems (Reid et al., 2009). Reid et al.'s (2009) model centers on the creation of collaborative researcher-facilitator community teams. These teams were integrated into local communities to improve and sustain reform in conservation of pastoral ecosystems. Reid et al. (2009) concluded that through the creation of "hybrid scientific-local knowledge" domains, their co-developed reform initiatives were more relevant, more likely to be implemented, and became more sustainable. The modified MEB model provides a theoretical standpoint to engage in reform, while Reid's (2009) "continual engagement" model takes this one step further by providing specific relationships between stakeholders that fosters collaborative knowledge generation and sustainable reform.

Integrating Reid's (2009) model with the modified MEB model within the context of school reform can inform researchers and teachers on how to form teams and collectively enact reform in school or university settings. The integration of these models offers a novel approach for creating a "continual engagement" between LP researchers, teachers, and participating students. In this context, a "continual engagement" model would include all stakeholders in multiple aspects of information gathering, interpretation, and development of LP models, potentially through a participatory action research process (McIntyre, 2007). By creating a research environment that is conducted by stakeholders and for stakeholders who are taking action allows for the inclusiveness of all individual's belief systems. Although this was the intended model in the NSF project, the reality was that a few select teachers were invited to become a part of the researchers' communities (i.e., universities) to become TiRs. The NSF TiR program allows these few teachers to be immersed in research in a year-long fellowship while they are on sabbatical leave from their school districts. The purpose of this program is to familiarize teachers with how research is conducted in institutions of higher education, and in the process, to become an ambassador for science education reform models. The relationship was never reversed; researchers were never expected to become immersed in the school environment. As a result, the TiRs had the burden of negotiating different epistemologies. This onus was not felt by the researchers who designed and financially supported the reform. The using the modified MEB model and Reid’s (2009) continuous engagement model would allow teachers and researchers to explicitly identify and reflect on different beliefs about teaching. Interestingly, the NSF does not have a reciprocal initiative to place researchers in K-12 classrooms, although they do support graduate students doing so in their NSF G-12 Fellowship Program. The National Center for Science Education, however, has a program called “Scientists in the Classroom” (National Center for Science Education, 2016), but it is not financially supported and is not tied towards research development. As a result, this program may not be practical for academic scientists and science educational researchers.

If the goal of LPs is to provide a model for teachers to apply in an effort to align curriculum to science education standards and students’ cognitive abilities, then we must find ways to align diverse sets beliefs. With this in mind, the tensions of different beliefs both within and between stakeholder groups found in this study illuminate this need. There are several possible ways forward using existing models to implement change and the integration of diverse knowledge systems is just one way that may support sustainable reform. Future LP research needs to more explicitly acknowledge both researchers and beliefs so all stakeholders can work through their respective tensions. By collaboratively working to design and implement science education reform programs, stakeholders can create LP models that are 1) meaningfully grounded in theoretical and practical evidence, 2) effectively implemented by teachers, and 3) sustainable in classrooms once reformers leave schools (or have no more funding to support reform efforts).

REFERENCES

Acar, O., Turkmen, L., & Roychoudhury, A. (2010). Student difficulties in socioscientific argumentation and decision-making research findings: Crossing the borders of two research lines. *International Journal of Science Education, 32*(9), 1191-1206.

Agrawal, A. (1995). Dismantling the divide between indigenous and scientific knowledge. *Development and Change,* 26: 413–439.

American Association for the Advancement of Science. (1985). *Project 2061: Education for a Changing Future: Phase 1, What Understanding of Science & Technology Will be Important for Everyone in Tomorrow's World?* New York, NY: ERIC Clearinghouse.

American Association for the Advancement of Science. (1989). *Science for all Americans: Summary, project 2061*. New York, NY: ERIC Clearinghouse.

American College Testing. (2012). *The Condition of College and Career Readiness: 2012*. Retrieved from: http://media.act.org/documents/CCCR12-NationalReadinessRpt.pdf

Anderson C., Wilson M., Schwille K., Mohan L., Gallagher D. (2010). *Award Abstract #1020187 CCE: A Learning Progression-based System for Promoting Understanding of Carbon-transforming Processes*. Retrieved from https://nsf.gov/awardsearch/showAward?AWD_ID=1020187

Alonzo, A. C. (2011). Learning progressions that support formative assessment practices. *Measurement: Interdisciplinary Research and Perspective*, *9*(2-3), 124-129.

Auguste, B., Hancock, B., & Laboissière, M. (2009). The economic cost of the US education gap. *McKinsey Quarterly*. Retrieved from http://www.sefi.be/wpcontent/uploads

Ausubel, D. P. (1963). Cognitive structure and the facilitation of meaningful verbal learning.

Journal of Teacher Education, *14*, 217–221.

Balgopal, M. M., & Montplaisir, L. M. (2011). Meaning making: What reflective essays reveal about biology students' conceptions about natural selection. *Instructional Science*, 39(2), 137-169.

Bandura, A. (1994). *Self-efficacy*. John Wiley & Sons, Inc. 39(2), 137-169.

Bandura, A. (1997). *Self-efficacy: The Exercise of Self-control*. Gordonsville, VA: WH Freeman & Co.

Bandura, A., & Locke, E. (2003). Negative self-efficacy and goal effects revisited. *Journal of Applied Psychology*, 88(1), 87.

Basu, S., and Barton, A. (2010). A researcher-student-teacher model for democratic science pedagogy: Connections to community, shared authority, and critical science agency. *Equity & Excellence in Education*, *43*(1), 72-87.

Bell, B., & Cowie, B. (2001). The characteristics of formative assessment in science education. *Science Education*, *85*(5), 536-553.

