AN EXPLORATION INTO THE INFLUENCE OF LABORATORY CONSTRAINTS ON BIOLOGY GRADUATE TEACHING ASSISTANTS' EPISTEMOLOGICAL BELIEFS AND SCIENCE INSTRUCTIONAL PRACTICES AS A COMPLEX SYSTEM

by

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With much love, I dedicate this work to my parents, Reno and Albertha 'Alphia' Napoleon, and my husband, Clifford Mario Fanis. Without your unconditional love, constant support, time, and encouragement, nothing I have ever accomplished would have been possible.

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ABSTRACT

Science reform is promoting change in undergraduate biology education. Biology graduate teaching assistants (GTAs) are vital instructors in undergraduate biology education. However, the culture of GTAs as laboratory instructors has not changed in a fashion that is analogous with the goals of science reform. Also, misalignments exist between GTAs' epistemological beliefs and science instructional practices that past research has not been able to explain.

An instructor's epistemological beliefs about teaching and learning are subject to laboratory constraints and can be transformed into classroom practices. The purpose of this study was to explore how laboratory constraints provide an understanding of misalignments between epistemological beliefs and science instructional practice, in order to inform how necessary changes in undergraduate biology education can be achieved. This research implemented an exploratory, multi-case design to answer the research questions: 1. How are the features of biology graduate teaching assistants' professed epistemological beliefs related to their science instructional practice in the laboratory, if at all? 2. How are misalignments between the features of professed epistemological beliefs and science instructional practice influenced by laboratory constraints, if at all? This study examined the relationship between the features of GTAs' professed epistemological beliefs, science instructional practices, and laboratory constraints with complexity theory as the theoretical foundation.

The study produced results that were significant in three ways. First, results indicated that the GTAs' epistemological beliefs transferred into their practice, and they taught science in the ways that they believed that it should be, drawing mainly from their

science learning experiences as students. Second, GTAs' beliefs either aligned or misaligned with their science instructional practices. Misalignments were influenced by laboratory constraints such as the amount of time allocated for laboratory, curriculum design, and resources, which resulted in conflicts between GTAs' core and peripheral beliefs. These results have potential pedagogical applications for the designers of GTA professional development. Finally, the study highlighted the connection among the three components—epistemological beliefs, science instructional practice, and contextual constraints—noting that each area is by no means independent and so closely related to each other that researchers cannot study one area without considering the other.

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CHAPTER I: INTRODUCTION

Introduction

A major goal of science reform in the United States is an emphasis on increasing the quality of science education in higher education (Wright, Sunal, & Day, 2004; U.S. Department of Education, Office of Innovation and Improvement, 2016). Science education scholars lament that traditional approaches to teaching undergraduate science introductory courses do not work effectively (Furtak & Penuel, 2019; Stage & Kinzie, 2009; Wright et al., 2004). For many years, graduate teaching assistants (GTAs) have been instructing classes in higher education and have an important role in introductory science courses at colleges and universities (Reeves et al., 2016). With an increase in interest in teaching practices at the higher education level, it is essential to assess the epistemological beliefs of GTAs by looking at their instructional practices and the context in which teaching occurs. This exploratory, multi-case study examined biology GTAs' epistemological beliefs about teaching and learning in science. It focused on the complex relationship between the features of GTAs' epistemological beliefs, science instructional practices, and contextual constraints of teaching in the laboratory.

Chapter I contains an introduction to the relevant research on the study of epistemological beliefs in education, acknowledging the influential role and significance of instructional practice. The complex beliefs of teachers are not always realized in their instructional practice due to contextual factors (Basturkmen, Loewen, & Ellis, 2004; Farrell & Bennis, 2013). Therefore, Chapter I subsequently describes the context that has been understood to mediate the relations between beliefs and practice. Furthermore, the chapter describes the role of GTAs in higher education, discusses the nature of the problem addressed, and the purpose of the study. The chapter ends with the significance of this study and the definition of key terms that will bring clarity as to how these terms were used.

Background of the Study

Rapid changes in the modern world have led to a variety of challenges for higher education systems. More specifically, reform initiatives are challenging the higher education community regarding the best and most effective ways to advance the success and learning of students (Hanauer & Bauerle, 2012). The *Vision and Change* report by the American Association for the Advancement of Science (AAAS, 2011) called on kindergarten to university (K-U) institutions including colleges, universities, and scientific communities to support reforms that will lead to the adoption of student-centered learning approaches and the organization of biology education around core concepts, competencies, and skills. Recognizing the need for improving teaching and learning in undergraduate science classrooms posits the need to change. However, change needs to commence with instructors (Hanauer & Bauerle, 2012).

In post-secondary education, the primary responsibility of GTAs is teaching. In the instructor role, their status and authority make GTAs a unique group of teachers. Research reveals that GTAs play a significant role in the quality of undergraduate education, especially in the sciences (Gardner & Jones, 2011; Luft, Kurdziel, Roehrig, & Turner, 2004). Institutions of higher education, faculty, and graduate students can benefit from the employment of GTAs. For example, employing GTAs is cost-effective for higher education institutions where senior faculty can instruct large numbers of undergraduates in lecture courses while experiments and discussions are conducted in small group contexts like the laboratory and directed by GTAs (Park, 2004). Graduate teaching assistants primarily instruct in small group settings like laboratories that allow more one-on-one work with students. Alongside the advantages of employing GTAs, there are also several drawbacks. It is challenging to ensure that undergraduates are receiving quality instruction since GTAs are inexperienced teachers who receive little training and may hold beliefs that can impede effective instructional practice (Nasser-Abu & Fresko, 2018). Many studies report professional development programs for GTAs and present findings on various intervention strategies (e.g., Gardner & Parrish, 2019; Lee, 2019). However, very little work has considered the features of GTAs' epistemological beliefs concerning pedagogical practices in the laboratory context. A research focus in this avenue may positively influence the quality of teaching and learning of science at the undergraduate level.

Epistemological Beliefs and Teachers' Belief Systems

Epistemology is a growing area of interest in both psychology and education (Fives & Buehl, 2017) and a construct that has been studied extensively in the field of psychology. This study used a psychological perspective to ground its theoretical backdrop. Philosopher and psychologist Ted Honderich (2005) defined epistemology as the theory of knowledge and knowing, an aspect of philosophy that deals with the nature of knowledge and knowing, its possibility, scope, biases, and justification of belief. Similarly, psychologists Belenky, Clinchy, Goldberger, and Tarule (1986) and Baxter-Magolda (1992) described epistemology as ways of knowing where epistemological perspectives embody individuals' interpretations of reality and make inferences about the truth, knowledge, and authority.

The study of epistemological belief systems spans many domains. In education research, epistemological beliefs are concerned with how individuals come to know, the beliefs and theories that they possess about knowing, and how these epistemological premises are constituents of and influence reasoning and cognitive thought processes (Hofer & Pintrich, 1997). Looking specifically at teachers, Pajares (1992) claimed that teachers have a range of beliefs that influence how they engage in their professional lives. Many terms have represented this range of beliefs, all of which fall under the umbrella term, *personal beliefs*. However, in this study, the term *beliefs* followed the line of research that considers the theories and beliefs that teachers have about knowing. As such, for the sake of consistency, the term *teacher beliefs* is used to include teachers' epistemological beliefs and will be in accordance with what Schraw, Brownlee, Olafson, and Vanderveldt (2017) explained as a set of beliefs that is primarily manifested in the teaching context where teachers make decisions about content, pedagogical approaches, and curriculum sequencing.

Epistemological beliefs have an influential effect on variables such as teachers' ways of defining teaching tasks and organizing the knowledge and information relevant to those tasks, teachers' levels of understanding, and their thinking processes (Nespor, 1987; Pajares, 1992). A considerable body of research on teachers' epistemological beliefs has indicated that there is a need to focus on teachers' epistemological thinking in order to promote positive changes in the teaching-learning process (e.g., Brownlee, Purdie, & Boulton-Lewis, 2001; Fang, 1996). Teachers' thinking about knowledge and knowing processes influences interactions with students, impacts teaching behaviors and context, and affects students' processing and attitudes in the classroom (Roth & Weinstock, 2013).

Personal experiences bias an individual's beliefs and are most often influenced by affective states. Beliefs may include contradictions and can be more resistant to change than knowledge structures (Nespor, 1987). However, in a study by Lee (2019), results indicated that GTAs' beliefs were malleable, and professional development activities were able to change their beliefs about teaching. Therefore, the positive changes in teaching and learning demanded by the AAAS (2011) and the National Research Council (NRC, 2012) may be brought about if research on epistemology in education is designed to determine what features of epistemological beliefs GTAs hold. Then, professional development programs can be designed around the findings.

Epistemological beliefs about teaching and practices can range from teacher-centered traditional teaching to student-centered, reform-based teaching (Luft & Roehrig, 2007). Epistemological beliefs can also be either naïve or sophisticated. Naïve epistemological beliefs are associated with naïve teaching and learning approaches that highlight the role of the teacher as transmitting information to students. On the contrary, sophisticated beliefs are associated with more profound teaching and learning approaches that focus on conceptual understanding and practices that emphasize the role of students developing their own ideas and conceptions (Luft & Roehrig, 2007; Schreiber & Shinn, 2003).

Levitt (2001) noted that teachers with naïve epistemological beliefs engage in simple, traditional instructional practices that do not enhance students' epistemological development. The opposite is revealed for teachers holding sophisticated thinking. Levitt also found that teachers who preferred more student-centered ways of teaching possessed more sophisticated epistemological beliefs about teaching and learning. Therefore, instructors need to hold sophisticated epistemological beliefs if education at higher institutions is to meet the changes and improvements that are required in undergraduate science education as demanded by AAAS (2011) in *Vision and Change*.

Schommer (1994) described the notion of having naïve or sophisticated beliefs extensively in her proposal of epistemology as a belief system with various domains. These domains, according to Schommer (1994), are more or less independent of each other, suggesting that individuals may have sophisticated beliefs in one domain and more naïve beliefs in another. The work of Schommer has implications in the classroom where teachers' sophisticated or naïve beliefs about a subject matter may influence their day-to-day decisions about what aspects of a subject area to skip, or how much class time should be devoted to particular content (Cronin-Jones, 1991). For example, Brickhouse, Bonder, and Neie (1987) noted that a teacher who believed that quantification distinguishes science from non-science placed greater emphasis on quantification during instruction.

Relationship between Epistemological Beliefs and Instructional Practice

In other research that explained teachers' epistemological beliefs and instructional practice, Hofer and Pintrich (1997) described these constructs as multidimensional yet interrelated in a relatively coherent and complex system. In addition, scholars Poulson, Avramidis, Medwell, and Wary (2001) stated that the relationship between teachers' beliefs and practice is complex. Complexity is often associated with the behaviors of elements of certain types of systems, such as classrooms or schools. Baicchi (2015) explained that the classifying of a system and its elements is complex if it displays behavioral properties such as non-linearity (i.e., not cause and effect), displays self-organization, and contains interacting components. A typical classroom would display the behavioral properties of a complex system, and these properties are associated with beliefs and instructional practice (Zheng, 2015).

Mansour (2013) noted that the complex interaction between a teacher's epistemological beliefs and actions identifies as a sociocultural construct as teaching occurs in a social arena. There are various theoretical underpinnings in education that advocate for social interactions as an aspect embodied in instructional practice. For example, both ecological systems theory and sociocultural theory have emphasized the importance of interactions in an individual's developmental processes as their teaching and learning experiences expand when engaged in educational settings (Phan, 2012).

Social processes are important aspects of instruction and classroom life. As early as 2000, reform efforts in science education embraced the departure from traditional teacher-centered modes and moved towards constructivist teaching where students can construct multiple meanings through interactive experiences (Beck, Czerniak, & Lumpe, 2000). In the same way that scientists are engaged in collaboration with others as they seek answers to questions about the natural world, students are encouraged to gain scientific understanding through these social processes. In linking the social aspects of the classroom to teachers' instructional practices, Fang (1996) argued that the complexities of socialization of classroom life might influence teachers to provide instruction that aligns with their beliefs. These complex relationships are best understood through the theoretical lens of complexity theory, which is more fully described in Chapter II.

The Significance of Instructional Practice and Teaching Contexts

Despite the substantial amount of research in education on epistemology with a focus on teachers' epistemological beliefs, many of these studies have not concentrated on how teachers' epistemologies might influence their actual teaching behaviors in the classroom in the context that they teach (Mansour, 2013; Roth & Weinstock, 2013). The work of Li (2015) used the action theory to investigate the relations between an individuals' espoused beliefs and actions and noted that actions are further complicated by the context, both micro and macro. As suggested by Fang (1996), there may be misalignments between teachers' epistemological beliefs and their instructional practices due to the complexities of micro-contexts such as classroom life. Classroom life poses constraints on teachers' abilities to follow and provide instructions aligned with their beliefs. An instructor's beliefs may be situational and may manifest in instructional practices only in relation to the complexities of the classroom (Mansour, 2013).

Drawing from evidence grounded on in-depth interviews, Kissau, Algozzine, and Yon (2012) reported that contextual challenges served as barriers to illuminating how beliefs informed instructional practices. These scholars suggested that other research incorporates context more. Thus, researchers need to study context-specific features of beliefs. There is a need for a specific focus on the connection between epistemological beliefs and contextual issues, which takes into consideration how the constraints of classroom contexts may provide more clarity as to why misalignment or inconsistencies exist between instructional practice and beliefs.

To ascertain whether the context within which laboratory courses are conducted is influential, education researchers need to pay specific conceptual and empirical attention to its possible efficacy in having an important connection to instructional practice. This connection draws away from the well-documented view that beliefs are the best indicators of the decisions that instructors make. Teachers' beliefs are influenced by interactions within the nested social and cultural contexts in which beliefs and practices are situated. Individuals develop as they participate in the activities of classroom cultural communities. Their development is mainly understood in light of classroom cultural practices and circumstances of their classroom communities, which can also change (Rogoff et al., 2003). With this experience, individuals can also gain cultural knowledge. Cultural knowledge plays a fundamental role in knowledge construction, specifically in science and science education (Bryan & Atwater, 2002).

Due to the various ways of living and experiences that both teachers and students bring to teaching and learning, learning that is mediated by the social and cultural identities of the laboratory instructor and the students may embed laboratory contexts (Brown & Redmond, 2008). Despite its vitality, much of the current work in science studies focus on interventions and enabling learning situations, and tend to ignore, underplay, or dismiss the possibility that the complex features of beliefs may systemically shape science instructional practice (Cross, 2004; Mansour, 2013). For example, in their discussion of the traditional approach of science instructional practices, French and Russell (2002) purported that in the past, laboratory instructors have used the *verification style* where students demonstrated a concept already taught in lectures, for which there was only one correct answer. Based on their claim, laboratory instructors have already established the results and possible conclusions of laboratory activities (French & Russell, 2002). As such, laboratory instructors—GTAs—view their role as the person who selects the hypothesis or generalization to be tested, chooses the experiment design, delineates the protocol, picks the variables to be tested, and predicts the outcome (French & Russell, 2002). This traditional method—also referred to as the *cookbook* approach—to teaching and learning science in the laboratory does not facilitate intellectual stimulation for GTAs who are mostly following the methods in the laboratory manual and checking students' answers against an answer key (French & Russell, 2002). Graduate teaching assistants of laboratory classes continue to employ this practice despite the call for more reform-based teaching and learning approaches (Addy & Blanchard, 2010; Nicklow, Marikunte, & Chevalier, 2007). However, there has been very little exploration of the relationship between these practices and GTAs' perceptions of knowing and scientific knowledge in science in the laboratory context.

The laboratory context is comprised of teaching and learning constraints, opportunities, or internal and external influences that may derive from sources that exist at various levels, such as that of the school or curriculum (Jordan, Ruibal-Villasenor, Hmelo-Silver, & Etkina, 2011). Also, laboratories operate within institutions and suffer contextual constraints that are common to those institutions. Examples of such contextual constraints include the roles and status of instructors and the degree of autonomy that instructors are given (Jordan et al., 2011). Due to these constraints, the beliefs of laboratory instructors may direct the actions and behaviors that they manifest.

Scholars contend that research on teaching at the higher education level has not focused on the contexts of teaching and learning (e.g., Devlin & Samarawickrema, 2010; Quinlan, 1999), more specifically the laboratory context which is taught mostly by GTAs (Gardner & Parrish, 2019; Luft, Kurdzeil, Roehrig, & Turner, 2004). Contextual factors play a vital role in shaping the beliefs, choices, and actions of teachers, and it is through investigating the various layers of contexts that researchers can discover the intellectual roots of teaching and learning (Quinlan, 1999; Zheng, 2015). The challenge remains to create scholarly discourse and a knowledge base about teaching and learning at the higher education level by looking more closely at laboratory context and its role in guiding the instructional practices of GTAs.

The Role of Graduate Teaching Assistants

The epistemological beliefs of instructors are important factors in their perceptions of a subject area and practice and are an essential variable in the teaching and learning process (Aslan & Zhu, 2017). Hofer (2001) cited the work of King and Kitchener (1994) and Kuhn (1991) to acknowledge that epistemological comprehension aids educators and education researchers with the understanding of how individuals find solutions for competing knowledge claims, assess new information, and make vital decisions that impact their lives and the lives of students. Therefore, if individuals—such as GTAs—are expected to engage in complex thinking activities like teaching at the undergraduate level, it is important that they hold sophisticated epistemological beliefs and thinking. The sophistication of beliefs is developed when individuals are advancing their education and enroll in graduate-level degrees. For example, graduate-level degrees advanced individuals' epistemological beliefs to be more sophisticated and less naïve (Lehman, Lempert, & Nisbett, 1988; Schommer, 1990, 1993a, 1994).

In many higher education institutions across the world, graduate students are given opportunities by the administration to teach or assist in undergraduate courses. The titles and roles of these graduate students vary across countries, institutions, and departments. For example, in Canada, there are graduate teaching fellows, whose primary responsibility is to design and administer courses. In contrast, another group called graduate teaching assistants (GTAs) are in charge of leading tutorials or laboratory sections, grading assigned work, holding office hours, and monitoring course websites (Hoessler & Godden, 2015). In the United Kingdom, GTAs in science departments facilitate laboratories and fieldwork (Park & Ramos, 2002). Nowlis, Clark, and Rock (1968) described the role of GTAs in the United States as being just as extensive as professors (where professors have complete teaching responsibility for an entire course) or as minimal as graders or clerical workers who hardly interact with students.

In the United States, science GTAs specifically in biology departments, carry a heavy load of the introductory courses. An approximation of 85 to 95 percent of STEM graduate students has an instructional role of GTA at some point during their graduate careers (Connolly, Savoy, Lee, & Hill, 2016). In a recent study of 3,060 science, technology, engineering, and mathematics (STEM) doctoral programs, 88.4% of participants functioned as teaching assistants, 51.4% served as guest lecturers, 33.4% functioned as instructors of record, and 11.7% were assigned some other teaching role during their time as graduate students (Gardner & Parrish, 2019). A report by Sundberg, Armstrong, and Wischusen (2005) found that specifically in biology disciplines, GTAs are responsible for teaching about 71% of undergraduate laboratory sections at large institutions and at least 91% at research institutions in the United States. According to Seymour and Hewitt (1997), GTAs are given a high degree of responsibility for the teaching of elemental aspects of the disciplines in which they teach and for responding to student issues such as questions and problems. The teaching responsibility of GTAs has not changed much with the change in time (Reeves et al., 2016).

The quality of undergraduate science education is determined by the extensive interactions and role of GTAs with students as well as their increased instructional responsibilities. The literature indicates that GTAs spend more time interacting with students than do professors, and as a result, undergraduate students reach out to GTAs rather than established faculty (Kendall & Schussler, 2012; Moore, 1991). Further, students view GTAs as more approachable and relatable (Kendall & Schussler, 2012). This may be a result of the similarity in age as well as the social status of undergraduate students and the GTAs (Kendall & Schussler, 2012; Moore, 1991). Also, Atkins-Randle (2012) noted that GTAs are often the first line of defense in their role as teachers, and as such, GTAs need to be prepared as teachers since they act as agents of the department in which they serve. Graduate teaching assistants require departmental support and training to help them transition from an undergraduate student into their real-life role as an educator (Kuther, 2003), primarily since conceptions such as beliefs and prior experiences influence GTAs' interactions with students and affect educational practice (Wheeler, Maeng, Chiu, & Bell, 2017).

The Problem Statement

Science reform is calling for a change in undergraduate science education. For example, *Vision and Change in Undergraduate Biology Education* (AAAS, 2011) has become a pivotal reform initiative towards the improvement of teaching and learning of biology at the undergraduate level. Biology GTAs are vital instructors in undergraduate biology education (Sundberg, Armstrong, & Wischusen, 2005). However, the features of

GTAs' epistemological beliefs are given little attention even though GTAs represent the primary teaching workforce for undergraduate students in discussion and laboratory sections at many universities (Lee, 2019).

Shifts in the educational orientations in science do not necessarily induce changes in teachers' epistemological beliefs and practice. The culture of GTAs as laboratory instructors has not changed in a fashion that is analogous with the goals of science reform (AAAS, 2011; NRC, 1996, 2012). Laboratory instruction is mostly teacher-centered and follows the traditional design (Gardner & Parrish, 2019; Handelsman et al., 2004; Lee, 2019), although science reform advocates for inquiry-based activities. The epistemological beliefs that GTAs hold may be an overriding factor that has served as a hindrance to the necessary changes in biology laboratory teaching and learning practices at the undergraduate level. According to Darling-Hammond et al. (2019) and Haney, Czerniak, and Lumpe (1996), the attitudes of educators appear to be a critical component of the educational change process. In order to bridge the gap between calls for reform in higher education science and actual changes in undergraduate teaching and learning, there is a need for a bottom-up focus which commences with the laboratory instructors—GTAs—who may be possible barriers to educational change (Brownell & Tanner, 2012; NRC, 2000; Van Driel, Verloop, Van Werven, & Dekkers, 1997).

Statement of Purpose

The changes in instruction promoted by science education experts as being the best and most effective teaching practices have not translated into instructional changes in science departments, more specifically so with GTAs (Addy & Blanchard, 2010; Gardner & Parrish, 2019; Lee, 2019). One proposed reason is the limited pedagogical preparation of GTAs, which, according to Lee (2019), is due to inadequate professional development and training on strategies that promote effective teaching. Another is the substantial impact of teachers' beliefs on instructional practices where belief systems influence the way teachers carry out the process of teaching. Scholars acknowledge that an understanding of teacher beliefs and how it affects practice may shed light as to how reform changes may be brought about since the implementation of any reform depends heavily on teachers such as GTAs who play a critical role in changing undergraduate science classrooms (Addy & Blanchard, 2010; Lee, 2019; Luft et al., 2004).

Despite these fundamental issues, there is a plethora of research on GTAs' beliefs and the influence on instructional practice (e.g., Addy & Blanchard, 2010; Gardner & Parrish, 2018; Lee, 2018). However, the findings from these past studies have not yet led to substantial changes in undergraduate science teaching and learning (Freeman et al., 2014). Empirical research also suggests that STEM GTAs' teaching beliefs and teaching practices may be affected by their experiences with various teaching mentors or teacher role models (Justice, Zieffler, & Garfield, 2017). This may be due to the very little training that they received during their graduate teaching experience. Hence, their teaching replicates that of their mentors (Mazur, 2009). This behavior—teaching like their role model or mentor—does not elude GTAs who enter into their role as science instructors with specific beliefs about knowing and knowledge as well as perspectives about teaching and learning (Gardner & Jones, 2011). These belief systems shape the teaching practices of GTAs (Kagan, 1992).

Savasci-Acikalin (2014) proposed that studies examining the association between teacher beliefs and practice should additionally consider the context in which teachers work in order to gain a better understanding of the relationship between teacher beliefs and practice. An emphasis on the role of the laboratory context in the understanding of the relationship between GTAs' epistemological beliefs and practice may explain why teachers adopt different teaching practices in particular teaching contexts. According to Turner and Meyer (2000), instructional context is significant because what students learn and how learning develops involve students' psychological reaction to the instructional context. Interactions between students and teachers influence the development of the teacher's beliefs on how learning occurs in the classroom.

A teacher's epistemological beliefs about teaching and learning are subject to the constraints and contingencies of the school context and can be transformed into classroom practices (Ernest, 1989). The conclusions of Cooney (1985) and Zeichner, Tabachnick, and Densmore (1987) were that apart from class size, physical classroom layout, and institutional constraints, learners' reactions can be an important constraint on their instructors' behaviors. Social interactions between teachers and students can lead the teacher to internalize a powerful set of constraints that may affect the demonstration of beliefs about teaching and learning during instruction. Ernest (1989) argued that the socialization effect of the context is so powerful that despite having different beliefs about teaching, teachers in the same school are observed to adopt analogous classroom practices. When looking at the relationship of beliefs to practice, a key element that underlies a teacher's thinking and beliefs about knowing and the nature of knowledge is context-sensitivity in choosing and implementing situationally appropriate teaching and learning strategies that are in accordance with teachers' beliefs (Earnest, 1989). Therefore, to promote and sustain the pedagogical change that is needed at the undergraduate level, the relationship that exists between GTAs' epistemological beliefs, instructional practice, and laboratory context (especially noting the constraints that may be present) should be investigated.

Research Questions

By focusing on the interactive dynamics among biology GTAs' epistemological beliefs, their laboratory practice, and instructional context, the researcher posed the following research questions:

1. How are the features of biology graduate teaching assistants' professed epistemological beliefs related to their science instructional practice in the laboratory, if at all?
2. How are misalignments between the features of professed epistemological beliefs and science instructional practice influenced by laboratory constraints, if at all?

Significance of the Study

Graduate teaching assistants have grown both in number and importance in the education of undergraduate students. Given the reliance on GTAs for a majority of science laboratory teaching in universities in the United States, an investigation into the epistemological beliefs of biology graduate teaching assistants about teaching and learning in science and their actual performance was valuable for many reasons. First, there is a disconnect between GTAs' science instructional practices and their beliefs (Justice et al., 2017). Gathering information regarding GTAs' previous teaching experience, their degree status (Master's or Ph.D.), and their training has not been helpful for discerning reasons for the dissociation between the two. Some researchers have discovered that the disconnect between beliefs and instructional practice may be due to the influence of contextual factors, such as the physical settings in which teachers work (Mansour, 2013). Thus, research like this study, which considers contextual factors of the laboratory context in which biology GTAs work, was necessary in order to reveal sources of dissonance between GTAs' epistemological beliefs and practice. In this case, understanding biology GTAs' epistemological beliefs necessitates interpreting them in locally applicable ways.

Second, this study contributed to current research by revealing how complexity theory may be used to illuminate and describe GTAs' epistemological beliefs, their practice, and the instructional context. An individual's belief systems are not necessarily logically and simplistically structured, and hence it may be possible that an individual holds beliefs that are incompatible or inconsistent (Andrews & Hatch, 2000; Richardson, 2003). To investigate these inconsistencies, previous research has utilized a linear and dualistic approach to gain an understanding of the relationship between beliefs and instructional practice. These methods may be due to the adopted view that simplifies the complex features of teachers' epistemological beliefs when relating them to practice. These linear, causal, and reductionist approaches of past research have not yet explained the mixed results in the relationship between teachers' beliefs and their instructional practice where teachers' practice has been found to vary from being consistent to inconsistent (Zheng, 2015). Therefore, in this study, a more holistic and emergent approach was used to provide a deeper understanding of these misalignments.

Third, this study provided insights into the training of GTAs, where the use of an epistemological frame of reference served as an invaluable training tool. There has already been a recognition of the necessity to prepare GTAs better, and a variety of approaches have been proposed and utilized across STEM disciplines to provide support for them (Tanner & Allen 2006). However, the focus of GTA professional development and research, in general, has overlooked the disjuncture between GTAs' perceptions about teaching and learning and students' expectations. Olafson and Shraw (2010) acknowledged that teachers with explicit epistemological worldviews are in a better position to reflect on their beliefs and proceed to change them. Training for GTAs should provide them with a framework that will allow them to understand and articulate their epistemological assumptions explicitly and to reflect on the pedagogical implications of having such beliefs. Discussions of the features of GTAs' epistemological beliefs during training sessions may promote awareness of GTAs' own epistemological beliefs about teaching and learning. The insights gained from these training sessions may enable GTAs to reflect on their teaching practices in the laboratory and their students' expectations of them as instructors, which in turn will encourage GTAs to negotiate their assumptions as well as those of their students (Jin & Cortazzi, 2002).

Finally, this study was an intellectual endeavor to connect two fields of research: epistemological beliefs research and GTA research. As such, this study served the purpose of laying a foundation for a continued inquiry into GTA populations in both of these research areas and better understanding the instructional practices of biology GTAs and the principles behind the sophisticated pedagogical decision-making process.

Definitions

Throughout this study, key terms are referred to repeatedly. This section is intended to bring clarity to the meaning of these terms.

Complexity Theory

Complexity theory is the study of the characteristics or behavior of systems in which the components interact in multiple ways. Although a generally accepted or exact definition of complexity theory does not exist, a discussion of complexity theory is provided in the literature review of Chapter II. This theoretical perspective seeks to account for the non-linear, self-organizing, and unpredictable features of the dynamic interactions that take place within a system. Central to this application is the idea that systems have components that interact in various ways to produce an overall state. This study looked at epistemological beliefs of GTAs and their instructional practice in the laboratory context as a systematic whole and used complexity theory to investigate the complex nature of how GTAs' epistemological beliefs interact with their mental and behavioral processes that are triggered by instructional practice in the laboratory setting.

Ecological Systems Theory

Ecological Systems Theory explains that the development of an individual is embedded in various environments and that the symbiotic interactions that occur in these environments are influential to the development of the person (Bronfenbrenner, 2005b). Originally conceptualized as a set of Russian nesting dolls, this theory explains that the environments are not nested but are networked through the various interactions that are present (Neal & Neal, 2013). Using Ecological Systems Theory, the researcher theorized that the laboratory context represents the environment that surrounds biology GTAs.

Epistemology

Epistemology is the theory of knowledge (Honderich, 2005) and knowing, a branch of philosophy that deals with the nature of knowledge and knowing. That is, it is "concerned with the origin, nature, limits, methods, and justification of human knowledge" (Hofer, 2002, p. 4).

Epistemological Beliefs

These are the specific beliefs that one has about some aspect of knowledge that is part of a broader epistemology; for example, the origin of knowledge (Hofer & Pintrich, 2002; Schommer-Aikins, 2004).

Graduate Teaching Assistant (GTA)

A graduate teaching assistant is a recognized position within higher education systems that employ graduate students as instructors and offer them the opportunity to enhance their teaching skills through hands-on experience. The GTA position provides funding for postgraduate research while additionally giving teaching support for the university (Park, 2004). In this study, GTAs were either master or doctoral students and unless otherwise indicated were supporting instruction in and teaching biology.

Interpretivist Approach

The interpretivist approach stems from a paradigm in science education research that focuses on the localized meanings of human experience. Research in this tradition emphasizes how individuals build their understanding based on their lived experiences, culture, and context and highlights the importance of human action by accentuating the situated meanings that people make out of social, educational interactions.

Laboratory Constraints

Laboratory constraints are the factors that limit or hinder the teaching and learning of science.

Laboratory Context

To bind the context of this study, laboratory context refers to the laboratory ecology which encompasses the structure and physical space/setting of the laboratory, materials and resources, behaviors, classroom management, sociocultural environment (interactions that students and GTAs establish), and the evaluative climate (i.e., types of student assessment).

Science Instructional Practice

Science instructional practices, also called science classroom or teaching practices and science teaching principles (Tokuma-Espinosa, 2014), refer to routine activities in which science instructors engage that are devoted to the enactment of plans and dialogical interaction that support student learning (Windschitl et al., 2012). Interactions include the connected work that occurs between the teacher and students over time to promote learning (Cohen, Raudenbush, & Ball, 2003). Research-based science practices outlined by the AAAS (1993, 2011) include starting lessons with questions about nature, engaging students actively, concentrating on the collection and use of evidence, providing students with historical perspectives, insisting on the use of clear expressions, using a team approach, not separating knowledge from finding out, and de-emphasizing the memorization of technical vocabulary.

Chapter Summary

Graduate Teaching Assistants play a vital role as teachers at many universities. Hence, their epistemological beliefs—a factor that influences classroom practices—is a construct worthy of exploration. This study sought to add to the body of literature regarding the epistemological beliefs of GTAs through the lens of complexity theory by focusing on the complex nature of the interactions that exist between beliefs, classroom practice, and context. This chapter provided background literature and presented the purpose of the study, research questions, significance of the study, and the theoretical lens that framed this study. Chapter II will present a summary of the relevant literature. Chapter III will provide a detailed description of the study methodology. Chapter IV will provide a discussion of the results. Finally, Chapter V provides a review and discussion of the results and future directions associated with this study.

CHAPTER II: LITERATURE REVIEW

Introduction

Graduate teaching assistants (GTAs) are part-time educators at colleges or universities whose primary responsibility is to provide teaching services to and support undergraduate students. GTAs are in charge of a significant proportion of undergraduate instruction in STEM disciplines, particularly introductory laboratory courses (Gardner & Jones, 2011; Miller, Brickman, & Oliver, 2014). Nicklow, Marikunte, and Chevalier (2007) reported that GTAs provide 91% of biology laboratory instruction at research universities and teach 25-50% of undergraduate courses. In their role, GTAs are expected to be content experts, make instructional decisions about the presentation of information, identify the concepts that should be emphasized, and be knowledgeable of suitable pedagogical strategies for undergraduate instruction (Luft et al., 2004; Sundberg, Armstrong, & Wischusen, 2005). These decisions are based on a GTA's own system of beliefs, which in turn filter, frame, and guide (Fives & Buehl, 2012) the experiences of GTAs.

The purpose of this literature review is to provide the underlying theoretical assumptions most central to this research study (Yin, 2014). To accomplish this, published works in the philosophical, psychological, and educational literature, including an overview of epistemological theories about the nature of knowledge and knowing from six major groups of researchers in the field, were examined. Also included is a discussion of the contents of teachers' epistemological beliefs, specifically regarding their beliefs about teaching, learning, and nature and knowledge in science. Since the epistemological beliefs of GTAs were central to this study, the next section of this review highlights GTAs' epistemological beliefs about science teaching and learning. Finally, and perhaps most importantly, this literature review describes the theoretical and conceptual frameworks used to guide this study. The theoretical framework emphasizes the use of complexity theory (the overarching theory) and Ecological Systems Theory (supporting theory) through the lens of the interpretivist approach to offer a conceptualization of how GTAs' epistemological belief system, instructional practice, and laboratory context interact.

Epistemology: A Historical Perspective

Philosophical Roots

Philosophical discussions about the nature of knowledge first began with the ancient Greeks. These discussions initiated the study of epistemology and laid a framework for others to approach the study of knowledge. In his dialogues *Meno* and *Theaetetus*, Plato distinguished true belief from knowledge. From his ideas emerged the view that knowledge is *justified true belief* which is founded on three conditions: truth, belief, and evidence.

It is important to note that the condition of truth implies that there is no false knowledge and that for knowledge to exist, a specified proposition must be true to expand on Plato's first condition regarding knowledge. Scheffler (1965) posited that there is a factual reference to knowing. Nevertheless, truthful and accurate representations of reality alone do not constitute knowledge, but knowledge is apparent only where there is belief. As such, belief, the second condition, is a necessity. The condition of belief stipulates that individuals must believe that a given proposition is true (Buehl, 2003). Although a multitude of propositions exists, an individual only *knows* the propositions that he or she accepts and internalizes. Evidence, the third condition, requires that individuals have adequate evidence to justify that a given proposition is true. This acknowledges that reason and data must support belief in the truth of a specified proposition. Over centuries, various philosophical approaches to and theories of knowledge have developed, holding different bodies of knowledge (e.g., mathematics, natural science) as being ideal. However, each, in some way, has addressed the three conditions as purported by Plato.

Definition of Epistemological Beliefs

Epistemology is one of the fundamental areas of philosophy that examines the nature, sources, boundaries, conceptual components of knowledge, and whether the existence of knowledge is possible (Baç, 2007). In the literature, the term *epistemological beliefs* is one of contention and is referred to and/or related to concepts such as epistemic beliefs, epistemic cognition, epistemological resources, epistemological theories, epistemological worldviews, epistemological development, epistemic cognition, epistemological reflection (Murphy, Alexander, Greene, & Hennessey, 2012), among others.

Pintrich (2002) categorized these various ideas into three general ways of researching epistemological beliefs: 1) developmental (e.g., epistemological development), 2) contextual (e.g., epistemological resources), and 3) cognitive (e.g., epistemological beliefs). In this literature review, the term epistemological beliefs is used for consistency. It is crucial to highlight literature on the central theories and models of epistemological development and epistemological beliefs that are relevant to the psychology of education in general and, more specifically, teaching and learning to develop a better understanding of epistemological beliefs. According to Hofer and Pintrich (1997), the examination of the developmental theories encourages the understanding of teachers' and students' beliefs, and thinking about knowledge will, in turn, provide a better understanding of the teaching and learning process in the classroom. Based on this perspective, Schommer-Aikin's (2004) and Hofer and Pintrich's (2002) definition of epistemological beliefs as beliefs regarding the source and certainty of knowledge, knowing, and learning aligns with the work from this study.

Epistemology: A Psychological Perspective

Epistemological Theories

The way that individuals think about epistemological concerns in education research has been conceptualized into two major lines of studies. Early studies assumed epistemological beliefs as unidimensional with development in fixed, progressive, sequential stages (e.g., Perry, 1970; Baxter-Magolda, 1992). Other views proposed that epistemological beliefs included several independent dimensions, were complicated, and could only be captured by using a multidimensional approach (e.g., Schommer, 1990, 1994). The description of the theories and models which follow represents both of these lines of research because together, they establish a more comprehensive model to explain the relationship between teachers' epistemological beliefs and other related beliefs such as beliefs about teaching and learning.