Bell, P., Bricker, L., Lee, T. , Reeve, S., & Zimmerman, H. (2006). Understanding the cultural foundations of children's biological knowledge: Insights from everyday cognition research. *Proceedings of the 7th International Conference on Learning Sciences*.1029-1035.

Bennett, R. E. (2011). Formative assessment: a critical review. *Assessment in Education: Principles, Policy and Practice*, *18*, 5-25.

Birkimer, J. C., & Brown, J. H. (1979). Back to basics: Percentage agreement measure are adequate, but there are easier ways. *Journal of Applied Behavior Analysis*, *12*(4), 535-543.

Black, P. J. (1993). Formative and summative assessment by teachers. *Studies in Science Education*, *21*, 49-97.

Black, P., & Wiliam, D. (1998). Assessment and classroom learning. Assessment in Education, *5*, 7–74.

Boyatzis, R. E. (1998). T*ransforming Qualitative Information: Thematic Analysis and Code Development*. Thousand Oaks, CA: Sage.

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology*, *3*(2), 77-101.

Brown, A.L., & Campione, J.C. (1994). Guided discovery in a community of learners. In K. McGilly (Ed.), *Classroom Lessons: Integrating Cognitive Theory and Classroom Practice.* P. 229–270. Cambridge, MA: MIT Press.

Bruner, J. (1960). *The Process of Education*. Cambridge, MA: Harvard University Press.

Bruner, J. S. (1966). *Toward a Theory of Instruction*. New York, NY: Norton.

Bryan, L. A. (2003). Nestedness of beliefs: Examining a prospective elementary teacher's belief system about science teaching and learning. *Journal of Research in Science Teaching*, *40*(9), 835-868.

Burrell, G., & Morgan, G. (1979). *Sociological Paradigms and Organisational Analysis* (Vol. 248). London: Heinemann.

Bybee, R. (2013). The next generation science standards and the life sciences: the important features of life science standards for elementary, middle, and high school levels. *NSTA Journal Series: Exploring the Science Framework and Preparing for NGSS.1*(1). 7-14.

Case, R. (Ed.). (1992). *The Mind's Staircase: Exploring the Conceptual Underpinnings of Children's Thought and Knowledge*. Hillsdale, NJ: Erlbaum.

Carpenter, T.P., & Lehrer, R. (1999). Teaching and learning mathematics with understanding. *Classrooms that Promote Mathematical Understanding*. (pp. 19–32). Mahwah, NJ: Erlbaum.

Chi, M. T. H., Feltovich, P. J., & Glaser, R. (1981). Categorization and representation of physics problems by experts and novices. *Cognitive Science*, 5, 121–152.

Clark, C. M., & Peterson, P. L. (1986). Teachers' thought processes. *Handbook of Research on Teaching* (pp. 255-296). New York: Macmillan.

Colorado Department of Education (2013). *Colorado and the Next Generation Science Standards (NGSS).* Retrieved from: http://www.cde.state.co.us/coscience/colorado-and-ngss

Cooper, H.(1998). *Synthesizing Research: A Guide for Literature Reviews.* Thousand Oaks, CA: Sage Publications.

Corcoran, T., Mosher, F. A., & Rogat, A. (2009). *Learning progressions in science: Centre for Continuous Instructional Improvements.* Columbia University, New York: Teacher College Press.

Coyne, I T. (1997). Sampling in qualitative research: Purposeful and theoretical sampling; merging or clear boundaries? *Journal of Advanced Nursing*, 26(3), 623-30.

Creswell, J. W. (2012). *Qualitative Inquiry and Research Design: Choosing Among Five Approaches*. Thousand Oaks, CA: Sage publications.

Cuban, L. (1990). A fundamental puzzle of school reform. *Schools as collaborative cultures: Creating the future now*, 71-77.

De Jong, O. (2007). Trends in western science curricula and science education research: A bird's eye view. *Journal of Baltic Science Education*, *6*(1), 15-22.

Dulberg, N. (2005). “The theory behind how students learn:” applying developmental theory to research on children's historical thinking. *Theory and Research in Social Education*, *33*(4), 508-531.

Duncan, R. G. & Hmelo-Silver, C. E. (2009). Learning progressions: aligning curriculum, instruction, and assessment. *Journal of Research in Science Teaching*, *46*(6), 606-60.

Duschl, R. A., Schweingruber, H. A., & Shouse, A. W. (Eds.). (2007). *Taking science to school: Learning and teaching science in grades K-8*. National Academies Press.

Duschl, R., Maeng, S., & Sezen, A. (2011). Learning progressions and teaching sequences: A review and analysis. *Studies in Science Education*, *47*(2), 123-182.

Duschl, R. A., & Grandy, R. (2013). Two views about explicitly teaching nature of science. *Science & Education*, *22*(9), 2109-2139.

Erduran, S., Simon, S., & Osborne, J. (2004). TAPping into argumentation: developments in the application of toulmin's argument pattern for studying science discourse. *Science Education*, *88*(6), 915-933.

Ernest, P. (1989). The knowledge, beliefs, and attitude of the mathematics teacher: A model. *Journal of Education for Teaching, 15*, 13-34.

Fennema, E., Carpenter, T. P., Franke, M. L., Levi, L., Jacobs, V. R., & Empson, S. B. (1996). A longitudinal study of learning to use children’s thinking in mathematics instruction. *Journal for Research in Mathematics Education*, *27*(4), 403-434.

Fennema, E., & Franke, M. L. (1992). Teachers’ knowledge and its impact. *Handbook of Research on Mathematics Teaching and Learning* (pp. 147-164). NewYork: Macmillan.