Unidimensional and Developmental Models

Perry's scheme of intellectual and ethical development. William Perry was a pioneer in research on epistemological beliefs. In the early 1950s at the Harvard Bureau of Study Counsel, Perry (1970) conducted two longitudinal studies in an attempt to understand how undergraduate students interpreted learning experiences. Perry’s studies were based on a series of annual interviews with students, which led him to develop a framework to describe their thoughts about the nature and process of building knowledge throughout their college years. Perry’s (1999) study identified a basic progression or development in ways of thinking. According to Perry (1999), there are four stages of development, within which are nine positions of how individuals view the world and build their knowledge as they face intellectual and personal obstacles in higher education. Table 1 includes a summary of these nine positions and their alignment to the four stages of development.

Table 1

Summary of Perry’s (1970) Four Stages of Development and their Nine Positions of Epistemological Beliefs

Stages	Positions
Dualism (1-2)	1. Knowledge handed down by authority is absolute. 2. Poorly qualified authority will have differences in opinion.
Multiplicity (3-4)	3. Uncertainty is temporary. 4. Relativistic knowledge is an exception to the rule.
Contextual Relativity (5-9)	5. Absolute knowledge is an exception to the rule. 6. There is a need for personal commitment in a relativistic world. 7. Initial commitment is made. 8. Exploring commitment. 9. Commitment is an ongoing, complex, and evolving process.
Commitment with Relativism (7-9)	7. Initial commitment is made. 8. Exploring commitment. 9. Commitment is an ongoing, complex, and evolving process.

Note. The numbers found within the parentheses beside the name of each stage correspond with the number for the positions that can be found with the stage.

There is an overlap between Perry's four stages. This indicates that an individual can be between two stages of the developmental process at any one time. For example, an individual can be in the Contextual Relativity stage while at the same time being in the Commitment with Relativism stage when he or she displays the position of initial commitment (Table 1).

Perry (1970) proceeded to describe each of his four stages of development. His view of dualism extended from position one through position four. Based on his work, Perry highlighted that dualism is characterized by an absolutist, right or wrong view of the world wherein authorities are anticipated to know the truth and convey it to the learner (Hofer & Pintrich, 1997). Dualists believe that the role of the teacher is to teach them.

Perry's second stage multiplicity is comprised of positions three and four, which describes individuals who think that all views are equally acceptable and that personal opinion is respected. Perry (1999) explained multiplicity as follows:

> A plurality of "answers," points of view, or evaluations concerning similar topics or problems. This plurality is perceived as an aggregate of discretes without internal structure or external relation, in a sense, "anyone has a right to know his own opinion," with the implication that no judgments among opinions can be made. (p. 286)

Individuals at this stage begin to recognize diversity and uncertainty and that he or she has a right to his or her own opinion. However, multiplists still hold the view that the absolute right answers are still held in the realm of authority.

Perry's (1999) third stage, contextual relativism, spanned positions five through nine. At this stage, individuals believe that knowledge is contingent and relative and that the answers to questions are relative to background context. There is a major shift from knowledge stemming from an authority figure to the individual being an active maker of meaning. Hence, from this perspective, an individual transforms from a dualistic view of the world to one with an increasing number of exceptions to the rule.

Perry's fourth and final stage is, commitment within relativism, which encompass positions seven through nine. One should note that this fourth and final stage shows overlapping with stage three (contextual relativity) where positions seven, eight, and nine are also identified. The difference between these overlapping elements is that individuals at the last stage hold the highest and more sophisticated level of beliefs and confirm their personal identity among multiple responsibilities. Also, in this final stage, individuals show more commitment to their jobs, values, and relationships. Although Perry proposed this fourth stage during his study, he acknowledged that college students do not typically reach this point and that the description of individuals within this stage of development was more expressive of graduate students.

Perry's work suggests that individuals first have simple, certain knowledge that is handed down to them by an authority. As they encounter complex, tentative information through various experiences like college classes, they undergo conflict with their epistemological beliefs and go through epistemic changes. Based on Perry's findings, undergraduate college students go through the first three stages but do not make it to the fourth. He proposed that continuing to graduate school may provide the experiences that will push students' epistemological beliefs into the fourth stage.

Epistemological reflection model. In order to explain adults' ways of knowing, Baxter-Magolda (1992) explored male and female undergraduate students' processes of thinking using Perry's (1970) model to explore the possibility of gender-related implications. Baxter-Magolda (1992) introduced her model of students' ways of thinking as the Epistemological Reflection Model. Her work included annual interviews and open-minded questionnaires across five years.

Baxter-Magolda's (1992) Epistemological Reflection Model captured students' conceptualizations of knowledge and learning and consisted of four different ways of knowing. Each way of knowing has its own epistemic assumptions. According to Baxter-Magolda (1992), each way of knowing leads to various expectations of learners, peers, and the teacher in learning settings and provides an understanding of how learning should be evaluated and what instructional decisions should be made.

Although she claimed that individuals adopt one of the four ways of knowing, Baxter-Magolda (1992) also presented a continuum of differences in how students justified their epistemic assumptions within each way of knowing. This continuum was identified as students' reasoning patterns. For example, individuals characterized as adopting an absolute way of knowing were placed in the reasoning continuum of *receiving* to *mastery* (Baxter-Magolda, 1992), or an individual in transitional knowing was inclined to take an *interpersonal* and *impersonal* reasoning approach and believed that knowledge could be either certain or uncertain (Baxter-Magolda, 1992). Independent knowing extended from *inter-individual* to *individual* reasoning patterns (Baxter-Magolda, 1992). Table 2 presents a summary of Baxter Magolda's (1992) ways of knowing, epistemic assumptions, and reasoning patterns.

Table 2

Summary of Baxter-Magolda's (1992) Epistemological Reflection

Ways of Knowing	Epistemic Assumptions	Reasoning Patterns
1. *Absolute Knowing*	Knowledge is certain and absolute; authorities have all the answers.	Receiving and Mastery
2. *Transitional Knowing*	Knowledge is certain and partially uncertain; authorities are not all-knowing.	Interpersonal and Impersonal
3. *Independent Knowing*	Knowledge is uncertain, and alternative views can be justified; one can have his/her own opinion, and authorities are not the only source of knowledge.	Inter-individual and Individual
4. *Contextual Knowing*	Knowledge is judged on the basis of evidence to structure personal perspectives.	Patterns from other ways of knowing converge

Reflective judgment model. King and Kitchener (1994) desired to understand the knowledge processes used in argumentation. Participants in their study included a cross-section of individuals with various educational experiences (e.g., high school students, college undergraduates, graduate students, and non-student adults). In order to assess individuals' beliefs about knowledge and to determine the justification of these beliefs, individuals were presented with four ill-structured problems that lacked definitive solutions. Based on participants' responses, King and Kitchener (1981) developed a seven-staged Reflective Judgement Model to describe individuals' views of knowledge and conceptions of justification and argumentation (Table 3). Within their seven-stage model, King and Kitchener (1994) proposed that individuals can display pre-reflective, quasi-reflective, and reflective thinking.

Table 3

Summary of King and Kitchener's (1981) Reflective Judgement Model

Levels of Thinking	Reflective Judgement Stages
Pre-reflective (1-3)	1. Absolute knowledge is handed down by authority.
	2. Absolute knowledge exists but is not necessarily known immediately.
	3. Some knowledge may be temporarily uncertain.
Quasi-reflective (4-5)	4. All knowledge is uncertain, and there is no way to determine which is correct or which is better.
	5. Knowledge is subjective, and claims can be made through subjective interpretation.
Reflective (6-7)	6. Knowledge cannot be objective, and the knower plays an active role in constructing claims.
	7. Knowledge is a continuous process of inquiry and may be considered as an estimation of reality.

Note. The numbers found within the parentheses beside each level of thinking correspond with the numbers of the reflective judgment stage found within each level.

King and Kitchener (1981) hypothesized that individuals undergo seven stages of development regarding beliefs about knowledge and reality. These beliefs direct individuals' reasoning in justifying knowledge claims. In addition, King and Kitchener (1981) claimed that the stages are developmental, there is an underlying organization within the stages, and each stage is qualitatively different and forms an invariant sequence. Based on their work, King and Kitchener (1981) assumed that an individual's reasoning might be at any stage at any time.

Multidimensional and Independent Models

Epistemological beliefs. A study by Schommer (1990) focused on epistemological beliefs, which she posited are multidimensional. She proposed a belief system with a set of more or less independent beliefs as opposed to Perry's (1970) model, where beliefs were unidimensional and developed in fixed stages. Here, a belief system is described as more than one belief. According to Schommer (1994), *more or less independent* meant that some individuals could be sophisticated in some beliefs but not necessarily sophisticated in others.

Based on the work of Schommer (1989), there are three more or less independent beliefs about the structure and source of knowledge. According to Schommer, knowledge can be either certain, simple, or handed down by authority. Schommer (1990) also outlined five dimensions of beliefs about the nature of knowledge, which she claimed that, although listed as five, the list was not exhaustive. Schommer claimed that the five dimensions exist independently, exist together, and are continuums that served as starting points for research. Table 4 summarizes Schommer's (1990) five epistemological dimensions and the continuums they represent.

Table 4

Summary of Schommer's (1990) Nine Positions of Epistemological Beliefs

Dimensions	Continuum
1. *Source of Knowledge*	Knowledge is handed down by authority. ←→ Knowledge is reasoned out through subjective and objective means.
2. *Certainty of Knowledge*	Knowledge is absolute. ←→ Knowledge is continuously evolving.
3. *Organization of Knowledge*	Knowledge is compartmentalized. ←→ Knowledge is interwoven and integrated.
4. *Control of Learning*	Ability to learn is predetermined. ←→ Ability to learn is acquired.
5. *Speed of Learning*	Learning is quick or not at all. ←→ Learning is gradual.

Schommer's (1993a) study of adult learning showed that the development of epistemological beliefs is affected by one's education and also indicated that as individuals increase in age, they become more assured that their learning ability can be improved. Hence, the assumption is that with more education obtained as an adult, individuals are more inclined to believe that knowledge is highly complex and is continually evolving. The work of Jehng, Johnson, and Anderson (1993) also supported Schommer's ideas that the higher the level of education completed, the more sophisticated and more complex their level of thinking. For example, Jehng et al. (1993) found that undergraduate students showed less complicated beliefs when compared to those of graduate students.

Epistemological reasoning in everyday life. Deanna Kuhn (1991) was motivated to explore individuals' beliefs about knowledge, more particularly reasoning that occurred in an individual's everyday life. Kuhn (1991) worked with participants whose ages ranged from the early teens to the sixties. She presented them with three ill-structured problems that required them to generate causal explanations as well as describe how they came to hold their specific views and justify their position by using supporting evidence. Next, Kuhn asked the participants to generate and rebut an opposing view, then offer a solution. Finally, participants were explicitly asked for an epistemological reflection of the reasoning presented.

Kuhn's analyses of the responses identified three distinct categories of epistemological views. Kuhn's three categories indicated that she focused on examining the certainty of expertise concerning epistemic assumptions. Furthermore, the categories appeared to align with the work of both Perry (1970) and King and Kitchener (1981, 1994). For example, Kuhn (1991) noted that absolutists claimed that experts could know for certain, multiplists declared that experts would never reach certainty and their own certainty equaled or exceeded that of the experts, and evaluativists asserted that although experts could not reach complete certainty, they are relatively more certain. Table 5 provides a summary of Kuhn's Epistemological Reasoning model showing three epistemological views.

Table 5

Summary of Kuhn's (1991) Epistemological Reasoning

Epistemological View	Epistemic Assumptions
1. *Absolutists*	Knowledge is certain and absolute, comes from an external source, and is not directly accessible.
2. *Multiplists*	Certainty of knowledge is equally valid; experts are uncertain, inconsistent, and skeptical about their expertise.
3. *Evaluativists*	Certainty of knowledge is skeptical, but viewpoints can be compared and evaluated.

Summary of Epistemological Models

The five central theories previously outlined comprised of work that began with William Perry where models focused to some degree on unidimensional, developmental sequences (Baxter-Magolda, 1992; Belenky et al., 1986; Perry, 1970), studies on epistemological assumptions and how they influence thinking and reasoning (King & Kitchener, 1994; Kuhn, 1991), and finally on a line of research that highlights epistemological ideas as systems of beliefs that were more or less independent rather than reflecting a consistent developmental structure (Schommer, 1990). Despite that researchers typically employ one of two lines of research (i.e., uni- or multi-dimensional) to investigate epistemological beliefs, the models which have been developed, although different, are related to a certain degree. Table 6 outlines how the epistemological perspectives from the various models align to coincide with the relative positions of Perry's (1970) model (adapted from Hofer & Pintrich, 1997).

Table 6

Summary of Five Models of Epistemological Development in Adults (Adapted from Hofer & Pintrich, 1997)

Perry's (1970) Scheme of Intellectual and Ethical Development	Baxter-Magolda's (1992) Epistemological Reflection	King & Kitchener's (1994) Reflective Judgment Model	Kuhn's (1991) Epistemological Reasoning in Everyday Life Model	Schommer's (1990) Epistemological Beliefs [a]
Positions	*Ways of Knowing*	*Reflective Judgment Stages*	*Epistemological Views*	*Dimensions*
Dualism	Absolute Knowing	Pre-reflective Thinking	Absolutists	Certainty of Knowledge
Multiplicity	Transitional Knowing	Quasi-reflective Thinking	Multiplists	Source of Knowledge
Relativism	Independent Knowing		Evaluativists	Origination of Knowledge
Commitment within Relativism	Contextual Knowing	Reflective Thinking		

Note. The stages and positions of the various models are aligned to indicate the similarities across the five models. Alignment is organized to coincide with the relevant positions of Perry's (1970) model.

[a] The work of Schommer (1990) does not follow a developmental structure like the first four models. However, the categories and descriptions of three of her positions on epistemological beliefs are, to some extent, analogous to that of Perry's and the other epistemological models.

Epistemology: An Educational Perspective

Research on teachers' epistemological beliefs about the nature of knowledge and how individuals acquire knowledge has been limited due to a lack of consensus about definitions for the construct (Munby, Russell, & Martin, 2001). Theoretical perspectives differ as to what constitutes a belief, the relationship between beliefs and teacher knowledge, teacher attitudes, perceptions, and actions. In general, teacher beliefs are described as separate from knowledge (Belbase, 2012; Chisholm, 1989).

Fenstermacher (1994) called for greater conceptual clarity, especially for the terms beliefs and knowledge, which have been used interchangeably in the literature regarding epistemological beliefs. Hofer and Pintrich (1997) used the word *slippery* to describe this issue of distinctly differentiating beliefs from other constructs such as epistemological beliefs. Knowledge is explained as scientific and objective and reflects the features of truth about the world. In contrast, beliefs are thought to be subjective and contain both evaluative and affective components (Jordan & Stanovich, 2003). This distinction becomes blurry when the research about the epistemological beliefs of teachers is carefully examined. However, a review of the intersection between the models of epistemological beliefs previously discussed, the core dimensions of epistemological beliefs (based on the literature), and the educational aspects of the nature of teaching and learning may shed more light on the matter.

The literature identified two main dimensions of epistemological beliefs: the nature of knowledge and nature of knowing. Suh (2016) identified four major theoretical sub-dimensions of epistemological beliefs, which she considered as four core dimensions of epistemological beliefs. The first, *changeability of knowledge*, is concerned with the nature of knowledge that describes how knowledge can be either certain or uncertain or changed or fixed. The second, *structure of knowledge,* is concerned with whether knowledge is complex or simple or inseparable or fragmented. The third, *source of knowledge*, is concerned with whether a person believes that knowledge comes from persons in authority or the individual and where knowledge resides, that is, either internally or externally. Finally, *justification of knowledge* describes procedures that individuals use to affirm or warrant knowledge claims as well as the ways and means that lead to the beliefs.

Considering these four sub-dimensions of epistemological beliefs, Suh (2016) posited that the changeability of knowledge and structure of knowledge is concerned with the nature of knowledge whereas, source of knowledge and justification of knowledge is focused on the nature of knowledge that describes the process of knowing. Table 7 shows an analysis of the four sub-dimensions of epistemological beliefs and their alignment with the models of epistemological beliefs discussed in the previous sections. Also included in Table 7 are the aspects of epistemological beliefs about the nature of teaching and learning, which are discussed in the sections that follow.

Table 7

Analysis of Epistemological Beliefs Models and the Sub-dimensions of Epistemological (adapted from Suh, 2016)

		The Nature of Knowledge			**The Nature of Knowing**	**Nature of Teaching and Learning**	
Scholars	**Model**	*Certainty of Knowledge*	*Structure of Knowledge*	*Source of Knowledge*	*Justification for Knowing*	*Ability to Learn*	*Process of Learning*
Perry (1970)	*Scheme of Intellectual and Ethical Development*	X		X			
King & Kitchener (1981)	*Reflective Judgement*	X	X	X	X		X
Baxter-Magolda (1992)	*Epistemological Reflection*	X		X	X	X	
Schommer (1990)	*Epistemological Beliefs*	X	X	X		X	
Kuhn (1991)	*Epistemological Reasoning in Everyday Life*	X	X	X	X		

Note. An 'X' indicates which of the aspects of epistemological beliefs (certainty of knowledge, structure of knowledge, source of knowledge, justification of knowledge, speed of learning, ability to learn, process of learning) are present under the three broad themes— Nature of Knowledge, Nature of Knowing, and Nature of Teaching and Leaning—that were highlighted by the models from the various scholars**.**

Beliefs about Teaching

Epistemological beliefs have a significant impact on the teaching and learning process in the classroom (Er, 2013). Teachers' beliefs about knowledge and knowing are related to learning how to teach as well as instructional practices (Brownlee, Schraw, & Berthelsen, 2011). In a review of the literature on personal epistemology, Feucht (2010) concluded that the beliefs of teachers span a developmental continuum that embraces an absolutist, multiplist, and evaluativist beliefs. Olafson and Schraw (2010) posited that absolutist teachers conform to the traditional instruction epistemology and believe that teaching encompasses the transfer of knowledge from the teacher—the expert—to the student who is, in contrast, the naïve, passive learner. For this reason, absolutist teachers adopt a *conduit metaphor* of instruction (Mascolo, 2009). Multiplist teachers adhere to a constructivist epistemology and create a learning environment that allows students to actively construct their own knowledge and meaning (Olafson & Schraw, 2010). Finally, the evaluativist teacher embraces the worldview that knowledge is tentative and contextual and, as such, promotes learning activities where students collaborate and construct knowledge based on shared understanding (Tsai, 2002).

Studies focusing on teachers' epistemological beliefs characterized teachers' epistemologies into three epistemological worldviews: realist, relativist, and contextualist. Epistemological worldviews are described as the collective attitudes of teachers towards the nature of knowledge and learning (Schraw, Brownlee, Olafson, & Brye, 2017). Teachers who exhibit a realist worldview presume that existing knowledge is objective, unchanging, and established by experts. Contrarily, relativist teachers assume that knowledge is subjective and liable to change. Teachers with a contextualist worldview assume that knowledge is shared and is context-dependent and tentative (i.e., these teachers demonstrate evaluativist thinking as described by Kuhn, 1990).

Epistemological beliefs influence teaching and therefore play an essential role in a variety of academic experiences (Hofer, 2000). A teacher's epistemological beliefs are closely associated with their actual teaching in the classroom. Factors like teachers' conceptualization of the nature and justification of knowledge and teachers' ideas about students' learning have been found to influence classroom discourse (Mansour, 2013). For example, if a science teacher views some aspects of scientific knowledge as tentative, this teacher may set up student discussions around controversies that exist in science on ideas such as stem cell research or genetically modified organisms (GMOs). Students interpret these classroom activities through their own epistemic lenses, and changes in their own personal theories may take place accordingly. A student in the science classroom just described may have previously viewed scientific knowledge as an unquestionable fact. However, through classroom debates with peers, these epistemological beliefs may move the student to accept that scientific knowledge can be subjective. Several studies support how teachers' epistemological beliefs influence their teaching practices, including Johnston, Woodside-Jiron, and Day (2001) and Muis and Foy (2010), who studied the epistemological beliefs of elementary teachers in English instruction and elementary mathematics teachers, respectively.

Chan and Elliott (2004) contended that epistemological beliefs influence the teaching approaches preferred by teachers. There is a shift in teachers' teaching conceptions from a traditional teaching conception based on the transfer of knowledge in the design and application of education to a constructivist conception, which emphasizes the transformation of knowledge (Ekinci, 2017). In this sense, constructivist teaching strategies require the active participation of students in the process of constructing knowledge. That is, teaching is more student-centered (Brownlee, Thorpe, & Stacey, 2005). Epistemological beliefs that encompass constructivist epistemology emphasize the acquisition of knowledge as the active construction of it by the learner rather than the passive acquisition of knowledge. Moreover, enhancing higher-order thinking skills will be the goal of constructivist teaching. Contrarily, traditional conceptions of teaching are more teacher-centered, because knowledge acquisition is via a one-way transmission process from teacher to student. Apart from playing a major role in knowledge transmission, the traditional conception of teaching also emphasizes curriculum materials and textbooks, mastery of first-order domain knowledge, and procedures (Biggs, 1999).

Tsai (2002) categorized the beliefs of Taiwanese teachers as either traditional or constructivist. In their examination of teachers' conception of teaching as being either traditional or constructivist, the conception of beliefs has been seen at either end of the continuum. According to work done by Chan and Elliot (2004) and Cheng et al. (2009), there are four major approaches to teaching: how to teach, the role of the teacher, the goal of teaching, and control of learning. Suh (2016) also highlighted these four approaches in her study of epistemic orientations towards teaching. Table 8 identifies how these four approaches are associated with teachers' conceptions of teaching at either end of the continuum.

Table 8

Teachers' Conceptions of Teaching

	Traditional Teaching	Constructivist Teaching
How to Teach	– Teacher-centered – Transmit core facts and concepts to students – Emphasize and value strict adherence to textbooks, workbooks, and curriculum materials	– Student-centered – Pursuit of student questions and interests is valued. – Emphasize students' motivation and interaction with each other and creating learning environments where students are engaged in constructing their own knowledge, reasoning, and critique
Role of Teacher	– Teachers disseminate information to students, the recipients of knowledge – Teacher's role is directive and rooted in authority	– Teachers are facilitators, have dialogues with and help students construct their own knowledge – Teacher's role is interactive, rooted in negotiation
Goal for Teaching	– Help students master low-order thinking or domain knowledge and basic procedure	– Help students develop conceptual understanding and higher-order thinking/evaluation skills
Control of Learning	– Teachers direct and guide student learning	– Students are in control of their own learning

Beliefs about Learning

One of the earliest studies on beliefs about learning was in the work of Schoenfeld (1983, 1985). Students were observed as they solved geometry problems and were encouraged to think aloud (Schoenfeld, 1983). Schoenfeld concluded that students' beliefs characterized three areas. First, only gifted authority figures can genuinely understand mathematics, which served as a precursor of students' belief in the *ability to* *learn.* Second, problem-solving questions in mathematics should be done quickly or not at all, which served as a precursor of students' belief in the *speed of learning*. Third, mathematics proofs are imparted by omniscient authority figures, which served as a precursor of students' beliefs regarding the *source of knowledge*.

Work by Dweck and Leggett (1988) supported that students have the perception that authorities are gifted experts and that gifted experts learn quickly. Accordingly, when individuals are faced with a difficult task, those who believe that the ability to learn is limited and fixed at birth (i.e., fixed mindset) will display behavior where they give up easily (Dweck & Leggett, 1988). Under the same circumstances, those with a strong belief that the ability to learn can improve or grow (i.e., growth mindset) will persist and try various strategies (Dweck & Leggett, 1988).

Using the literature base, findings from the extensive work completed by Schoenfeld (1983, 1985) and Dweck and Leggett (1988) to examine beliefs about learning, Suh (2016) proposed two dimensions of learning that researchers should consider: the ability to learn and how to learn. First, regarding how teachers view learning, Bendixen and Corkill (2011) reported that experienced teachers viewed learning as fixed and innate, a perception that differed in inexperienced pre-service teachers. This view suggested that increased classroom experience caused teachers to view learning ability as fixed. Second, it was noted that teachers considered the characteristics of the students, such as whether students have cognitive disabilities or not when thinking about how students learn. Findings of a study by Schwartz and Jordan (2011) reported that teachers' beliefs about the nature of the ability to learn predicted how much attention was paid to students who have learning difficulties. This claim proposes that teachers' beliefs about students' learning abilities are related to certain classroom practices. According to Jordan and Stanovich (2003), teachers perceive their responsibilities for the instruction of students with cognitive disabilities as minimal and therefore acted accordingly.

Beliefs about the Nature of Knowledge and Knowing about Science

Teachers' epistemological beliefs have been met with growing attention from science education researchers. Reform efforts in science education have urged teachers to generate learning environments where students actively make sense of nature for themselves (AAAS, 1993; NRC, 1996, 2000, 2012). As part of the reform initiative, the Next Generation Science Standards (NGSS, NGSS Lead States, 2013) highlight eight features of scientific knowledge and development that include practices and cross-cutting concepts that facilitate students' understanding of the nature of science (NOS) if they are embedded in science instruction. These NGSS features are consistent with the tenets of NOS that scholars like McComas, Clough, and Almazroa (1998) and Lederman (2013) have posited to be ways of describing the nature of science. The features are as follows:

(1) scientific investigations utilize a variety of methods;

(2) scientific knowledge is founded on empirical evidence;

(3) scientific knowledge is open to revision in consideration of new evidence;

(4) scientific models, laws, mechanisms, and theories describe natural phenomena;

(5) science is a way of knowing;

(6) scientific knowledge assumes order and consistency in natural systems;

(7) science is a human endeavor; and

(8) science addresses questions about the natural and material world.

The work of Suh (2016) categorized these features into the following three dimensions of science-specific epistemological beliefs: (1) changeability of knowledge, (2) process/source of knowing, and (3) justification of knowing. These dimensions are important in investigating biology GTAs' epistemological beliefs regarding the teaching and learning of science, where professed beliefs of teachers can be aligned with one or more of these dimensions (Table 9). As such, this study includes these eight nature of science dimensions of epistemological beliefs as an analytical framework to determine the features of biology GTAs' epistemological beliefs.

Table 9

Dimensions of Epistemological Beliefs in Science (Adapted from Suh, 2016)

Epistemological Beliefs Dimension	Nature of Science (NOS)
Changeability of Knowledge	– Scientific knowledge is open to revision, taking into account new evidence.
Process/Source of Knowing	– Scientific investigations use a variety of methods. – Scientific models, laws, mechanisms, and theories clarify natural phenomena. – Science is a human endeavor. – Scientific knowledge assumes order and consistency in natural systems.
Justification of Knowing	– Science is a way of knowing. – Scientific knowledge is based on empirical evidence. – Science deals with questions about the natural and material world.

NOS is defined as a way of knowing that includes a set of values and beliefs that are inherent to the development of scientific knowledge (Hodson, 2014; Lederman,

Lederman, & Antink, 2013). Clough (2006) also noted that NOS involves what science is, how it works, the operations of scientists as a social group, and how society influences and reacts to scientific endeavors. Research indicates that individuals with strong NOS understanding excel at problem-solving strategies and goal-setting (Cavallo, 2003; Lin & Chiu, 2004). Lederman et al. (2013) purported that instructors who plan their lessons for NOS content create learning environments that relegate NOS content to implicit instruction via experiments or use of historical examples.

Even so, science teachers must switch their focus on instruction from designing inflexible, traditional teacher-centered lessons to creating an environment where students actively participate. Constructing a learning environment for students' engagement in science practices is an instructional approach epistemologically different from the traditional approach focused on the transmission of knowledge. It is neither common nor easy to produce such learning environments. Windschitl (2002) contended that a priority and emphasis on teacher education should be to encourage teachers to change their epistemological beliefs. In such a frame of reference, teachers' epistemological beliefs have received new attention in science teacher education.

As the education paradigm shifted from traditional instruction to constructivism, there has been an increase in research on teachers' beliefs and belief systems. The importance of appropriate conceptions about teaching and learning science was highlighted by Hewson and Hewson (1987) and Hewson, Hewson, and Mariana (1988). Hewson and Hewson (1987) underscored the need for an in-depth study of how beliefs affect science instruction. Since then, many have studied science teachers' epistemologies regarding pedagogical beliefs. Maor and Taylor (1995) found that teachers' epistemologies continue to perform an essential role in mediating the quality of science teaching even in digital classroom environments. Also, Abd-El-Khalick, Bell, and Lederman (1998) and Lederman (1992, 1999) acknowledged the possible impact of teachers' beliefs about the nature of science in instructional plans and practice.

In the teaching of science, beliefs are considered as core and peripheral (Brownlee, Boulton-Lewis, & Purdie, 2002) as well as epistemologically oriented (Bendixen, Dunkle, & Schraw, 1994). The more a belief is connected to other beliefs, the more central and impervious to change it becomes. Peripheral beliefs are more likely to change and are context-specific (Brownlee, 2001). As teachers engage in science instruction, their beliefs change and expand in their epistemological orientation (Luft & Roehrig, 2007). As such, capturing the beliefs of teachers is essential in science education since beliefs reveal how teachers view knowledge and learning and also suggest how teachers enact classroom practices.

Regarding epistemological beliefs about science and science knowledge, many have researched the views of NOS and its influence on teaching strategies (e.g., Ackerson, Abd-El Khalick, & Lederman, 2000; Duschl, 1990; Lederman, 1992; Lederman & Lederman, 2014). The NOS includes values and beliefs that are essential for the development of scientific knowledge (Hodson, 2014; Lederman, 1992). While there is no unified definition of NOS, various approaches have been employed to examine the relationship between teachers' views of NOS and their instructional practices. Also, there have been studies that attempted to link epistemological beliefs to NOS. For example, Deniz (2011) described three methods of teaching that he claimed could improve NOS understanding and/or epistemological reasoning. One is direct instruction using standard science textbooks, materials, and problems as a body of knowledge rather than a way of knowing. A second is using open inquiry where students are expected to construct knowledge and NOS understanding. The third is through guided inquiry where teachers or more advanced peers mentor students. The claim is that these three strategies should be employed with all groups of students, including pre-service teachers, because they may increase awareness and sophistication of epistemological beliefs regarding NOS as well as increase understanding of NOS through authentic science inquiry (Deniz, 2011).

Koballa, Graber, Coleman, and Kemp (2000) proposed three categories for science teacher beliefs about knowledge and knowing: traditional, process, and constructivist. According to Koballa et al. (2000), the traditional category perceives teaching science as transferring knowledge from teachers to students, learning science as acquiring and or reproducing knowledge from credible sources, and scientific knowledge as being correct answers and/or established truths. The process category highlights science teaching and learning as activity-based with a focus on the processes of science or problem-solving procedures. The process category also perceives scientific knowledge as facts that are discovered through the scientific method. The constructivist category perceives science teaching as helping students construct knowledge and learning science as constructing understanding and science as a way of knowing. Building upon those ideas, Luft and Roehrig (2007) reported that beginning secondary science teachers' beliefs could be categorized as being transitional, instructive, transitional, responsive, and reform-based.

In further examination of science teachers' beliefs about knowledge, Yang and Tsai (2010) reported that science teachers believed that they were merely presenters of factual knowledge that aligned with the traditional-oriented conception about the teaching and learning of science. These findings reflected earlier research by Aguirre, Haggerty, and Linder (1990). Furthermore, Yang and Tsai (2010) suggested that many teachers hold traditional views of teaching science, and this may be a result of their own school science experience. Science classes, laboratory activities, and even activities from teacher training programs may have reinforced science teachers' traditional views.

Kagan (1992) identified teachers' beliefs to be tacit assumptions about situational factors (e.g., student experiences, classroom settings) and course content. Kruse and Roehrig (2005) found that the teaching beliefs of high school chemistry teachers strongly correlated with the adoption of reformed teaching practices. Addy and Blanchard (2010) found no significant correlation between an overall measure of reformed teaching practices among biology GTAs and their teaching beliefs. However, beliefs were found to correlate with some specific measures such as propositional knowledge (i.e., what the teacher knows and how well they can organize and present material), the quality of student-student interaction, and student-teacher relationships. These measures may be more subject to change in lab environments where GTAs are provided materials and told what to teach.

GTAs' Beliefs about Science Teaching and Learning

Teacher's beliefs lie "at the very heart of teaching" (Kagan, 1992, p. 85), and are a driving force behind pedagogical decisions made by science instructors. Considering the role of GTAs as teachers who influence the quality of undergraduate instruction, one would assume that their training would be of high precedence. Surprisingly, Gardner and Jones (2011) found that the training of GTAs is not highly prioritized in the United States, and GTAs often face many hurdles to their training as instructors. For instance, considering their role within the academic department, GTAs find it challenging to find a niche and may identify themselves as one or more of several things such as a graduate student, an academic and a professional, a scientist, or even an instructor (Muzaka, 2009). According to Park and Ramos (2002), GTAs are both the student and the teacher but neither entirely one, and there is an underlying tension between responsibility and power with the marginalized niche that GTAs occupy within departments and the lack of ownership of the teaching and learning process. This marginalization is a result of how GTAs perceive themselves and their roles as instructors (Muzaka, 2009).

Despite the difficulties of defining their identities as science instructors, GTAs enter their academic careers with beliefs about what effective science teaching should be (Gardner & Jones, 2011). Kagan (1992) proposed that since GTAs have had very little explicit teacher training, their instructional identities may be based on past experiences as students, untested personal beliefs of teaching and learning, and fantasized views of teaching. The fantasized views of teaching that GTAs display is the first of a four-stage theory of teacher development proposed by Ryan (1986).

Gardner and Jones (2011) purported that GTAs have limited conceptions about the way that students learn, how science should be taught, and of teaching in general. These conceptions are like that of traditional learning theories, where it is believed that knowledge is tangible and that the role of the instructor is the sole transmitter of knowledge (Gardner & Jones, 2011). As a result, these views and conceptions limit the insight of GTAs to what students need to learn science effectively.

Studies that examined the beliefs of GTAs found that they tend to believe that content knowledge is an important necessity for being an effective teacher. Science content is an essential component of teaching, but it may be problematic when science GTAs perceive that it is the only type of knowledge that is required to teach. In a study of 11 GTAs from science, biology, and physics conducted by Luft et al. (2004), findings indicated that experience, intuition, and practice were more critical than knowledge of pedagogy. Also, Herrington and Nakhleh (2003) reported that Chemistry GTAs compartmentalized knowledge and claimed that there were four types of knowledge required for effective teaching: knowledge about student learning, knowledge about teaching, knowledge about content, and knowledge specific to laboratory tasks. However, Herrington and Nakhleh (2003) did not explicitly identify knowledge of pedagogy as vital.

In a national study of college instructors, Stark (2000) surveyed 2,311 faculty members teaching introductory courses across multiple disciplines, 85% of which were general education courses. Stark found that instructors' beliefs about their students and their discipline strongly influence the way they plan their courses. That is to say that beliefs act as filters through which teachers make decisions regarding instruction and play a critical role in classroom practice (Richardson, 1996). Even though teachers' beliefs about knowledge affect their decision-making process, their behaviors in class are direct consequences of beliefs that have developed via various experiences (Pajares,1992). Other studies that support that these beliefs significantly influence teachers' behaviors in class and the educational environment they create include the work of Deniz (2011), Kagan (1992), and Schraw et al. (2017).

An examination of GTAs' epistemological beliefs and their influence requires a theoretical framework by which the researcher can connect to existing knowledge. Although teachers' (which includes GTAs) beliefs are substantial in shaping their actions, the relationships among beliefs, practices, and context are not always linear but are most often interactive (Zheng, 2015). These interactions become far more complicated when teachers engage in education, such as at the university level, where they are required to confront and resolve problems caused by apparent contradictions related to their epistemological and pedagogical beliefs (Gay, 2010). For example, if a teacher prefers to use group work to promote understanding of a particular concept, there may be students who oppose this way of teaching because these students may believe that they work best when they work alone. GTAs may encounter such problems, especially in laboratory settings, when students are encouraged to work in groups (Springer, Stanne, & Donovan, 1999). In this study, complexity theory, which shares an emphasis on holistic approaches, provides a theoretical lens for analyzing GTAs' epistemological beliefs, practices, and classroom context.

Misalignment between Teacher Beliefs and Instructional Practice

Zheng (2015) proposed that some consistent relationships between teachers' beliefs and instructional practices may be superficial in that teachers claim strongly about certain beliefs without implementing them in their practice, which indicates a misalignment between instruction and practice. In this case, instructors may adopt certain practices that may represent either their core or peripheral beliefs, where contextual factors determine the prevailing belief. Core beliefs about knowing reflect an individual's beliefs about what knowledge is, how it is obtained, how certain it is, and the parameters and criteria for determining knowledge (Perry, 1999). The more connections that exist between any particular belief and other beliefs within an individual's belief system, the more central (core) and impervious to change that belief will be. However, core beliefs about knowing are relativistic in nature and may influence beliefs about teaching and learning. Contrarily, peripheral beliefs are more likely to change depending on the particular learning context (Hofer & Pintrich, 1997) and are context-specific. Therefore, beliefs, influences, and conceptions about teaching and learning strategies are more likely to change depending on the contextual factors (Pajares, 1992).

The research shows that researchers employ various terms to describe when action and practices do not coincide. For example, terms used include *dissociation* (McGinnis, 2017; Staats, 2016) and *token association* (Zheng, 2015). For teachers, the complex dynamic between what they profess and what they actually do in the classroom result in the development of dissociations or token adoption. This is not to say this misalignment is intentional or malicious. Instead, it is an unfortunate consequence of the influence of contextual factors of the teaching and learning environment.

There are reports in the literature that reveal misalignments between teachers' expressed beliefs and their instructional practice (e.g., Chen, 2008; Cohen 1996; Mansour, 2013; Zeichner, Tabachnick, & Densmore, 1978). Although teaching has been considered as an intentional activity, not all instructional activities are based on a teacher's intentions and beliefs since the environment that surrounds teachers have a stronghold on decision-making. Analysis of studies that report inconsistencies between instructor beliefs and instruction revealed that there are internal and external factors that cause the inconsistencies identified. External and internal factors that surround teachers have a strong hold on the decision-making (Levin, 2015; Lowyck, 2003) and include limited or inappropriate content knowledge, contextual constraints, learner factors, teaching goals, the curriculum, and departmental or school policies (Ball & Cohen, 1996; Chen, 2008; Mansour, 2013). Internal factors include teachers' experience, sense of self-efficacy, self-awareness, self-reflection, and other beliefs (Buehl & Beck, 2015).