Fischer, K. W. & Farrar, M. J. (1987). Generalizations about generalization: How a theory of skill development explains both generality and specificity. *International Journal of*

Psychology, 22, 643-677

Fischer, K. W & Silvern, L. (1985). Stages and individual differences in cognitive development. *Annual Review of Psychology*, *36*, 613-648.

Flavell, J. H. (1982). On cognitive development. *Child Development*, *53,* 1-10.

Flavell, J. H. (1985). *Cognitive Development* (2nd ed.). Englewood Cliffs, NJ: Prentice-Hall.

Flavell, J. H. (1992). Cognitive development: Past, present, and future. *Developmental Psychology, 28*(6), 998.

Foster, J., & Wiser, M. (2012). The potential of learning progression research to inform the design of state science standards. *In Learning Progressions in Science* (pp. 435-460). Rotterdam, Netherlands: Sense Publishers.

Fuller, S. (1997). *Science*. Buckingham, UK: Open University Press

Furtak, E. M., & Heredia, S. C. (2014). Exploring the influence of learning progressions in two teacher communities. *Journal of Research in Science Teaching*, *51*(8), 982-1020.

Gagne, R. M. (1965). *The Conditions of Learning*. New York, NY: Holt, Rinehart and Winston.

Gee, P. (1990). *Social Linguistics and Literacies: Ideology in Discourses, Critical Perspectives on Literacy and Education.* New York, NY: Routledge

Gess-Newsome, J. (1999a). Teachers' knowledge and beliefs about subject matter and its impact on instruction. *Pedagogical content knowledge: The Construct and Its Implications for Science Education*. Dordrecht, the Netherlands: Kluwer.

Gess-Newsome, J. (1999b). Pedagogical content knowledge: An introduction and orientation. *Examining Pedagogical Content Knowledge*. Boston: Kluwer Academic Publishers.

Gess-Newsome, J., & Lederman, N. G. (1995). Biology teachers' perceptions of subject matter structure and its relationship to classroom practice. *Journal of Research in Science Teaching*, *32*(3), 301-325.

Gill, M. G., Ashton, P. T., & Algina, J. (2004). Changing preservice teachers' epistemological beliefs about teaching and learning in mathematics: An intervention study. *Contemporary Educational Psychology*, *29*(2), 164-185.

Glaser, R. (1963). Instructional technology and the measurement of learning outcomes. *American Psychologist*, *18*, 510–522.

Glaser, R. (1984). Education and thinking: The role of knowledge. *American Psychologist*, *39*(2), 93.

Gotwals, A. W. & Songer, N. B. (2010). Reasoning up and down a food chain: using an assessment framework to investigate students' middle knowledge. *Science Education*, *94*, 259–281.

Gotwals, A. W. & Songer, N. B. (2013). Validity evidence for learning progression-based assessment items that fuse core disciplinary ideas and science practices. *Journal of Research in Science Teaching*. *49*(4), 192-213.

Halliday, M. A. K. & Martin, J. R. (1993). *Writing Science: Literacy and Discursive Power*. *Pittsburgh*, PA: University of Pittsburgh Press.

Harding, S. G. (1998). *Is Science Multicultural: Postcolonialisms, Feminisms, and Epistemologies*. Bloomington, IN: Indiana University Press.

Hayes, N. (1997). *Theory-led Thematic Analysis: Social Identification in Small Companies*. In N. Hayes (Ed.), Doing Qualitative Analysis in Psychology. Hove, UK: Psychology Press.

Heppner, F., Hammon, C., Kass-Simon, G., & Kruger, W. (1990). A de facto standardized curriculum in US college biology and zoology. *Bioscience*, *40*(2), 130-134.

Hollon, R. E., Roth, K. J., & Anderson, C. W. (1991). Science teachers' conceptions of teaching and learning. *Advances in Research on Teaching*, *2*, 145-186.

Inhelder, B. & Piaget, J. (1958). *The Growth of Logical Thinking from Childhood to Adolescence*. New York: Basic Books.

Inhelder, B. & Piaget, J. (1964). *The Early Growth of Logic in the Child: Classification and Seriation*. London: Routledge and Paul.

Irzik, G., & Nola, R. (2011). A family resemblance approach to the nature of science for science education. *Science & Education*, *20*(7-8), 591-607.

Jenkins, E. (1990). Scientific literacy and school science education. *School Science Review*, 71, 43–51.

Ji-Sook, H. (2009). *Relationship Between three Levels of Epistemology of Science and Three Stages of Scientific Reasoning Ability*.(Unpublished doctoral dissertation), Arizona State University, Tempe, Arizona

Karplus, R., & Butts, D. P. (1977). Science teaching and the development of reasoning. *Journal of Research in Science Teaching*, *14*(2), 169-175.

Kennedy, C. A., Brown, N. J., Draney, K., & Wilson, M. (2005, April). Using progress variables and embedded assessment to improve teaching and learning. *American Education Research Association*. Presented at the annual meeting of the American Education Research Association, San Francisco, California.

Keys, C. W., & Bryan, L. A. (2001). Co-constructing inquiry-based science with teachers: Essential research for lasting reform. *Journal of Research in Science Teaching*, *38*(6), 631-645.

Krummheuer, G. (1995). *The Ethnography of Argumentation.* Hillsdale, NJ: Lawrence Erlbaum.

Kuhn, T. (1996). *The Structure of Scientific Revolutions*. Chicago, IL: University of Chicago Press.

Kyle, W.C. (1994). School reform and the reform of teacher education: Can we orchestrate harmony? *Journal of Research in Science Teaching*, 31, 785 - 786.

Laugksch, R. C. (2000). Scientific literacy: A conceptual overview. *Science Education*, *84*, 71-94.

Lawson, A., Alkhoury, S., Benford, R., Clark, B.., & Falconer, K. (2000). What kinds of scientific concepts exist? concept construction and intellectual development in college biology. *Journal of Research in Science Teaching*, *37*, 996-1018.

Lijphart, A. (1971). Comparative politics and the comparative method. *The American Political Science Review*, 65, 682-694.

Louden, W. (1992). Understanding reflection through collaborative research. *Understanding Teacher Development*, 178-215.

Luft, J. A., & Roehrig, G. H. (2007). Capturing science teachers' epistemological beliefs: The development of the teacher beliefs interview. *Journal of Science Education*, *11*(2).

Matloob Haghanikar, M. (2012). *Exploring Students' Patterns of Reasoning*. (Unpublished doctoral dissertation). Kansas State University. Manhattan, Kansas

McIntyre, A. (2007). *Participatory action research* (Vol. 52). Sage Publications.

MacKay, T. (2003, March). Gee's theory of D/discourse and research in teaching English as a second language: Implications for the mainstream. In *Proceedings of the Symposium" Theory, Culture and Discourse in Education*.

McKinsey & Company. (2009). *The Economic Impact of the Achievement Gap in America's Schools*. Atlanta, GA: McKinsey & Company.

Merriam, S.B. (1985). The case study in educational research: a review of selected literature. *Journal of Educational Thought*, 19(3), 204-217.

Merriam, S. B. (2009). *Qualitative Research: A Guide to Design and Implementation*. San Francisco, CA: Jossey-Bass.

Metz, K. (2009). Rethinking what is "developmentally appropriate" from a learning Progression perspective: The power and the challenge. *Review of Science, Mathematics and ICT Education, 3*(1), 5-22.

Midgley, C., Anderman, E., & Hicks, L. (1995). Differences between elementary and middle school teachers and students: A goal theory approach. *The Journal of Early Adolescence*, *15*(1), 90-113.

Miles, M.B. & Huberman, A.M. (1994). *Qualitative Data Analysis: A Sourcebook of New Methods* (2nd e.d). Thousand Oaks, CA:Sage.

Mohan, L., Chen, J., & Anderson, C. W. (2009). Developing a multi-year learning progression for carbon cycling in socio-ecological systems. *Journal of Research in Science Teaching*, *46*(2). 56-78.

Morgan, D. L. (2007). Paradigms lost and pragmatism regained methodological implications of combining qualitative and quantitative methods. *Journal of Mixed Methods Research*, *1*(1), 48-76.

Morse, J. M. (2003). Principles of mixed methods and multimethod research design. *Handbook of Mixed Methods in Social and Behavioral Research*, (pp. 189-208). Thousand Oaks, CA: SAGE Publications.

National Assessment Governing Board (NAGB). (2008). *Science Framework for the 2009*

National Assessment of Educational Progress. Washington, D.C.: US Department of Education.

National Center for Education Statistics (2011).The Nation's Report Card: Science 2009 (NCES 2011–451). *Institute of Education Sciences* (pp. 675 -698). Washington, D.C.: U.S. Department of Education.

National Center for Science Education (2016). *Scientists in the Classroom*. Retrieved from https://ncse.com/scientistinclassroom.

National Research Council (2000). *How People Learn*. (Ed.). Washington, DC: National Academy Press.

National Research Council. (2005). *Systems for State Science Assessment*. Washington, D.C.: National Academy Press.

National Research Council (2007). *Taking Science to School: Learning and Teaching Science In Grades K-8.* Committee on Science Learning, Kindergarten through eighth grade. Washington D.C.: National Academy Press.

National Research Council (1996). *National Science Education Standards*. Washington, DC: The National Academy Press.

National Research Council (2012). *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas*. Washington, D.C.: The National Academy Press.

National Science Board (2012). *Science and Engineering Indicators 2012*. Arlington VA: National Science Foundation.

National Science Teachers Association (2014). *NSTA Position Statement: the Next Generation Science Standards*. Retrieved from http://www.nsta.org/docs/PositionStatement_NGSS.pdf

Nespor, J. (1987). The role of beliefs in the practice of teaching. *Journal of Curriculum Studies*, *19*, 317–328.

NGSS.(2013). *Next Generation Science Standards: For States, By States.* Washington, DC: The National Academy Press.

Nieswandt, M. & Bellomo, K. (2009). Written extended-response questions as classroom assessment tools for meaningful understanding of evolutionary theory. *Journal of Research in Science Teaching*, *46*, 333-356.

Pajares, M.F. (1992). Teachers' beliefs and educational research: Cleaning up a messy construct. *Review of Educational Research*, *62*, 307–332.

Peterson, P. L., Fennema, E., & Carpenter, T. P. (1991). Teachers' knowledge of students' mathematics problem-solving knowledge. *Advances in Research on Teaching, 2*, 49-86.

Piaget, J. & Inhelder, B. (1969). *The psychology of the child*. New York, NY: Basic Books.

Project 2061, American Association for the Advancement of Science. (1989). *Science for All Americans: A Project 2061 Report on Literacy Goals in Science, Mathematics, and Technology* (Vol. 1). Washington, D.C.: AAAS

Programme for International Student Assessment. (2010). *PISA 2009 Results: What Students Know and Can Do: Student Performance in Reading, Mathematics and Science*. Paris: OECD.

Ralph, J., & Fennessey, J. (1983). Science or reform: some questions about the effective schools model. *The Phi Delta Kappan*, *64*(10), 689-694.

Reid, R. S., Nkedianye, D., Said, M. Y., Kaelo, D., Neselle, M., Makui, O., & Ogutu, J. (2009). Evolution of models to support community and policy action with science: Balancing pastoral livelihoods and wildlife conservation in savannas of East Africa. *Proceedings of the National Academy of Sciences*, *113*(17), 4579-4584.