Several researchers have attempted to account for the inconsistencies between beliefs and practice. A few studies have examined the related depth of teachers' espoused beliefs by considering the connection between the various types of core underlying beliefs (Arvold, 2002; Levin, 2015; Speer, 2002). Other studies looked at teachers' level of consciousness of their own beliefs and the degree to which teachers reflect on their practice (Buehl & Beck, 2015; Ernest, 1989). Finally, investigators have considered the influence of social context, an area that has not been adequately represented in current literature regarding a means of explaining the misalignment between teacher beliefs and practice. Since none of the past studies have provided an adequate explanation for the disparities or unpacked the complex relationship between teacher beliefs and instructional practices, the current study was particularly interested in how contextual constraints of the laboratory can consequently inform why instructional practices that would otherwise align with GTAs' beliefs about knowledge and the nature of knowing would not.

Contextual Constraints of the Laboratory

Although it has been accepted that the study of how beliefs about knowledge and knowing is important to the understanding of instructional practices and teachers' decisions in the classroom, there is also a growing body of research that argues that teacher beliefs should be studied within a framework that takes contextual constraints into account (Mansour, 2013). According to Lederman (1992), the transposition of teachers' beliefs into their instructional practice is mediated by situational variables such as constraints imposed by the immediate classroom environment. Tamimy (2015) posited that although teaching is an intentional activity, not all instructional activities are based on a teacher's beliefs since the environment that surrounds teachers has a stronghold on instructional practices. Contextual constraints may affect the enactment of the models of teaching and learning in the classroom. Fishbein and Ajzen (1977) have also credited the role of contextual factors in classroom behavior prediction. The effect of context and its constraints also causes teachers in the same school who hold varying sets of beliefs to adopt similar teaching practices (Mansour, 2013).

The undergraduate laboratory environment is not without its constraints. Some of the most challenging laboratory constraints include time allocated for instruction (Jordan, Ruibal-Villasenor, Hmelo-Silver, & Etkina, 2011; Keiser & Lambdin, 1996), teaching resources and equipment (Jordan et al., 2011), systems of assessing students and student safety (Hensiek, 2018), learner responses, individual student differences, and student expectations (Mansour, 2013; Round & Lom, 2015), physical structure such as class size (Freeman et al., 2014), and institutionalized curriculum (Earnest, 1988; Mansour, 2013). According to Nespor (1987), the context and environments within which teachers engage in instructional practice and many of the problems that they encounter are deeply entangled. This insinuates that the laboratory constraints may influence teaching instructional practices of laboratory instructors. Therefore, it is also important to consider the science instructional practices of laboratory instructors. The next section describes the scientific practices that are considered as research-based practices that should be threaded into laboratory teaching practices of science instructors.

In their study on laboratory instruction, Jordan et al. (2011) also identified other factors that may pose as laboratory constraints. According to the researchers, laboratory instructors may feel that their instruction is inhibited by three driving factors: the procedural focus of the laboratory task; the disconnect between instructor and student goals for the laboratory experience; and a focus on laboratory curriculum materials such as the laboratory manual and the associated equipment provided to complete laboratory activities. First, the procedural focus on the laboratory activities is analogous to the traditional teaching approach, which was also identified as the *cookbook* mentality where students are led to focus on task completion instead of thinking about the experimental outcomes (Schamel & Ayres, 1992). Second, there seems to be a difference between the instructor and students' expectations for the laboratory (Chang & Lederman, 1994). While the instructor's outlooks include a broader context of the inquiry experience, students tend to view laboratory task completion as the major goal of the laboratory. The third factor (i.e., laboratory resources), which includes laboratory equipment and the laboratory manuals that support how to use the equipment, can serve to distract students from more significant ideas and conceptual understanding (Jordan et al., 2011). According to Hofstein and Lunetta (2004), during their laboratory experience, students tend to focus on manipulating equipment instead of critically thinking. The objective of engaging students using science inquiry practices through laboratory experiences is not an easy one to achieve. A few of the reasons include that students have difficulty asking productive science-related questions (Marbach-Ad & Sokolove, 2000) and that students often have trouble articulating the use of evidence to support scientific claims (Ryder, Leach, & Driver, 1999).

According to Nespor (1987), the context and environments within which teachers engage in instructional practice, and many of the problems that they encounter are deeply entangled. This insinuates that the laboratory constraints may influence teaching instructional practices of laboratory instructors. Therefore, it is also important to consider the science instructional practices of laboratory instructors. The next section describes the scientific practices that are considered as research-based practices that should be threaded into laboratory teaching practices of science instructors.

Science Teaching Practices

Epistemology of the nature of knowing and knowledge in and about science has been emphasized in science standards for many decades (e.g., AAAS, 2013; NRC, 2012). Project 2061 (AAAS, 2013), a reform initiative that evaluated the feasibility of incorporating the central ideas of the K-12 science reform movement into the undergraduate curriculum, has promoted the understanding of the epistemology of science using cross-cutting concepts and science teaching practices. A new direction for laboratory curriculum development is the integration of authentic science practices. The American Association for the Advancement of Science (1990) has long encouraged teachers to incorporate research-based science practices that:

1. *Start with questions about nature*: raise questions about phenomena that are interesting and familiar to students that will encourage them to observe, collect information, describe, ask questions, and try to find answers to their own questions.
2. *Engage students actively*: provide students with opportunities to collect, sort, make notes, catalog, sketch, measure, systematically observe, count, graph, etcetera. Among the diverse activities, students should be provided the opportunity to determine which instruments techniques to use as well as how to use them to generate and make sense of results of their investigations.
3. *Concentrate on the collection and use of evidence*: provide students with problems based on their prior knowledge and level of maturity that require them to decide what evidence is relevant in addition to offering their own interpretation of what the evidence means.
4. *Provide historical perspectives*: provide students with historical contexts of scientific ideas that will enable them to understand the scope of the scientific enterprise and help them develop a sense of how science really happens and how scientific ideas grow through twists and turns to give our current understanding of scientific ideas. In addition, to afford students an understanding of the roles of scientific investigators and commentators and the relationship between evidence and theory over time.
5. *Insist on clear expression*: provide students with the opportunities to develop effective oral and written communication by highlighting clear

expression as the role of evidence and unambiguous replication of evidence may not be understood without a struggle.

6. *Use a team approach*: reinforce the collaborative nature of scientific work through frequent group activity in the classroom so that students can gain experience of sharing responsibility for learning with each other.
7. *Do not separate knowledge from finding out*: provide students with opportunities to develop their scientific reasoning, not as a set of procedures that are separate from other materials such as the scientific method but in a manner that will help students acquire both scientific knowledge of the world as well as acquire scientific habits of the mind.
8. *De-emphasize the memorization of technical vocabulary*: Provide students with the chance of understanding rather than learning vocabulary. Students should be allowed to learn technical terms as a need to clarify thinking and to promote effective communication that will, in turn, enable students to gradually build a functional vocabulary that will be retained in students' long-term memory rather than just for their next test.

Science is defined as much by what it does and how it is done as it is defined by the results that it achieves. Students should be able to have experiences of thought and action that is typical of science to understand science as a way of thinking and doing and as a body of knowledge. As such, science instructors would need to teach science in a manner that is consistent with the nature of inquiry. These guidelines for science practices purported by AAAS are reiterated in their *Vision and Change in Undergraduate Biology Education: A Call to Action* (AAAS, 2013) as well as other *Science for all*

Americans (SFA) publications. Since the current study aimed to identify essential features of epistemological beliefs about the teaching and learning of science that are compatible with the theoretical foundations of current reform movements in science education, these eight features of science teaching practices serve as theoretical sub-dimensions of science-specific instructional practices. These science teaching guidelines and how they are defined were used to analyze the laboratory practices of biology GTAs. The theories that were used to guide this study are discussed in the section that follows.

Theoretical Framework of Study

It is essential for contemporary researchers to choose, with satisfactory argument and justification, a theoretical framework that will guide their research. This section provides a review of complexity theory and Ecological Systems Theory, as well as the interpretive paradigm, as a theoretical perspective to further an understanding of the features of the GTAs' epistemological beliefs and the relationship between context and the instructional practice. To begin, this section provides a discussion of the complexity theory followed by Ecological Systems Theory.

Complexity Theory

Complexity theory is a theory of learning systems. It provides a framework for researchers who are interested in investigating how systems develop and change and is transdisciplinary in nature as it draws on insights from diverse fields across both the hard and social sciences. The application of complexity theory in education may provide a complex rather than simplistic view of teaching and learning (Martin, McQuitty, & Morgan, 2019). Additionally, complexity theory has the potential to offer an alternative to the linear and reductionist conceptualizations that have been previously used in education studies, with implications for methodology of teacher education research along with its analysis and design.

The study of complex systems has been defined as “a collection of individual agents with freedom to act in ways that are not always totally predictable and whose actions are interconnected so that one agent’s actions changes the context for other agents” (Plsek & Greenhalgh, 2001, p. 625). Complexity theory is concerned with relationships and the emergence of something new. It is a holistic theory that invites researchers to look for connections. There are various metaphors associated with complexity theory to provide an understanding of the theory itself. One such example is the metaphor of the *butterfly effect*. This metaphor describes an analogy about how a butterfly flapping its wings in the Caribbean may lead to a tornado in Tennessee. One cannot know the bearing of that particular factor—the wings flapping—on the weather conditions in Tennessee without taking into consideration the whole agglomeration of factors that constitute weather systems. However, that small flap of the butterfly’s wings, in conjunction with other components in the weather system at the time, may contribute to a much greater effect than just the butterfly itself and the flapping of its wings. Hence, one needs to consider the myriad of contributing factors that are unclear, especially when one does not know what the salience of each factor is. It is also challenging to determine what components matter the most and to what degree of predictability. The components of the system are, therefore, important to consider due to their effect on a system.

The components of a complex system are most commonly modeled as agents, that is, individual elements that act upon their environment depending on the events they experience. Examples of components or agents are people, cells, animals, molecules, classrooms, institutions, etcetera. This study focused on the laboratory as a complex system within which were found two components: contextual constraints and features of GTAs' epistemological beliefs. It must be noted that other components can be found in the laboratory system; however, this study concentrated only on those mentioned above.

Apart from the components of a system, complexity theory is also explained by focusing on its attributes. The attributes of complexity theory allow the understanding of a system and how its components interact to support, compete, condition, or affect each other. These attributes include self-organization, emergence, non-linearity, connectivity, and autonomy and co-adaptation (Davis & Sumara, 2006).

Foremost, complexity theory views a system as self-organizing. The process of self-organization typifies complex systems as spontaneously organizing themselves to better deal with various internal and external perturbations and conflicts. This allows the system to evolve and adapt to a continually changing environment. The processes of self-organization create order out of disorder (Mason, 2008). Also, there is no top-down, centralized mechanism for coordinating the whole system. Within complex systems, components have a degree of autonomy that is dependent on its ability to co-adapt, often through the system's capacity to adapt to its local environment according to its own set of instructions, without centralized coordination, and with a degree of autonomy. Thus, self-organization depends on the local interactions that exist between agents.

The process of co-adaptation and autonomy of the components of a system allows the self-organization of that system to take place as it adjusts to changes in the environment (Casti, 1997; Freeman & Cameron, 2008; Lee & Kim, 2014; Pae, 2015). As agents within a system adapt, any modifications within them influence other agents within the system and influence how the first set of adaptations continue to change. Eventually, there is the emergence of novel and coherent structures and patterns (Goldstein, 1999). As a result of these changes, the emergence of new phenomena is supported.

In complexity theory, any subtle change in initial conditions can create immense implications for the future behavior of the system as a whole due to the interconnectedness of all components/agents involved (Gleick, 1987; Larsen-Freeman, 1997). How components connect and what is connected to what become the main questions. Furthermore, at some critical level of connectivity, the system stops being a set of parts, becomes a network of connections, and is now all about how things flow in this system. Finally, complex systems show non-linear dynamics. This means that the system may suddenly change behavior or move to another regime or form of management. Besides, the system may move from a high degree of stability to volatile behavior or vice versa.

Researchers in the field of education and educational psychology have used complexity theory to investigate teachers' beliefs. For example, Zheng (2015) studied teachers' beliefs about the English language as a complex system. Furthermore, complexity theory has been used to view beliefs in general, not as a single agent but as a system that consists of interactive substructures of beliefs (Richardson, 2003; Zheng, 2013). More recent studies have used complexity theory to focus on eliciting different kinds of interactions among components such as teachers' beliefs, practices, and contexts (e.g., Zheng, 2015). The context of the laboratory was very significant in this study.

Ecological Systems Theory and Interpretivist Approach

The theoretical framework of this study incorporated the Ecological Systems Theory as it attaches great significance to the context or contextual factors. Bronfenbrenner (2005b) developed the Ecological Systems Theory and posited that an individual's development is affected by everything in his or her immediate surroundings. Bronfenbrenner's work contributes to the complexity framework by concentrating on the understanding of relationships and the interconnectedness of individuals and contexts. In this regard, teacher beliefs or instructional practices are not static, and context is not a consistent background variable that exists outside the individual. According to Zheng (2015), the mental activities of teachers and context are linked, which indicates an interconnectedness and symbiotic relationship between teacher beliefs and context. By amalgamating Ecological Systems Theory with complexity theory, this study was able to investigate the contextual factors of the laboratory and their influence on the behavior of GTAs during instruction. Figure 1 provides a visual representation of the theories that guided this study.

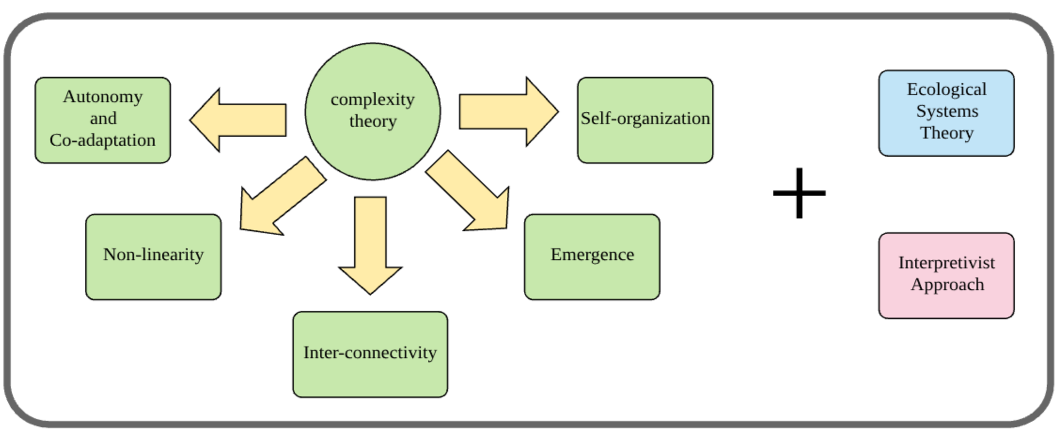


Figure 1. Theoretical foundation of the study.

The use of complexity theory is not without criticism. Critics argue that the complexity theory only provides descriptions and no explanations or solutions. In order to conceptualize how epistemological beliefs of GTAs interact with their teaching practice, an explanatory model of research is needed. In this case, the interpretivist paradigm was used to construct this aspect of the theoretical framework. Feryok (2010) and Zheng (2015), who examined the applicability of complexity theory to the study of language teachers' cognition and belief systems, respectively, have used such integration in an exploratory study.

A look at both the constructive role of contexts and the interpretive role of GTAs' epistemological beliefs is vital in understanding the instructional practice. The interpretivist framework was useful in this study since it supported the perspective that an understanding of GTAs' beliefs and practices depended on the comprehension of their intentions and interpretations of laboratory situations such as constraints that may have influenced instructional decisions. However, there seems to be a conflict between the two frames: the complexity theory and the interpretivist approach. The complexity theory focuses on analyzing systems and interactions and relationships between components that extend beyond just the individual component. On the contrary, the interpretivist approach aims to understand how the individual interprets his or her own views of the world around him or her. Using either one or the other of these two frames of reference would not help to achieve the goal of this study.

To meet the objective of this study, both perspectives were adopted to analyze and interpret the interactions that extended beyond the individual in a certain context. In addition, together, the two frameworks provided the connection between *macro* and *micro* research (Morrison, 2008). The macro aspect of this research focused on the GTA in the laboratory context and the micro research was concerned with the GTA as an individual and his or her professed epistemological beliefs.

Chapter Summary

The preceding literature review of epistemological beliefs laid the theoretical and analytical foundation for this study. This review started with a historical perspective of epistemology and included a definition of epistemology and epistemological beliefs, followed by a psychological perspective that acknowledged the various theoretical models that have been developed from the research in the field. Next, literature from education that highlighted teacher beliefs about teaching, teacher beliefs about learning, and teacher beliefs about the nature of knowledge and knowing in science was presented. Also, an exploration of the theoretical gap concerning the biology GTAs and their epistemological beliefs and the dynamic and complex relationship between GTAs' beliefs and their instructional practice was provided. This issue was addressed through the lens of the complexity theory, which allowed for the conceptualization of GTAs' epistemological beliefs as a complex, dynamic, contextualized system. Finally, the analytical framework provided the limitation of the complexity theory in that it does not allow for the explanations but provides descriptions of phenomena. To compensate for this insufficiency, the interpretivist perspective was used to generate explanations of the representation of epistemological beliefs. Together, the complexity theory and the interpretivist perspective enabled an investigation into the matter of interrelationships and interactions between beliefs, practices, and contexts. The next chapter will provide details of this research methodology, as informed by this literature review.

CHAPTER III: METHODOLOGY

Introduction

Epistemological beliefs of teachers continue to be an area of interest in education. Theory and research over the last four decades demonstrate that individuals' epistemological beliefs filter their approach to teaching and learning (Brownlee, Schraw, & Berthelsen, 2011; Schraw et al., 2017). Biology graduate teaching assistants (GTAs) are a significant group of teachers who make important contributions to the educational mission of universities, specifically in introductory laboratory courses (Reeves et al., 2016). A key factor that contributes to promoting student learning is how an instructor teaches (Hennessey, Murphy, & Kulikowich, 2013). Identifying the features of GTA epistemological beliefs will help science researchers and educators to understand classroom instruction, which in turn will influence student learning (Schraw et al., 2017). In addition, while some studies have found teachers' beliefs match their instructional practices (e.g., Artzt & Armour-Thomas, 1999; Reed, 2003; Tsai, 2006), findings from other studies show contradictions between teachers' espoused beliefs and actual classroom practices (e.g., Mansour, 2013; Vartuli, 1999). This indicates a potential misalignment between instructional practice and teachers' beliefs. Zheng (2015) acknowledged that the mechanism underlying the relationship between teachers' beliefs and instructional practices lies in the study of the instructional contexts. To this end, this study took a qualitative, etic approach to investigate how the contextual factors such as laboratory constraints provided insight regarding misalignments between features of epistemological beliefs and science instructional practices of GTAs.

This chapter begins with a research overview, which includes a description of the methodological framework that guided this inquiry and is followed by a detailed description of the procedures and confirmed strategies for maintaining methodological rigor. This exploratory study utilized a multi-case study methodology to answer the research questions. What follows is a general overview of the research context within which the study was conducted, a description of the study's participants, the types of data collected, and the instruments and procedures used to gather data. Next, the techniques employed to analyze the data to address the study's research questions are described. Finally, the limitations and delimitations of the study, along with measures taken to assure the study's trustworthiness, enhance credibility and validity, reduce bias, and address ethical concerns, are presented.