Richardson, V. (1996). The role of attitudes and beliefs in learning to teach. *Handbook of Research on Teacher Education* (pp. 102–119). New York: Macmillan.

Russell, T. L. (1983). Analyzing arguments in science classroom discourse: Can teachers' questions distort scientific authority? *Journal of Research in Science Teaching, 20*(1), 27–45.

Schraw, G., Crippen, K. J., & Hartley, K. (2006). Promoting self-regulation in science education: Metacognition as part of a broader perspective on learning. *Research in Science Education*, *36*(1-2), 111-139.

Shepard, L. (2000, April). The role of assessment in a learning culture. *Presidential Address* Presented at the annual meeting of the American Educational Research Association, New Orleans, LA.

Salinas, I. (2009). Learning progressions in science education: Two approaches for development. *In Learning Progressions in Science.* Presented at the (LeaPS) Conference, Iowa City, IA.

Sadler, D. R. (1989). Formative assessment and the design of instructional systems. *Instructional Science*, *18*(2), 119-144.

Sadler, D. R. (1998). Formative assessment: Revisiting the territory. *Assessment in Education*, *5*(1), 77-84.

Sandelowski, M. (1995). Sample size in qualitative research. *Research in Nursing and Health*, *18*, 179-183.

Sarason, S. B. (1982). *The Culture of the School and the Problem of Change* (2nd ed.).

Boston: Allyn & Bacon

Schweingruber, H. (2006). *Thoughts on Advancing the Learning Progressions Framework. Measurement: Interdisciplinary Research and Perspective 4(1-2).* Retrieved from http://bearcenter.berkeley.edu/measurement/pubs/toc412.html

Shavelson, R. J. & Kurpius, A. (2012). Reflections on learning progressions. *In Learning Progressions in Science* (pp. 13-26). Rotterdam, Netherlands: Sense Publishers.

Shin, N., Stevens, S. Y., Short, H., & Krajcik, J. (2009, June). Learning progressions to Support coherence curricula in instructional material, instruction, and assessment design. *In Learning Progressions in Science Conference*. Conference conducted at Learning Progressions in Science Conference, Iowa City, Iowa.

Simon, S. (2008). Using Toulmin's argument pattern in the evaluation of argumentation in school science. *International Journal of Research & Method in Education*, 31(3), 277-289.

Smith, E. L., Blakeslee, T. D., & Anderson, C. W. (1993). Teaching strategies associated with conceptual change learning in science. *Journal of Research in Science Teaching*, *30*(2), 111-126.

Smith, C., Wiser, M., Anderson, C.W., & Krajcik, J. (2006). Implications for children's learning for assessment: A proposed learning progression for matter and the atomic molecular theory. *Measurement*, *14*(1-2), 1–98.

Stake, R. E. (1995). The art of case study research. Thousand Oaks, CA: Sage.

Steedle, J. T., & Shavelson, R. J. (2009). Supporting valid interpretations of learning progression level diagnoses. *Journal of Research in Science Teaching*, *46*, 699-715.

Stevens, S. Y., Shin, N., Delgado, C., Krajcik, J., & Pellegrino, J. (2007, April). Developing a learning progression for the nature of matter as it relates to nanoscience. *American Educational Research Association.* Presented at the AERA 2007 conference, Chicago, IL.

Sullivan, G. B. (2002, September). Reflexivity and subjectivity in qualitative research: The utility of a Wittgensteinian framework. In *Forum Qualitative Sozialforschung/Forum: Qualitative Social Research* (Vol. 3, No. 3).

Taber, K. S. (2009). *Progressing Science education: Constructing the Scientific Research Programme into the Contingent Nature of Learning Science*(Vol. 37). Springer Science & Business Media.

Taylor, C. (1996). *Defining Science.* Madison, WI: University of Wisconsin Press.

Tengö, M., Brondizio, E. S., Elmqvist, T., Malmer, P., & Spierenburg, M. (2014). Connecting diverse knowledge systems for enhanced ecosystem governance: the multiple evidence base approach. *Ambio*, *43*(5), 579-591.

Thompson, A. G. (1984). The relationship of teachers' conceptions of mathematics and Mathematics teaching to instructional practice. *Educational Studies in Mathematics*, *15*, 105-127.

Thompson, A. (1992). Teachers' beliefs and conceptions. In D. A. Grouws (Ed.), *Handbook Of Research on Mathematics Teaching and Learning* (pp. 127-146). New York: Macmillan.

Trachtman, R., & Cooper, B. S. (2011). Teaching principals to be master teachers, again. *Finding, Preparing, and Supporting School Leaders: Critical Issues, Useful Solutions*, 41.

Trumbull, D., & Slack, M. J. (1991). Learning to ask, listen, and analyze: using structured interviewing assignments to develop reflection in pre-service science teachers. International Journal of Science Education, 13 (2), 129–142.

Toulmin, S. (1958). *The Uses of Argument.* New York, NY: Cambridge University Press.

Tsai, C. C. (2002). Nested epistemologies: science teachers' beliefs of teaching, learning and science. *International Journal of Science Education*,*24*(8), 771-783.

Tsai, C. C. (2007). Teachers' scientific epistemological views: The coherence with instruction and students' views. *Science Education*, 91(2), 222-243.

Van Driel, J. H., Beijaard, D., & Verloop, N. (2001). Professional development and reform in science education: The role of teachers' practical knowledge. *Journal of Research in Science Teaching*, *38*(2), 137-158.

Wallace, C. S., & Kang, N. H. (2004). An investigation of experienced secondary science teachers' beliefs about inquiry: An examination of competing belief sets. *Journal of Research in Science Teaching*, *41*(9), 936-960.

Weinberg, A. E. (2013). *Computational Thinking: An Investigation of the Existing Scholarship and Research* (Doctoral dissertation, Colorado State University).

William, D., Lee, C., Harrison, C., & Black, P. (2004). Teachers developing assessment for learning: Impact on student achievement. *Assessment in Education*, *11*, 49–65.

Woodbury, S., & Gess-Newsome, J. (2002). Overcoming the paradox of change without difference: A model of change in the arena of fundamental school reform. *Educational Policy*, *16*(5), 763-782.

Woolley, S., & Woolley, A. (2004). Construct validity of a self-report measure of teacher beliefs related to constructivist and traditional approaches to teaching and learning. *Educational and Psychological Measurement*, *64*(2), 319-331.

Wright, B. (2004). More art than science: The post-secondary assessment movement today. *Elements of Quality Online Education: Into the Mainstream, 5*, 185-197.

Yilmaz-Tuzun, O., & Topcu, M. S. (2008). Relationships among preservice science teachers' epistemological beliefs, epistemological world views, and self-efficacy beliefs. *International Journal of Science Education*, *30*(1), 65-85

Yin, R.K. (1981). The case study crisis: some answers. *Administrative Science Quarterly, 26*, 58-65.

Zeidler, D. L. (2002). Dancing with maggots and saints: Visions for subject matter knowledge, pedagogical knowledge, and pedagogical content knowledge in science teacher education reform. *Journal of Science Teacher Education*, *13*(1), 27-42.

APPENDIX A

Prior NSF Teacher in Residence Interview Consent Form

By signing at the bottom of this page you are agreeing to participate in an interview regarding your previous participation as a Teacher in Residence within an NSF research project titled: Culturally Relevant Ecology, Learning Progressions and Environmental Literacy.
As part of the interview you will be asked several guiding questions regarding your beliefs on learning, teaching, and about the Learning Progression model, as depicted by the NSF project you participated in. Your answers will be shared with researchers and possibly used within my dissertation. Your participation in this study will help us improve science teaching in the future by understanding how research models are conveyed and used within science educators through the Teacher in Residence process.

Your privacy will be protected and no published or public work will associate your name with the data obtained within the interview. There is minimal risk involved in participating.

If you have any general questions please feel free to contact me (Neely Clapp, fnc6884@gmail.com). If you have any questions or concerns about your role and rights as a research participant, would like to obtain information or offer input, or would like to register a complaint about this research study, you may contact, anonymously if you wish, Colorado State University's Research Integrity & Compliance Review by phone: (970) 491-1553 or by e-mail: RICRO@research.colostate.edu
Thank you in advance for your consideration.

I ______________________ understand that my interview response will be used for research purposes.

Signature____ Date ___________________

Prior NSF Teacher in Residence Semi-Structured Teacher Interview Questionnaire

Thank you for volunteering your time and participating in this interview.

Introduction/Purpose:

The purpose of this interview is to learn and understand your perceptions of how a student learns, as well as your perceptions of Learning Progressions. With your permission, I will audio record our interview and then transcribe it on my personal computer. All of the identifying information (for example, your name, gender, specific grade level, specific names of the courses you teach, and your school name will be removed from any data analyses).

This interview is semi-structured. I will ask you thirteen questions, which I have handed to you, but I may ask other questions to help me clarify your comments. I anticipate that this interview will last around 45 minutes. Do you have any questions before we begin?

Questions:

1. How do you maximize student learning in your classroom?
2. How do you describe your role as a teacher?
3. How do you know when your students understand?
4. In the school setting, how do you decide what to teach and what not to teach?
5. How do you decide when to move on to a new topic in your classroom?
6. How do your students learn science best?
7. How do you know when learning is occurring in your classroom?
8. How can assessments of learning inform how you teach?

Part II:

1. Please describe the Learning Progression model in your own words.
2. Describe how LPs can support learning
3. Please describe your role and responsibilities as a Teacher-in-Residence within the NSF project at CSU?
4. Please explain how the TiR experience influenced how you teach about carbon (i.e., did it challenge or support your previous teaching strategies?) and How did it challenge or support your prior ideas about teaching?
5. I invite you to include other comments regarding your TiR experience, the LP model, or the experience returning to the classroom after a year-long sabbatical at the university.

Prior NSF Teacher in Residence Semi-Structured Researcher Interview Questionnaire

Thank you for volunteering your time and participating in this interview.

Introduction/Purpose:

The purpose of this interview is to learn and understand your perceptions of how a student learns, as well as your perceptions of Learning Progressions. With your permission, I will audio record our interview and then transcribe it on my personal computer. All of the identifying information (for example, your name, gender, specific grade level, specific names of the courses you teach, and your school name will be removed from any data analyses).

This interview is semi-structured. I will ask you thirteen questions, which I have handed to you, but I may ask other questions to help me clarify your comments. I anticipate that this interview will last around 45 minutes. Do you have any questions before we begin?

Questions:

1. How do you believe that student learning can be maximized in a classroom?
2. How would you describe the role of a teacher?
3. How do teachers know when their students understand?
4. Pretend you are a K-12 science teacher, how would you decide what to teach and what not to teach?
5. Again, pretend you are a K-12 science teacher, how would you decide when to move on to a new topic in your classroom?
6. How do students learn science best?
7. How would a teacher know when student learning is occurring in his/her classroom?
8. How can assessments of learning help teachers inform what they teach?