Research Overview

The research design was qualitative in nature. Qualitative research is used when the goals of a study are to explore and become immersed in a phenomenon or issue in its natural setting to gain an understanding of the phenomenon (Creswell, 2014). The phenomenon under examination was the features of GTA epistemological beliefs. Case research, in its versatility, was used in an interpretative manner to understand biology GTAs' assumptions about the nature of knowing and knowledge. Cavaye (1996) emphasized that case research can be employed using interpretative methods to elicit meaning in the social setting. An interpretative case study approach was utilized as it permitted the researcher to recall the holistic and meaningful characteristics of realistic events (Yin, 2003) and explore a "real-life, contemporary bounded system over time, through detailed, in-depth data collection containing multiple sources of information"

(Creswell, 2014, p. 97). The interpretative stance allowed the researcher to understand the phenomenon from the outlook of participants directly involved in the research. Keen (1991) posited that interpretivism shows the relevance of the research by explicitly including an investigation of the context of the phenomenon under study. The interpretative methodology lies in examining the *process* (i.e., actions or behavior of participants) rather than the *outcome* (i.e., a consequence of actions or behavior) and elicits discovery rather than confirmation (Merriam, 2009).

In this study, a multi-case design with multiple units of analysis was utilized. Yin (2003) stated that while a multi-case design is complex, it permits the creation of rich and reliable models. Considering the objectives of this study were to capture the features of epistemological beliefs of biology GTAs and to determine how contextual constraints influenced science instructional practices, the qualitative method with a case study design was appropriate.

This multi-case study explained the phenomenon and the real-life context in which it occurred using a descriptive approach (Yin, 2014). The study was based on the theoretical application of the complexity theory supported by ecological systems theory and the interpretivist approach. The study addressed two central questions:

1. How are the features of biology graduate teaching assistants' professed epistemological beliefs related to their science instructional practice in the laboratory, if at all?
2. How are misalignments between the features of professed epistemological beliefs and science instructional practice influenced by laboratory constraints, if at all?

Research Context

The elements of the research context were based on the selection of the multi-case study participants. These contexts included the school at which the study took place and the participants' background. The study focused on biology GTAs who were given teaching assignments as undergraduate biology laboratory instructors to non-majors.

School Context

This study was conducted at a public doctoral/research university in the Southeastern United States that primarily served undergraduate students, the majority of whom were in-state residents. Departmental data indicated that in the fall of 2018, the Department of Biology had a total of 47 GTAs, in which 49% were working on a master's degree, and 51% were working toward a Doctor of Philosophy (Ph.D.). Before each semester, the Department of Biology held a mandatory orientation meeting for all GTAs during which departmental rules and guidelines were established. Following this meeting, GTAs met with the respective faculty member in charge of various laboratory sections to discuss the specific course syllabus and expectations. In addition to this general meeting, GTAs met weekly with head faculty to discuss the laboratory for each week and review content material from PowerPoint presentations and handouts. During these meetings, there were typically not many discussions of teaching strategies, pedagogical approaches, or methods of assessing student learning.

As with other universities of this size, laboratory sections were a separate component of biology courses and taught by GTAs. It was typical for each GTA to present and assess laboratory material how he or she deemed suitable since the laboratories of a course augmented the biology content of the course itself. This study specifically included four parallel sections of the laboratory portion of introductory biology courses for non-majors.

Participants

Four experienced biology GTAs were purposefully selected for this study. Requirements for participants included being in the role of GTA for over a year with one year or more of science teaching experience. Participant selection was guided by purpose, which was to identify the common features of GTAs' epistemological beliefs and to understand how constraints of the laboratory context influenced misalignments between the features of epistemological beliefs and science instructional practices. According to Patton (2015), using the purposeful sampling strategy allows for the selection of information-rich cases whose study will illuminate the questions under investigation. Since the study aimed to use experienced participants who had enough time and familiarity as GTAs and had established some degree of professional competence, the four cases were selected through purposeful sampling. In addition, professional expertise is a crucial aspect of instructional practice (Shulman, 1987), a requirement that all participants met. Participants also had various cultural backgrounds, differed in their biological gender and science teaching experience, and were pursuing either a Doctoral or Master of Science degree.

Instruments and Data Sources

To build a better understanding of the cases in this investigation, the researcher collected information from several sources. Yin (2003) noted that data from multiple sources are necessary to create strong descriptions of participants' experiences when using case study methodology. Data sources included semi-structured interviews, lesson observations and field notes, video recordings, and a researcher's reflective journal. Table 10 shows a summary of the data sources and collection methods that were used in this study, along with their alignment with the research questions.

Table 10

Data Sources and Collection Methods used During the Study

Research Question	Data Collection Method
1. How are the features of biology graduate teaching assistants' professed epistemological beliefs related to their science instructional practice in the laboratory, if at all?	– Audio-recorded, semi-structured teacher belief interview with each GTA – Four audio-recorded Video Stimulated Recall interviews with each GTA after each lesson – Four laboratory lesson observations along with field notes for each GTA – Researcher reflective journal
2. How are misalignments between the features of professed epistemological beliefs and science instructional practice influenced by laboratory constraints, if at all?	– Four laboratory lesson observations along with field notes for each GTA – Video Stimulated Recall interviews – Researcher reflective journal

Using multiple sources of data and data collection methods to confirm emerging findings is known as triangulation (Creswell, 2014). Denzin (1978) noted that the rationale for methodological triangulation is that the limitations of one method are often the strength of another method. Thus, the use of multiple methods allowed the researcher to gather a robust pool of data from each while disabling each method's unique deficiencies. For example, in a study by Zheng (2015), it was noted that there might be instances where an instructor's beliefs were not accurately obtained because the instructor's explanation was not precise enough. Conversely, some individuals may answer according to what they think the interviewer would like to hear. Being aware that GTAs may be either unaware or have limited awareness of their own epistemological beliefs implied that they may not be able to describe them explicitly or may want to provide information that they thought that the researcher would want. In this study, such distortions were tempered by using interviews to record professed epistemological beliefs and video recordings to record actual actions of biology GTAs in the laboratory. The triangulation of data using these multiple methods and data sources permitted a more comprehensive understanding of the phenomenon under study.

Semi-structured Interviews

The primary data source used for capturing the epistemological beliefs of GTAs was a one-on-one, audio-recorded interview with each GTA to capture their epistemological beliefs using a semi-structured interview protocol (see Appendix B) based on the work of Suh (2016). The interview is one of the most useful methods for revealing the meaning of an individual's beliefs and experiences (Kvale, 1999). According to Seidman (1998), the interview can provide the context of one's conceptions and actions, as noticed during a classroom observation. As such, interviews were used both before and after their instruction to probe GTAs regarding their epistemological beliefs, their beliefs and thoughts about teaching and learning, and beliefs about the contextual constraints of the laboratory. Two types of interviews were conducted. The first was a GTAs' beliefs interviews that collected information related to GTAs' beliefs and thoughts about knowing and knowledge, beliefs about teaching, beliefs about learning, and beliefs about the nature of science. The second was a video stimulated recall (VSR) interview that asked a series of open-ended questions designed to determine the reasons for specific instructional enactments selected after reviewing episodes of the GTAs' laboratory lesson. When necessary, the researcher used informal interviews to ask follow-up questions that provided additional details regarding GTAs' perspectives and beliefs that were not captured during formal interviews. Transcripts were derived from all interviews, and participants were asked to review and verify their responses in the transcripts.

Laboratory Lesson Observations

The researcher carried out observations of each GTA's laboratory lessons on the topics: Fermentation, DNA Extraction, Genetics, and Biotechnology, for a total of 16 observations. Laboratory observations were documented for four weeks using video and audio recordings and field notes. Field notes were electronically recorded using a Livescribe pen. Observations provide opportunities to record information in context and allow for the study of actual behavior (Creswell, 2014) as well as confirm what is reported during an interview (Patton, 2015). Laboratory lesson observations permitted the investigation of GTAs' enactments of decisions and beliefs and visualized the contextual constraints of the laboratory.

Video and Audio Recording of Laboratory Lessons

Each laboratory session was audio and video recorded by the researcher to ensure accurate collection of data. Video recordings were uploaded immediately after observations for analysis for the VSR interviews. The videos were also used for the second round of analysis that was specific to determining the science teaching practices of each GTA as defined by research question two.

Video-Stimulated Recall Interviews

Stimulated recall was used to examine biology GTAs' epistemological beliefs, thoughts, and decisions for their action. Stimulated recall allows individuals some degree of access to their professional thinking and performance, which can then be represented in words (Calderhead, 1981). VSR is the least intrusive, yet most inclusive way of studying classroom phenomena (Pirie, 1996) and allows instructors to relive a teaching incident by providing a precise, retrospective, and verbalized account of instructors' thought processes (Calderhead, 1981). For this research, the VSR technique was used to explore biology GTAs' laboratory observations and commentaries regarding actions that needed further investigation. From the analysis of video recording of laboratory lessons, noteworthy instances were selected for VSR interviews with participants. For example, a noteworthy instance would be a point in time during instruction where a GTA's actions seemed to oppose his or her proclaimed epistemological belief, an instructional decision or enactment that needed to be explained, a moment where the researcher recognized the prevalence of a factor that appeared to be a laboratory constraint and needed justification, or even an instance during which time a laboratory constraint seemed to influence a GTA's science instructional practice. Together, the researcher and GTAs reviewed these noteworthy instances by looking at and examining specific portions of video-recorded lessons. GTAs were then asked to explain what they were doing and why during those particular times. All video stimulated recall interviews were audio-recorded.

Researcher Reflective Journal

The researcher played a significant role in the collection of data for the research study (Creswell, 2014). The researcher kept a reflective journal to describe her feelings about researching in this area of study. The use of reflective journals adds rigor to qualitative inquiry since the investigator can record his or her reactions, assumptions, expectations, and biases about the research process (Morrow & Smith, 2000). Reflective journaling allowed the researcher to become an instrument in the study (Creswell, 2014) as well as facilitated the refining, meaning-making, and interpretation of her role. This enabled the researcher to understand more thoroughly the responses of participants (Slotnick & Janesick, 2011). Furthermore, writing in a reflective journal allowed the researcher to practice reflexivity. Reflexivity is described as when one "thinks about how one thinks and enquires into our thinking patterns even as one makes observations of what is around" (Patton, 2015, p. 70).

The researcher was embedded within the context that was being studied and used her observational skills, trust with the participants, and the ability to extract the correct information to collect data for this study. The personal insights, knowledge, and experiences of the laboratory context were critical for accurately interpreting the phenomenon of interest. Additional qualifications of the researcher included 14 years of teaching experience with 11 of those years in K-12 education as a science teacher and three years teaching students enrolled in biology courses but not majoring in biology. The researcher also had two and a half years of coursework toward a Doctor of Philosophy degree in mathematics and science education with a concentration in biology education. The coursework completed by the researcher included a course in qualitative research methods. Other experiences that complemented the work done in this study were the researcher's background in teaching and prior work with pre-service teachers.

Procedures

This section describes the steps that were taken to collect data for this study during the spring semester of 2019. The biology department predetermined the course content for non-majors. However, GTAs were given autonomy over how to deliver the content and assess students' understanding. Figure 2 displays the timeline of the study.

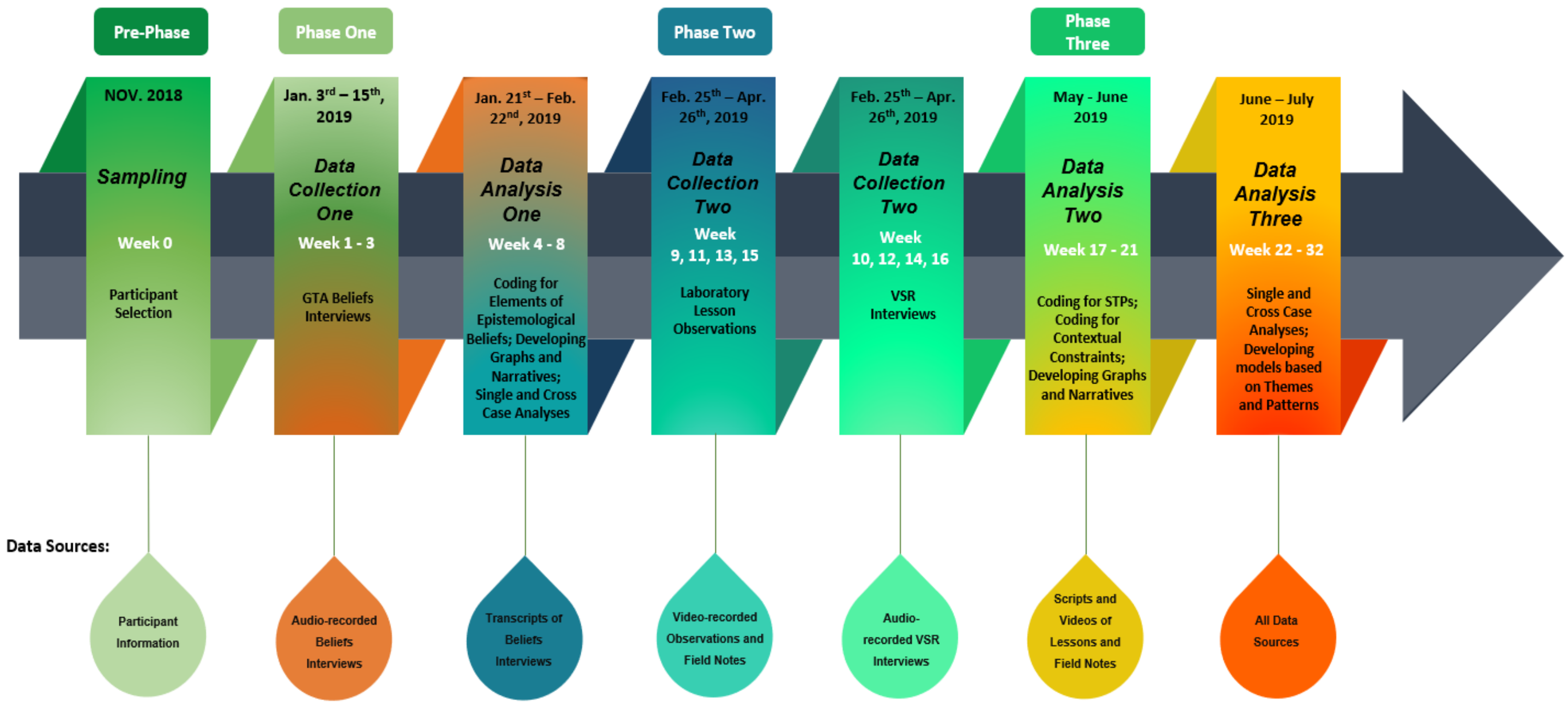


Figure 2. Timeline of the study.

Data Analysis

In this research, a hybrid approach of qualitative methods of thematic analysis incorporating both the inductive and deductive approach was used. This strategy complemented the research questions by allowing the tenets of the interpretative approach to be integral to the process of deductive thematic analysis while also ensuring open-minded engagement with the data and allowing salient themes to emerge (Fereday & Muir-Cochrane, 2006; Zheng, 2015). The evaluation of epistemological beliefs required an amalgamation of approaches that gathered relevant information about what instructors know, what they believe, what they do, and the reasons for their actions (Baxter & Lederman, 1990). This study employed multiple sources of data in order to capture biology GTAs' beliefs (interviews), what they did (laboratory lesson observations), and the reasons for their actions (VSR interviews). Yin (2014) posited that several data sources are necessary to generate a robust description of the participant's knowledge and teaching practice. Data sources included semi-structured interviews (Appendix A), classroom observations (see Appendix B for observation protocol), video recordings, VSR interviews, field notes, and a researcher's reflective journal.

Bogdan and Biklen (2006) purported that the process of data analysis is a systematic searching and arranging of transcripts and notes that the research accumulates. To accomplish this, data were collected in three phases (Figure 2). Phase one included conducting GTA belief interviews regarding participants' epistemological beliefs, in general, and beliefs about science, teaching, and learning. All beliefs interviews from phase one were transcribed and then analyzed using the template analysis format (Crabtree & Miller, 1999; King, 2004, 2012), a style of thematic analysis that balances a high level of structure in the process of analyzing textual data while having the ability to be flexible in adapting it to the needs of a particular study (King, 2012). This form of thematic analysis allowed textual data to be coded using a template of codes designed by the researcher. Codes derived from template analysis methods are often hierarchical in nature, beginning with broad themes and moving toward more narrow or specific ones. Figures 3 and 4 provide an outline of the template codes that were used to analyze the data for research questions one and two. A more in-depth discussion of template coding is provided in the next section, the Analytical Framework.

Codes for Epistemological Beliefs of GTAs

1. **Nature of Knowledge and Knowing**
    1.1. Epistemological Beliefs in General
        1.1.1. Changeability of knowledge
        1.1.2. Justification of Knowledge
        1.1.3. Source of Knowledge
        1.1.4. Structure of Knowledge
    1.2. Epistemological Beliefs about Science
        1.2.1. Open to Revision
        1.2.2. Way of Knowing
        1.2.3. Variety of Methods
        1.2.4. Answers Questions about Nature
        1.2.5. Open to Revision
        1.2.6. Based on Models and Theories
        1.2.7. Human Endeavor
        1.2.8. Based on Empirical Evidence
        1.2.9. Assumes an Order and Consistency
2. **Nature of Teaching and Learning**
    2.1. Beliefs about Learning
        2.1.1. Ability to Learn
        2.1.2. How to Learn
        2.1.3. Role of Student
        2.1.4. *Control of Learning
    2.2. Beliefs about Teaching
        2.2.1. Goal of Teaching
        2.2.2. Role of GTA
        2.2.3. How to Teach

** Code was not part of original template*

Figure 3. Template codes for research question one: features of epistemological beliefs.

Codes for Science Instructional Practices

1. Introduction
    1.1. Introducing the Lesson
        1.1.1. Start with questions about nature
        1.1.2. Do not start with questions about nature
2. Content
    2.1. Background and Content of Lesson
        2.1.1. Provide historical perspectives
        2.1.2. Do not provide historical perspectives
3. Student Involvement in Hands-on Activities
    3.1. Student Engagement
        3.1.1. Students are actively engaged
        3.1.2. Students are not actively engaged
4. Findings from Laboratory Experiments
    4.1. Results of Laboratory Investigations
        4.1.1. Concentrate on the collection of evidence
        4.1.2. Do not concentrate on the collection of evidence
5. Communication
    5.1. Students' Communication of Scientific Information
        5.1.1. Insist on clear expression
        5.1.2. Do not insist on clear expression
6. Lesson Activities' Format
    6.1. Group or individual Activities
        6.1.1. Use team approach
        6.1.2. Do not use team approach
7. Knowledge
    7.1. How Knowledge is Emphasized
        7.1.1. Do not separate knowledge from finding out
        7.1.2. Do not separate knowledge from finding out
8. Student Assessment
    8.1. Assessment Emphasis
        8.1.1. De-emphasize memorization of technical vocabulary
        8.1.2. Emphasize memorization of technical vocabulary

Figure 4. Template codes for research question one: science instructional practice.