Part II:

1. Please describe the Learning Progression model in your own words.
2. Describe how LPs can support learning
3. Please describe your role and responsibilities as a Teacher-in-Residence within the NSF project at CSU?
4. Please explain how the TiR experience influenced how you teach about carbon (i.e., did it challenge or support your previous teaching strategies?) and How did it challenge or support your prior ideas about teaching?
5. I invite you to include other comments regarding your TiR experience, the LP model, or the experience returning to the classroom after a year-long sabbatical at the university.

Science Teacher Perceptions of Learning Progressions Recruitment E-mail

Hello, my name is Neely Clapp and I am a Doctorate Student from Colorado State University in the School of Education. We are conducting a research study on teacher beliefs of Learning Progressions, researcher beliefs of Learning Progressions, and how teacher-in-residence models may impact teacher practice around Learning Progressions. The title of our project is Science Teacher Interpretations and Implementations of Learning Progressions.

The Principal Investigator is Meena Balgopal and I am the Co-Principal Investigator. Given that you were a previous teacher-in-residence in a recent Math and Science Partnership Project we would like you to participate in a semi-structured interview. Participation will take approximately 45 minutes to one hour for the interview. Your participation in this research is voluntary. If you decide to participate in the study, you may withdraw your consent and stop participation at any time without penalty.

Would you like to participate?
If yes: Proceed.
If no: Thank you for your time.

We will not collect your name or personal identifiers. When we report and share the data with others, we will combine the data from all participants. There are no known risks or direct benefits to you, but we hope to gain more knowledge on teacher perceptions of Learning Progressions and how teacher-in-residence models may impact teacher practice around Learning Progressions.

You can contact me directly by e-mail: fnc6884@gmail or by phone (561)460-7181 if you have further questions regarding the study. If you have questions about your rights as a volunteer in this research, contact Janell Barker, Human Research Administrator, 970-491-1655.

Table 7. Initial 21 Codes from the Open Coding Analysis.

Codes	Code Description	Examples
Hard to translate to practice	Taking science or pedagogical theory and transcribing it into classroom instruction	"...the teacher needs to be a good coach essentially. That is easy to say and hard to pull off." - Participant #10.
External context	Outside factors that influence the behavior of the stakeholder's instruction. Ex: State & National Science Standards, Department Protocols.	"I can build my IB units based on what standards we are supposed to be covering for our grade level based on our district instruction" - Participant #8.
Internal context	Personal factors that influence the behavior of the stakeholder's instruction. Ex: Personal beliefs, age, personal pedagogy	"I am more inclined to focus on helping to build citizens" - Participant #8. "my background is environmental engineering. I brought a pretty good educational piece and application piece to my classroom already" - Participant #5.
Tension	Conflict between external and internal contexts	"rigor to them(K12 Sciende Dept.) is like "doing a lot of stuff" you know maybe not going deep into something it is like, rigor to them is doing very-giving them the chemistry you know to getting them so prepped for chemistry that it is really rigorous, even though they do not all need that." - Participant #9.
Frantic pace	Fast "race-like" coniditions in teaching in a K12 environment versus teaching/researching collegate academia	"The first couple of months in the classroom after my full year was a reality check. The treadmill was on high speed and it was flying hard" - Participant #5
Importance of Language as an assessment	Student use of specific scienific language/jargon as an indicator of student understanding	"That's very anthropomorphic not using science language when students are talking science" - Participant #3. "ways of viewing the world which are built into our language and therefore everybody acquires them and learns how to speak grammatical English or Spanish or whatever but are unscientific in important ways. Learning science is like learning a second language. " - Participant #10
Cognitive assessment	Writen or oral assessments that determine a student's understanding of science content	"A good pre-assessment with a clearly stated concepts and sub-concepts will allow the teacher to give a pre-assessment to find out where their students are. " - Participant #7
Affective assessment	Visual and oral clues from students that show their emotional response to instruction	"where is each student at, where is their frustration level, and if I hit that frustration level, then I am going to go on." - Participant #8
Focus on Citizenship	A internal context that instruction should emphasis "civic duty" and a students active engagement in a community	"I am more inclined to focus on helping to build citizens" - Participant #8. "will this content help you be more successful as a citizen or in conducting your own personal life." - Participant #10.
Formative assessment	Assessments which provide feedback to the instructor to modify instruction in ways to more efficiently connect with the study body.	"do a constant formative assessment of where a students' are and try to figure out if the student is struggling, why they are struggling" - Participant #4.
Generalization	The behavior of students can be patterned and predicted across a larger body of students.	"There is myriad of ways what could just be totally, can't be quite random because there is a pattern but something is at play and we are not pretending to understand what that is." - Participant #4. "knowledge of student general patterns of a students kind a of cognitive ability and where kids are at a different stages or ages" - Participant #6.
Non-Generalizable	The behavior of students is unique and individualistic. Due to this assessment need to cater to a greater diversity of student backgrounds, culture, and behavior.	"sometimes the assessments are not necessarily in a form that every student can identify with. This frustrates me about the standardized testing because standardized tests only are coming at you in one mode" - Participant #1
Rigor	Instruction based on science content tied to state and national science standards.	" I have already talked about it within our school and then we have a really, they, I do not know, rigor to them is like "doing a lot of stuff" you know maybe not going deep into something it is like, rigor to them is doing very-giving them the chemistry you know to getting them so prepped for chemistry that it is really rigorous, even though they do not all need that. " - Participant #9
LPs as a complex model	Defined the Learning Progression model as a complex model that ties predictiable student cognition, assessment, and instruction	"a framework that allows us to take data from assessments and moving through their responses and see which level they are at and what we can do to help connect them relationships. " - Participant #7
LPs as a Rubric	Defined the Learning Progression model as a rubric, standard, or basic formative assessment	"Oh it is definitely a rubric." - Participant #2. " Well, yeah, it is a formative assessment " - Participant #1
Budget	An external context regarding funding for instruction, research, or other aspects of a stakeholder's occupation	"The only thing that constrains them are budgets but everybody has got budgets, budgets and time, money and time, are the only things that constrain you and the rest is to be creative to come up with ways to present materials to challenge students and provide opportunities for them at the same time. " - Participant #4
Professionalism (Practical)	Methods of a instructional professional nested in day to day classroom activities and goals	"You have to maximize every minute that you have. It starts with the engagement. You need to get kids thinking from the very beginning. I technically use a prompt of the day. When the kids are walking in the classroom, they know what the routine is." - Participant #5