Video data collected from phase two—video recordings of laboratory lessons—were analyzed briefly to select enactments that needed further discussion during VSR interviews with the participants. As previously noted, these selections were based on circumstances where the participants' instructional actions seemed to contradict their proclaimed epistemological beliefs or circumstances where certain decisions made during teaching merited further explication. VSR interviews were transcribed and analyzed using the codes from Figure 3 to determine the features of participants' epistemological beliefs. Phase two also entailed data analysis of beliefs interview transcripts for laboratory constraints that influenced the science instructional practice of participants. Phase three involved the completion of both single and cross-case analyses for mapping and aligning participants' science teaching practices with laboratory constraints. Further analysis in this third phase included the development of models based on themes and patterns derived from the data.

Apart from the beliefs professed during the beliefs interview, the epistemological beliefs of participants were scrutinized by looking at their interactions and enactments in the laboratory. Tudor (2001) acknowledged that in its own right, the classroom is a social and communicative reality where instructors interact with students, negotiate their own beliefs, and implement instructional practices. Additionally, one way of exploring the interaction between epistemological beliefs and science teaching practices may reside in analyzing how the participants interpret opportunities and constraints imposed by the laboratory context.

In qualitative research, the closest thing to reliability is the concept of rigor that is used in interpretative studies. Rigor, in this case, is described by Merriam (2009) as a product of the entire research process that "derives from the researcher's presence, the nature of the interaction between researcher and participants, the triangulation of data, the interpretation of perceptions and rich, thick descriptions" (p. 165). In this study, a collaborative research team formed the backbone of the process of developing a coding system and applying it to the data in a manner that was considered rigorous. The researcher enlisted the assistance of an expert other with knowledge and familiarity with the topic. The expert other's expertise included prior experience with qualitative coding analysis, specifically in the area of GTA beliefs and professional development. Data analysis considered consensus or agreement as described by Taylor, Gilligan, and Sullivan's (1995) interpretive community as using multiple perspectives throughout the data analysis process and using a consensus to arrive at judgments about the meaning of the data. For this study, both the research and the expert other agreed on the final coding templates (Figures 3 and 4).

The process of coding was undertaken using the qualitative research software, NVivo 12 Plus. Coding by both the researcher and expert other was completed for the semi-structured interview questions, which were asked in the same order to each participant, as advised by Morse (1997). The unstructured, interactive VSR interviews were coded by the researcher based on what was learned from participants and on written reflections about the phenomenon under investigation. The notion of learning from the participants as they spoke about their beliefs and assumptions was crucial in supporting the fluid nature of coding the unstructured interviews. The reflective journal kept by the researcher logged the researcher's reflections and assisted with the coding of the unstructured portions of data (post-instruction VSR interviews).

Analytical Framework

The analytic process followed a qualitative method of thematic analysis that was both inductive and deductive in nature. The inductive approach was data-driven and entailed identifying themes and patterns that emerged directly from the data. This meant that the researcher recognized important moments and encoded them before the process of interpretation (Boyatzis, 1998). Also integrated into this step was encoding the information that organized the data in a way that identified and developed themes. The deductive approach incorporated the use of *a priori* template of codes approach outlined by Crabtree and Miller (1999). In template analysis, the coding template is developed in two stages based on themes that arise from the body of textual data. For the first stage, the researcher developed an initial template based on a combination of *a priori codes* and preliminary reading and coding of a subset of the textual data from the GTA beliefs interviews. In the second stage, the initial template was then applied to the whole data set, and codes were added to the template as new themes arose. This led to the creation of the final template. The final template was then used to interpret the textual data set as a whole (King, 2004, 2012).

Research question one was concerned with two major concepts: features of epistemological beliefs and science instructional practices in the laboratory. As such, the data were analyzed to examine these two constructs in two different ways. First, the two concepts were coded independently of each other, and separate coding templates were used. Second, the resulting analysis was then compared to determine the nature of the relationship between the two concepts. Figures 5a, 5b, 6a, and 6b show the steps of the analytical process for research question one. Although presented as a linear, systematic procedure, the data analysis was an iterative and reflexive process. Further description of the analytical process is provided in the paragraphs that follow.

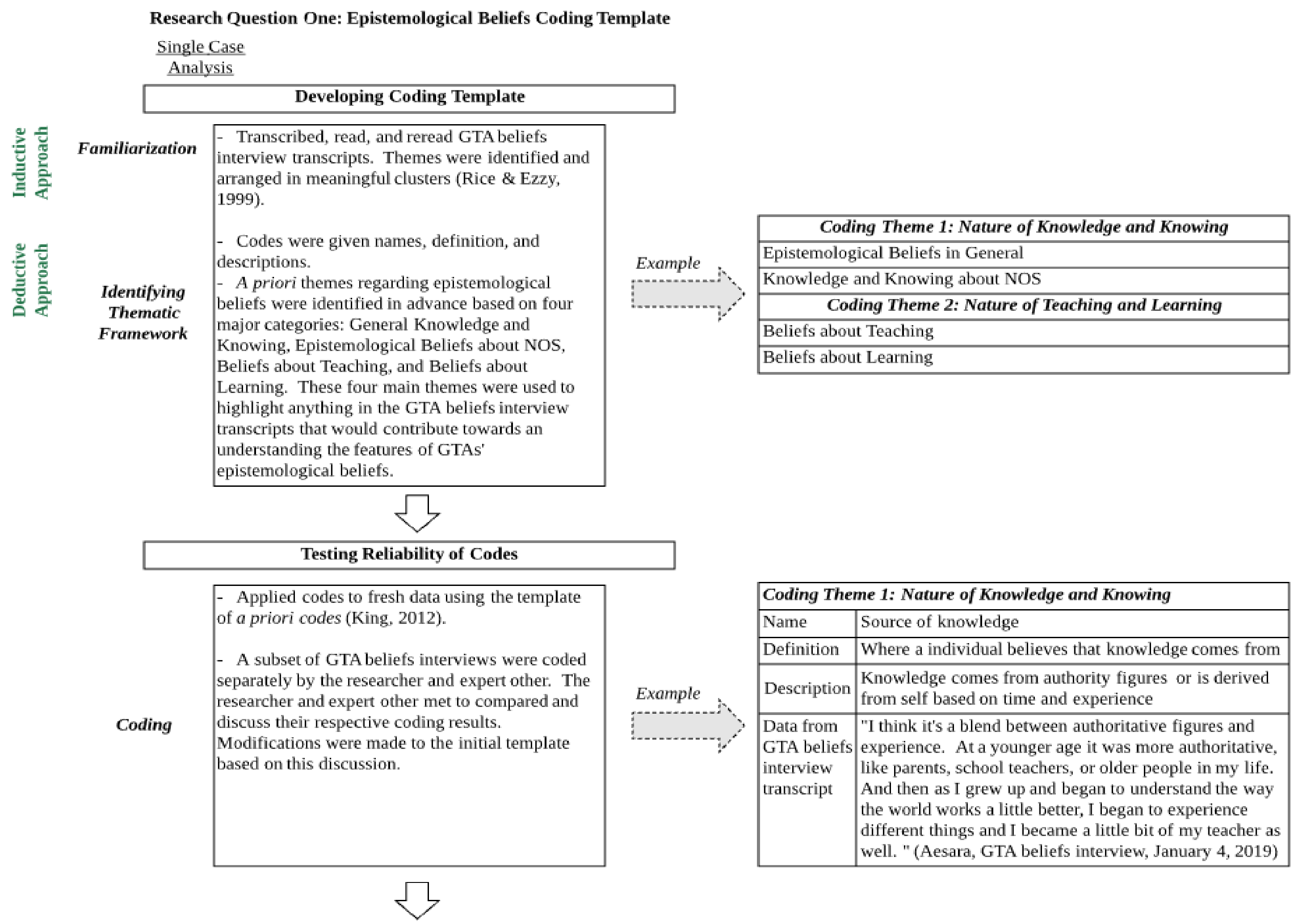


Figure 5a. Summary of the study's analytical process for research question one specific to epistemological beliefs. Notations in green highlight the type of analytical approach used during the various parts of the analytical process.

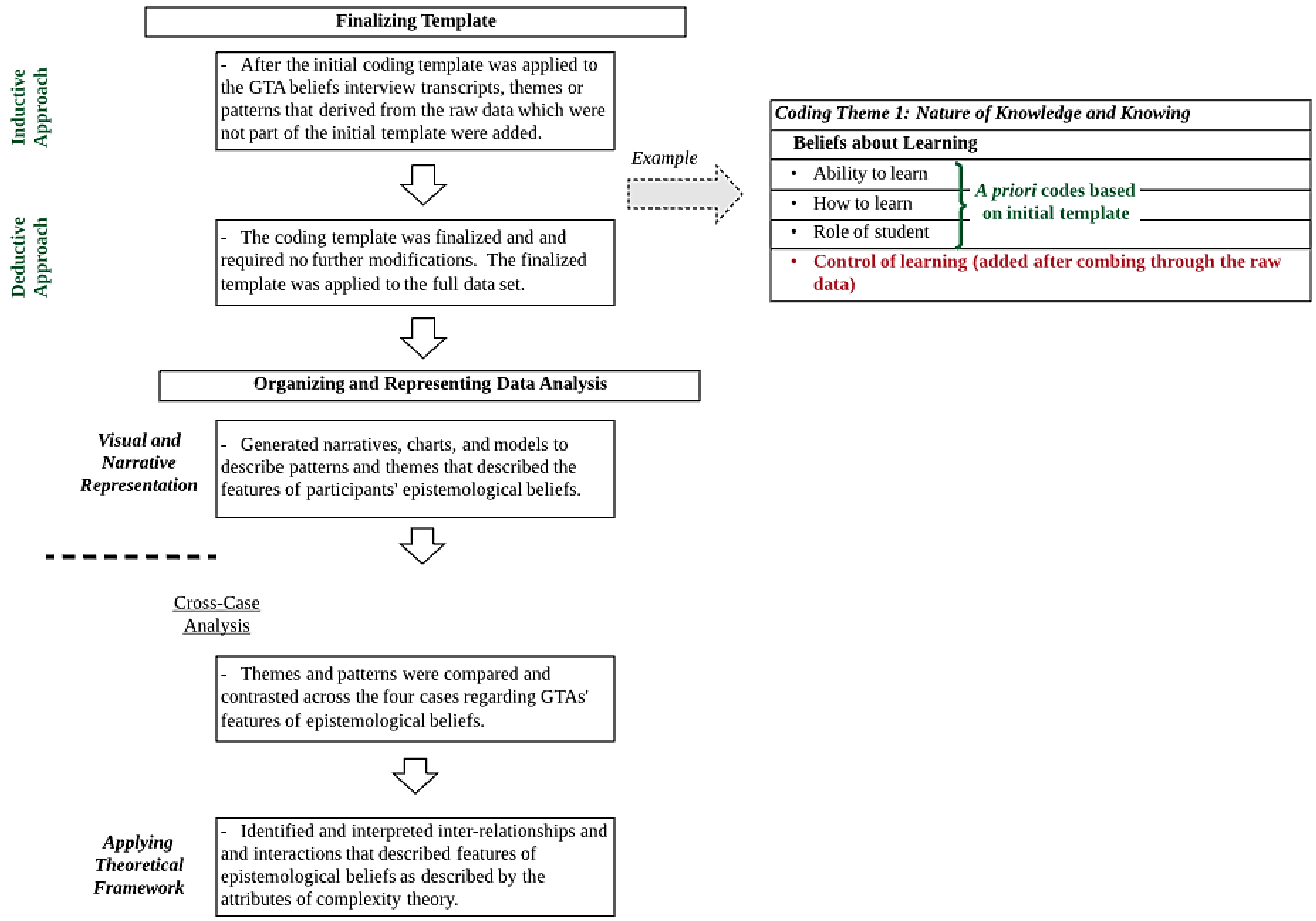


Figure 5b. Summary of the study's analytical process for research question one specific to epistemological beliefs. Notations in green highlight the type of analytical approach used during the various parts of the analytical process. Notations in red highlight the codes—not part of the predetermined codes (curly brackets)—derived after going through the raw data.

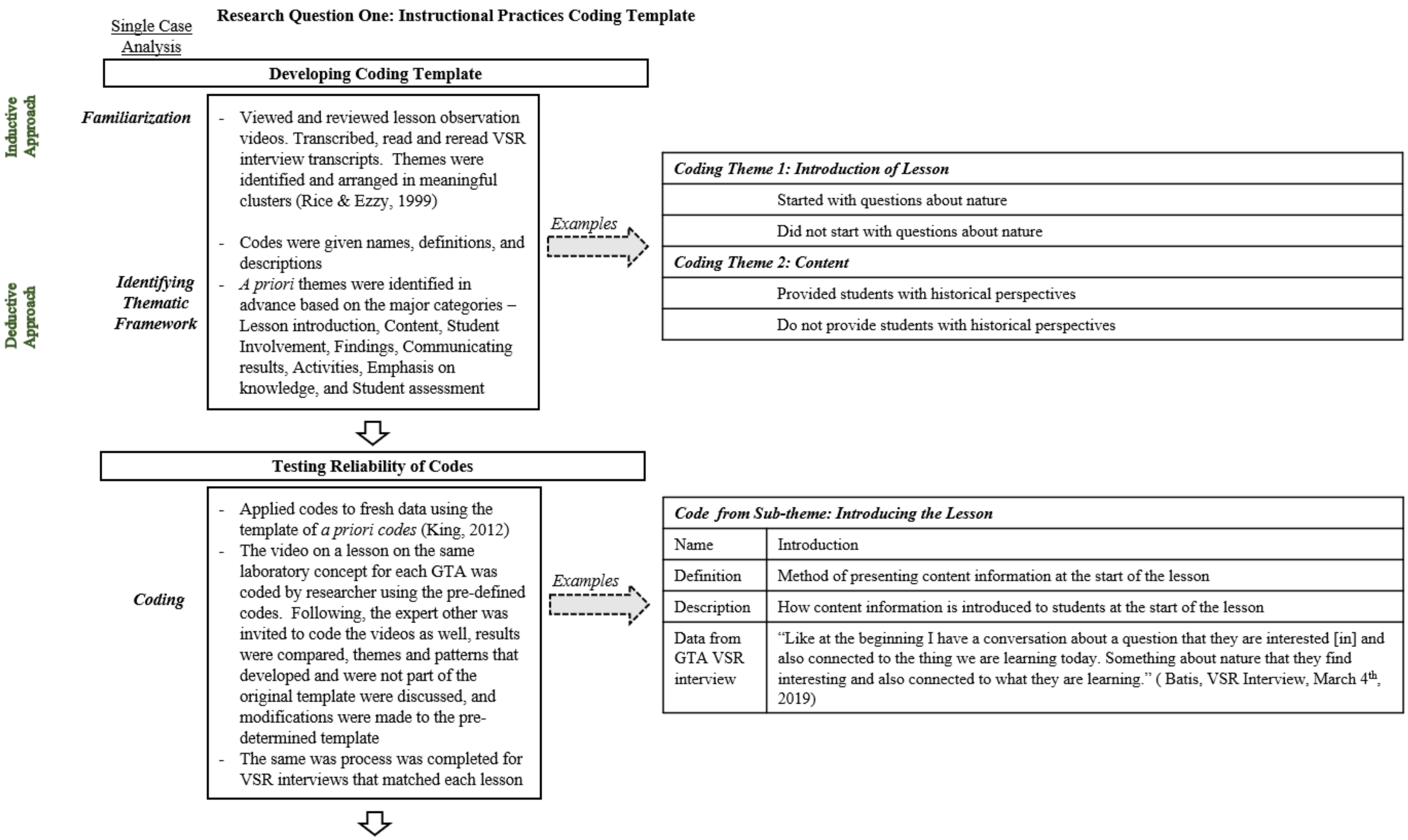


Figure 6a. Summary of the study's analytical process for research question one specific to science instructional practice.

Notations in green highlight the type of analytical approach used during the various parts of the analytical process.

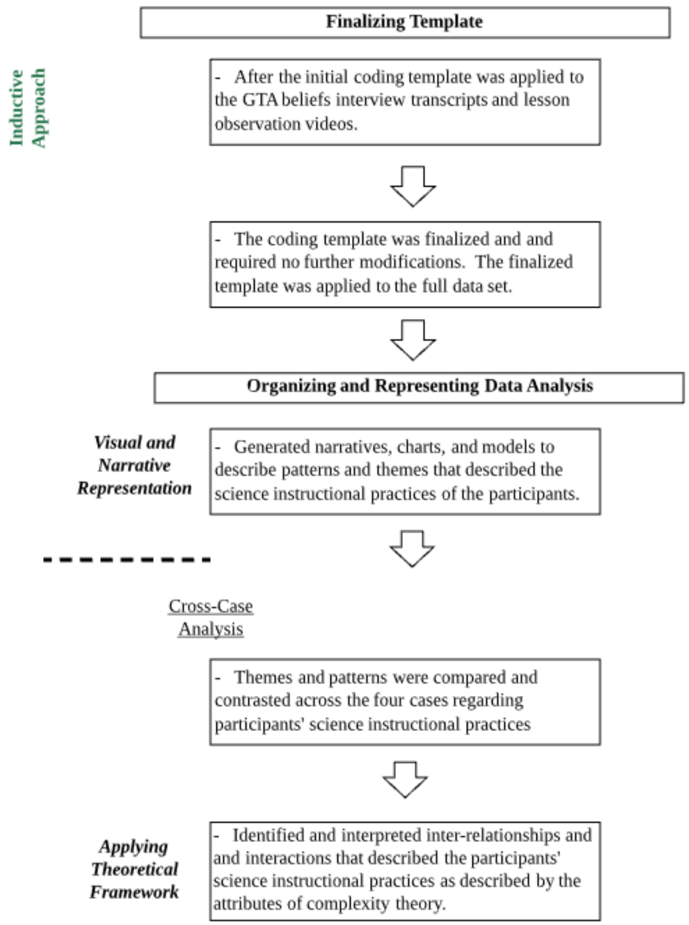


Figure 6b. Summary of the study's analytical process for research question one specific to science instructional practice. Notations in green highlight the type of analytical approach used during the various parts of the analytical process.

Research Question One

How are the features of biology graduate teaching assistants' professed epistemological beliefs related to their science instructional practice in the laboratory, if at all?

Analyzing for Features of Epistemological Beliefs

Familiarization. The first phase of data analysis commenced with the organization of the data, a process that continued throughout data collection. Familiarization involved the verbatim transcription of belief interviews. All audio-recorded interviews were transcribed and emailed to participants for verification. This verification process involved revision, clarification, and the addition of any pertinent details. The participants verified and confirmed that the information was correct. The transcripts were then ready for the next step of the analytic process.

Identifying the thematic framework. For the semi-structured interviews, the thematic framework—making judgments about meaning, relevance, the importance of issues, and implicit connections between ideas—followed an approach used by Crabtree and Miller (1999) and King (2004) called template analysis. Template analysis is a type of thematic analysis which highlights the use of hierarchical coding with a high degree of structure in the process of analyzing qualitative data. Template analysis uses template coding as an analytical tool where the researcher defined the codes.