Professionalism (Theoretical)	Methods of a instructional professional nested in broad theory	"..old professionalism which is what tends to be advocated by teachers unions and university-based teacher education programs and that has to do with a typically encourages understanding students, multi-culturalism, teacher autonomy, standards….The new professionalism tends to make teachers more into performers or drill sergeants. What we are striving for is something more like what a good coach does which involves both being responsive to and understanding of the players the coach is working with and at the same time constantly pushing for higher standards of performance." - Participant #10.
Differentiation/Responsiveness	Pedagogy that focuses on understanding, connecting, and acknowledgeing varying students' backgounds, culture, and upbringing.	"Teaching middle school you never know what kind of elementary background the kids have. At the school I am in has a wide variety of feeder schools. You have to be able to support the ones that it is new to and yet continue to challenge the kids that already know it." - Participant #5. "the ability to build relationships with students." - Participant #7.
Teachers as facilitators	Teacher role as a guiding students to arrive at their own answers and understanding of the material	"As a teacher I am a facilitator. " - Participant #5. "Teachers are guides and mentors and someone that can engage kids in wanting to know more or just being inquisitive, seeking out information and not just like being alone." - Participant #9.
Trade-Offs	Compromising in instruction	"traditionally been a dilemma that if you do more of one you end up doing less of the other or even when you want to do them both at the same time. I think the only way out of this dilemma is to build up more professional resources than teachers typically have access to." - Participant #10.

APPENDIX B

Colorado State University
Knowledge to Go Places

PROTOCOL
Social, Behavioral & Education Research
Colorado State University

Protocol # 14-4879H
Date Printed: 01/20/2015

Protocol Title:	Science Teacher Perceptions of Learning Progressions
Protocol Type:	Social, Behavioral & Education Research
Date Submitted:	03/06/2014
Approval Period:	04/01/2014-03/18/2015
Important Note:	This Print View may not reflect all comments and contingencies for approval. Please check the comments section of the online protocol. Questions that appear to not have been answered may not have been required for this submission. Please see the system application for more details.

---

* * * Personnel Information * * *

IMPORTANT NOTE: Mandatory Personnel on a protocol are: Principal Investigator and Department Head. Only the Principal Investigator can submit the protocol; although other personnel listed on the protocol can create the protocol. Human Subjects Protection Training is mandatory for Principal Investigator, Co-Principal Investigator, and Key Personnel (as defined by NIH). Training must be updated every three (3) years.

Principal Investigator Mandatory

Name of Principal Investigator (Faculty, Staff or Postdoc)	Degree	Title
Balgopal, Meena	PhD	Assistant Professor
Email	**Phone**	**Fax**
Meena.Balgopal@colostate.edu	(970) 491-4277	
Department Name	**Campus Delivery Code**	
1588 School of Education		
Human Subjects Training Completed? PIs must complete Training every three (3) years		Y

Co-Principal Investigator

Name of Co-Principal Investigator (This can include Master's or Ph.D. students)	Degree	Title
Clapp, Neely	MEd.	Graduate Assistant
Email	**Phone**	**Fax**
Neely.Clapp@colostate.edu	(970) 491-1604	
Department Name	**Campus Delivery Code**	
1588 School of Education		
Human Subjects Training Completed? Co-PIs must complete Training every three (3) years.		Y

No training data is available.

Additional Co-Principal Investigator

Name of Additional Co-Principal Investigator	Degree	Title

Page 1 of 12

POUDRE SCHOOL DISTRICT

2/11/15

Neely Clapp,

Please consider this document as formal approval for you to conduct research within Poudre School District based on your application materials originally received 1/20/15. Research project name: "Interpretations and Implementations of Learning Progressions."

* Date of project: Between February 2015 and May 2016 (If additional time is needed to complete the study, please notify me via email).

* I would like to add two conditions: 1) it is requested that the researcher provide PSD an electronic copy of the project summary at the end of the project, and 2) if you decide to submit an article for publication, please provide an electronic version of the article to PSD when completed.

* Priority consideration for future research partnerships with PSD will be given to individual researchers that have a demonstrated track record of submitting final reports for PSD consideration.

* Please feel free to use this email in your correspondent with PSD schools and personnel regarding this research project.

This approval letter signifies that you have successfully met all PSD criteria for conducting research within PSD. Approval from building principals where research activities may occur is also needed prior to beginning research activities at any particular PSD school. Providing principal(s) with a copy of this letter is an important step in your communication with principals, but please keep in mind that principals have the right to refuse to participate in any proposed research activities that involve the students, teachers, or facilities that they are responsible for. Furthermore, a principal may exercise their right of refusal at any point during the implementation of an authorized research proposal. Thank you for considering Poudre School District as a research partner. Please feel free to contact me if you have any questions, and I look forward to reading your findings.

Dwayne Schmitz

Dwayne Schmitz, Ph.D. | Director of Research and Evaluation

POUDRE SCHOOL DISTRICT

970-490-3593
dschmitz@psdschools.org

What would you do if you knew you would not fail?

2407 LaPorte Avenue · Fort Collins, CO 80521-2297 · (970) 482-7420