In this study, the researcher used *a priori* themes drawn from the literature review to analyze data for question one, which looked explicitly at (1) features of epistemological beliefs of GTAs and (2) the science instructional practice of GTAs in the laboratory. These themes were derived from the literature review for this research, more specifically from the work of Suh (2016). For example, a major theme identified in the literature that stemmed from the two major lines of research on epistemological beliefs—unidimensional and multidimensional—was beliefs about the nature of knowledge and knowing. Based on the work of Suh (2016), two subcategories pertained to the nature of knowledge and knowing: epistemological beliefs in general and beliefs about science. Regarding the category, epistemological beliefs in general, the literature confirmed that there were four areas to consider: changeability of knowledge, justification of knowledge, source of knowledge, and structure of knowledge. These four areas were used as coding categories in the coding template. Looking specifically at literature concerned with teachers' epistemological beliefs about science indicated that teachers' beliefs revolve around an understanding of NOS. Hence, the characteristics of NOS were used as coding categories under the theme, epistemological beliefs about science.

In like manner, the literature was also used to guide this study's coding for the other aspect of research question one, which dealt with GTAs' instructional practices. A review of studies conducted on teachers' epistemological beliefs identified two major components: beliefs about teaching and beliefs about learning. These two categories can be classified under a broader theme—nature of teaching and learning—in the coding template for research question one (Suh, 2016). Figure 4 provides a more detailed description of the coding template for GTAs' instructional practice.

Coding. The interview data were coded and analyzed using NVivo 12 Pro computer software. Creswell (2014) highlighted that the use of computer analysis programs facilitates "the process of storing, analyzing, and sorting the data" (p. 234). NVivo software has powerful tools to aid the researcher in exploring possible relationships amongst themes (Gibbs, 2002). Eighteen codes were defined for a preliminary analysis of the beliefs interview based on the *a priori* themes as previously discussed: beliefs about knowledge and knowing, beliefs about the nature of science, beliefs about teaching, and beliefs about learning (Figure 3). The coding process followed an approach called template coding, an approach outlined by Crabtree and Miller (1999). This method complemented the research question by allowing the tenets of the interpretative approach to be integral to the process of deductive thematic analysis which considered a template consistent with prior assumptions and categories identified and constructed by the researcher while allowing the opportunity for themes to emerge directly from the data if there was a need. That is to say, any concepts, themes, or patterns that came up during coding that was not a part of the original template were identified as an additional code. A notable example is the coding for *the control of learning* was not part of the initial coding template and was added afterward because of the description in the data that suggested that participants held different beliefs regarding who is in *control of learning* in the classroom. The participants believed that the student was not always the one in control of learning and regarded this feature as being different from the feature, *role of student*, which the participants claimed to include students being curious and wanting to know more about various scientific concepts (see the example provided in Figure 3).

Initial analysis. First, the GTA belief interviews were read multiple times to gain an initial perspective—first and second readings—then a strong perspective of each participant's professed epistemological beliefs. Next, the data were coded based on the coding template. If a portion of the interview data was not related to any of the pre-determined coding scheme used to identify the features of epistemological beliefs, it was classified as a new code. For example, the code control of learning was not a part of the initial coding template but was added after the data revealed information that did not fit into the original coding scheme. This process highlighted the hybrid analytical approach—deductive and inductive—previously mentioned. The deductive approach was used as the researcher employed a pre-established coding template while the inductive approach was used when the data revealed additional codes after combing through the data.

Analyzing for Science Instructional Practices

Familiarization. Familiarization involved the verbatim transcription of VSR interviews and the creation of typed transcripts from videos of lesson observations. Audio-recorded interviews were transcribed and emailed to participants for verification, where participants confirmed that the information was correct and added any pertinent details that they thought were relevant. The transcripts were then ready for the next step of the analytic process.

Identifying the thematic framework. To look at the instructional practice of GTAs in the laboratory, the researcher used *a priori* themes drawn from the literature review based on studies from the ongoing science education movement in the U.S. (e.g., AAAS, 1993, 2013; NRC, 1996, 2000, 2012) rooted in an outgrowth of constructivism; knowledge is not directly transmitted from one knower to another but constructed within individual minds (Richardson, 1997). Eight science instructional practices were described.

Coding. The interview data were coded and analyzed using NVivo 12 Pro computer software. The eight science instructional practices formed the coding template for investigating the participants' instructional practices in the laboratory. Furthermore, the coding process involved recognizing and capturing the qualitative richness of the phenomenon (Boyatzis, 1998) by encoding and organizing the data to identify and develop themes from them. According to Boyatzis (1998), a theme is a pattern in the data that, at the very least, describes and organizes possible observations and, at maximum, interprets aspects of the phenomenon. Therefore, the coding template for looking at participants' science instructional practice also included *anti-codes* (codes that were opposite to the codes initially generated from the literature) where both the actions and inactions of participants would be captured. An example of a code and its anti-code used in this study included: participant started the lesson with questions about nature (code), and participant did not start the lesson with questions about nature (anti-code). Figure 4 provides a more detailed description of the coding template for participants' science instructional practice.

Initial and final analysis. First, the researcher looked at lesson observation videos several times to gain an initial perspective of participants' science instructional practices. Afterward, the data were coded based on the coding template. Both the researcher and the expert other agreed that there was no need for changes or modifications to the initial coding scheme after this preliminary round of analysis. The codes for science instructional practices were finalized and used across all the data. Also, each unit of science instructional practice was coded and ranked, based on the total amount of instructional minutes devoted to it, as well as the percentage of the frequency of the demonstrations of science instructional practice that occurred during the lessons.

Interpretation of data. This stage of the analytical process led to the development of narrative descriptions that reflected the features of epistemological beliefs and science instructional practices of each case. The descriptions included how the features of participants' epistemological beliefs were reflected in their instructional practices. In addition, this stage of the process included generating visual representations of the data as related to research question one.

Cross-Case Analysis

After belief interviews and lesson observations were analyzed for each case, the summary results were compared and contrasted among the four cases. After reading and analyzing the summaries and visual representations, common themes for each code and category were identified, and a summary of multiple-cases was drafted based on the shared themes identifying the features of epistemological beliefs, science instructional practices, and the relationship between the two constructs.

Research Question Two

How are the misalignments between professed epistemological beliefs and instructional practice impacted by laboratory constraints, if at all?

Analyzing for Laboratory Constraints

Familiarization. As with the analysis of semi-structured interviews, the first phase of analysis for research question two began with organizing audio- and video-taped laboratory lessons, observation logs, field notes, and VSR interviews to produce typed transcripts. Field notes had been recorded using a Livescribe pen. Notes were uploaded and saved for analysis. As previously noted, transcribed VSR interviews and lesson observation scripts were e-mailed to participants for verification. Verification included participants' revision, clarification, and addition of any relevant details that may have been overlooked and returned to the researcher after confirming verification.

Identifying a thematic framework. Videos of laboratory lessons, field notes from laboratory lesson observations, and VSR interviews were analyzed using the thematic codes identified in Figure 7. Both a deductive and inductive approach was taken for this step in the data analysis. The data were reviewed and coded for the identified codes (deductive) and also analyzed for constraints that were not included in the initial template. For example, the code, constraints related to student assessment, was not included in the original template derived from the literature review following the template analysis method.

Codes for Constraints of the Laboratory Context

1. Constraints Related Specifically to the GTA
    - 1.1. GTAs' Intrinsic Factors
        - 1.1.1. *GTA's sentiments about the lesson
        - 1.1.2. GTA's lab lesson preparation
        - 1.1.3. GTA's science content knowledge
2. Constraints Related Specifically to Laboratory Context
    - 2.1. Physical
        - 2.1.1. Class size
        - 2.1.2. Physical layout
    - 2.2. Structural
        - 2.2.1. Content material
        - 2.2.2. Class time
        - 2.2.3. Order and structure of activities
        - 2.2.4. Amount of content
        - 2.2.5. Teaching resources
3. Constraints Related Specifically to the Learners
    - 3.1. Individual differences in learners
    - 3.2. Expectations of Learners
    - 3.3. Responses of learners
4. *Constraints Related Specifically to Student Assessment
    - 4.1. Determining Student understanding
        - 4.1.1. Questioning during lesson
        - 4.1.2. In-lab assignment

** Code was not part of original template*

Figure 7. Template codes for research question two: laboratory constraints.

Coding. Codes were developed *a priori* based on the literature review that guided this study and were applied to the data – video data from laboratory lessons, VSR interviews, and the researcher's reflective journal. The coding process for research question two was conducted in two parts. First, the data were coded, looking for laboratory constraints. Codes with the asterisks (*) in the template codes for laboratory constraints shown in Figure 7 are codes that were revealed (inductively, rather than *a priori*) in the data analysis process. The second part involved the coding for participants' science teaching practices in the laboratory. Coding the participants' instructional practices included analysis of data for instances of instructional practices that were present in the data as well as those that were not present or visible. This approach allowed the researcher to make connections between the data from VSR interviews, where the participants were asked to justify their actions and laboratory constraints that persisted during laboratory lessons.

Initial analysis. Data from VSR interviews, lesson observation videos, and researcher field notes were reviewed multiple times to gain a general perspective. Then the data were coded based on the coding scheme that was developed. The portion of the data that could not be classified under any of the codes of the pre-determined scheme was discussed by the researcher and the expert other and then were added as new codes under the relevant themes.

Visual and narrative representation. The frequency of specific participant actions that aligned with the research-based science teaching practices was noted, quantified, and charted in the form of graphical representations. Also, narratives were formed from the data analysis to describe the associations and to provide explanations that emerged from the data that were reflective of each participant and echoed the relationship between the instructional practice of the participants and laboratory constraints. Figures 8a and 8b highlight a more detailed display of the analytical process for research question two.

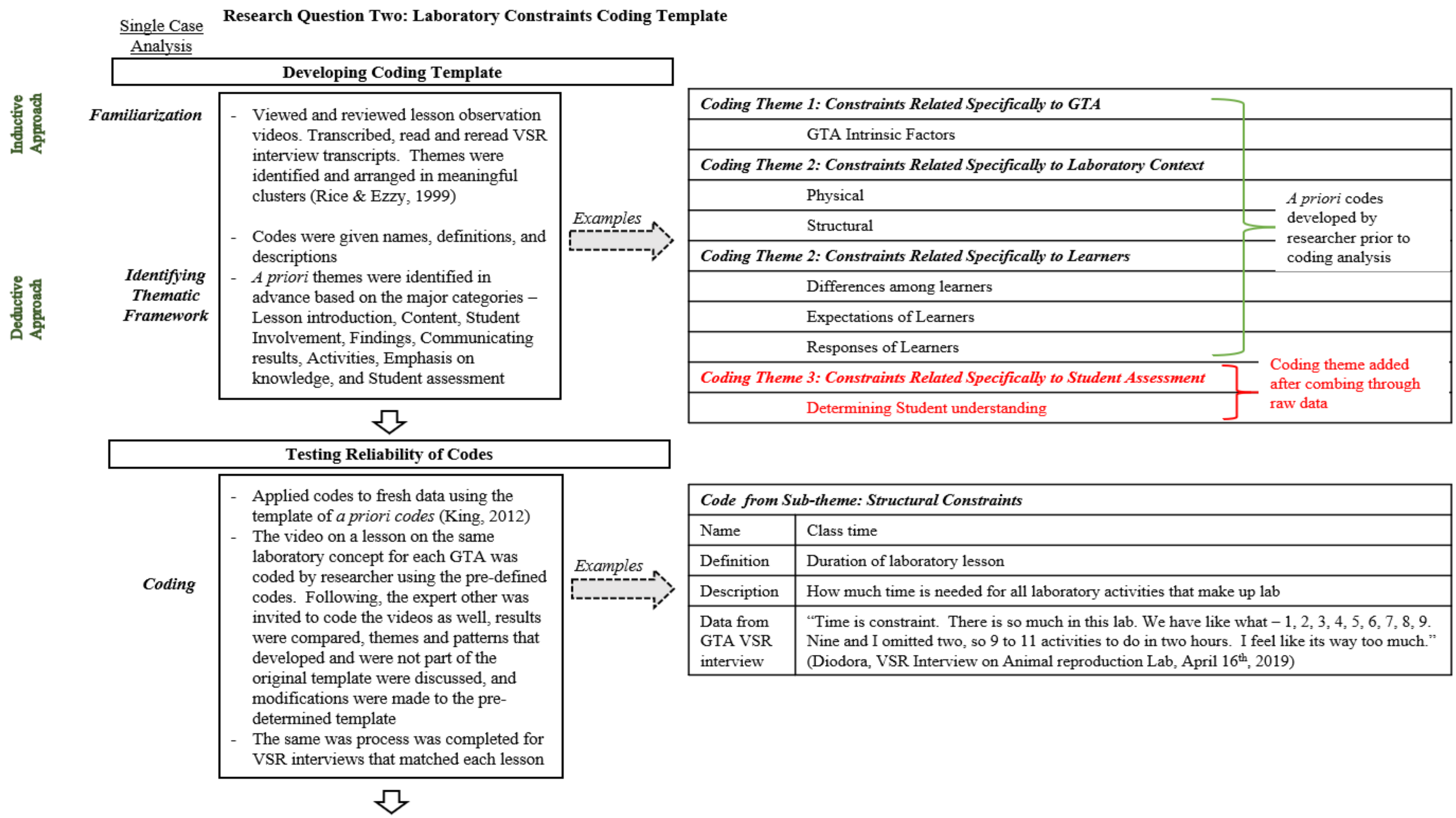


Figure 8a. Summary of the study's analytical process for research question two specific to laboratory constraints. Notations in green highlight the type of analytical approach used during the various parts of the analytical process. Notations in red highlight the codes—not part of the predetermined codes (light green curly brackets)—derived after going through the raw data.

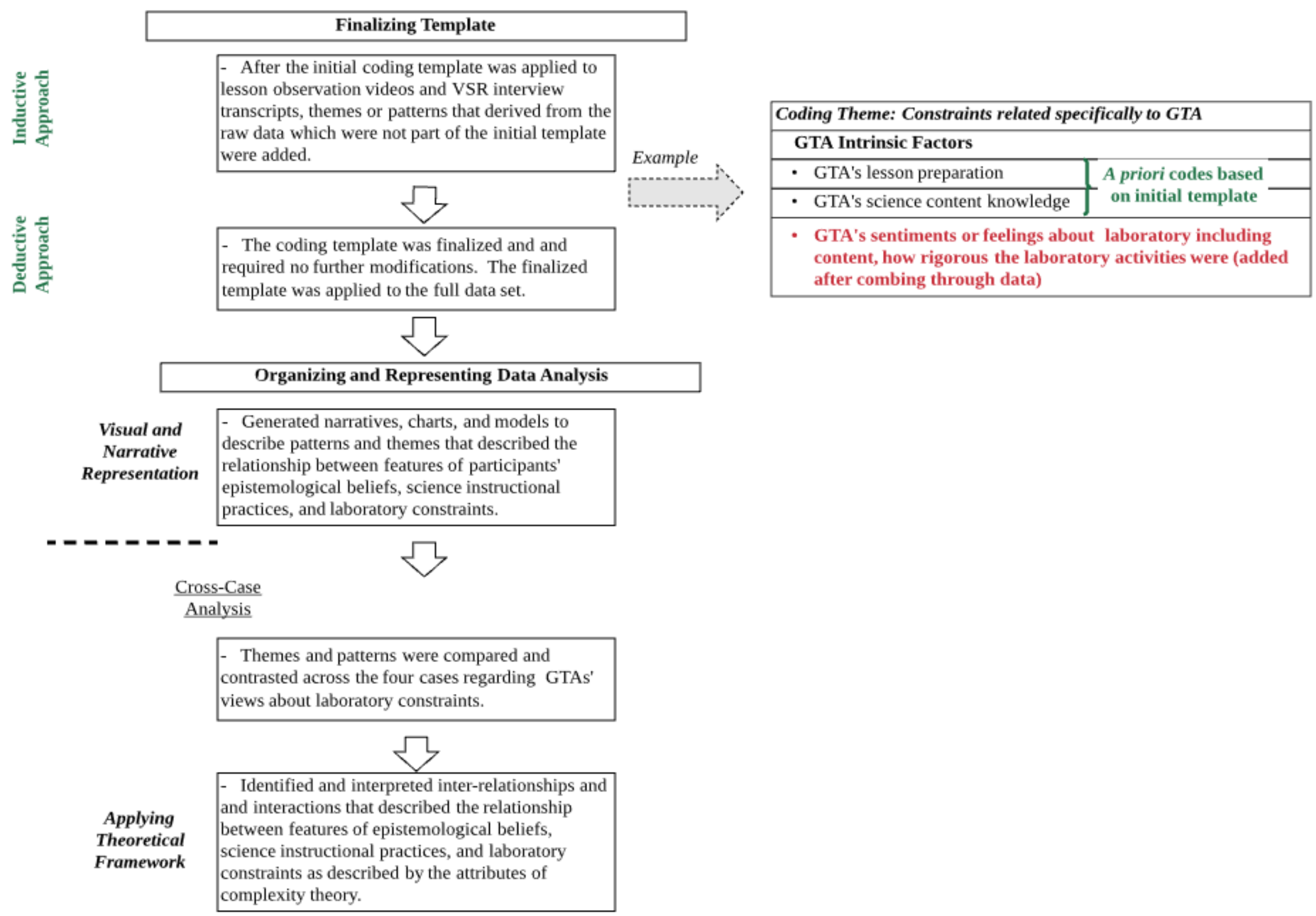


Figure 8b. Summary of the study's analytical process for research question two specific to laboratory constraints. Notations in green highlight the type of analytical approach used during the various parts of the analytical process. Notations in red highlight the codes—not part of the predetermined codes (light green curly brackets)—derived after going through the raw data.

Interpretation of data. The interpretation stage of the analytical process for each case analysis led to the development of narrative descriptions of laboratory constraints and the relationship between these contextual constraints to the instructional practices of the participants. The descriptions also highlighted the features of participants' professed epistemological beliefs that did not align with their science teaching practice in the laboratory, as well as the various laboratory constraints that seemed to give rise to the misalignment. The researcher also included visual representations of the data that were generated to reflect the interpretation of the data.

Cross-Case Analysis

After VSR interviews, lesson observations, and researcher field notes were analyzed for each case, and the summary results were compared and contrasted among the four cases. Through reading and analyzing the summaries and visual representations, common themes for each code and coding theme were identified. Per common themes identified, a summary for multiple-cases was drafted for misalignment between science instructional practice and professed epistemological beliefs and laboratory constraints and the relationship between them. The analytical process for research question two is present in Figures 8a and 8b.

Connections Across Research Questions and Theoretical Framework

The complexity of the classroom system is indisputable. One way in which complex systems differ from simple systems is the existence of heterogeneous components. In this study, the laboratory was considered a complex system that contains a set of components that interact in particular ways to produce an overall state of the system at a particular time. To be more precise, the researcher regarded the features of

GTAs' epistemological beliefs, science instructional practice, and the laboratory context (specifically the constraints) as components of the laboratory system where each one of these components contributed to the whole system. Jointly, the research questions in this study explored these three components. Research question one was concerned with determining the features of GTAs' epistemological beliefs and science instructional practice while research question two investigated the laboratory context.

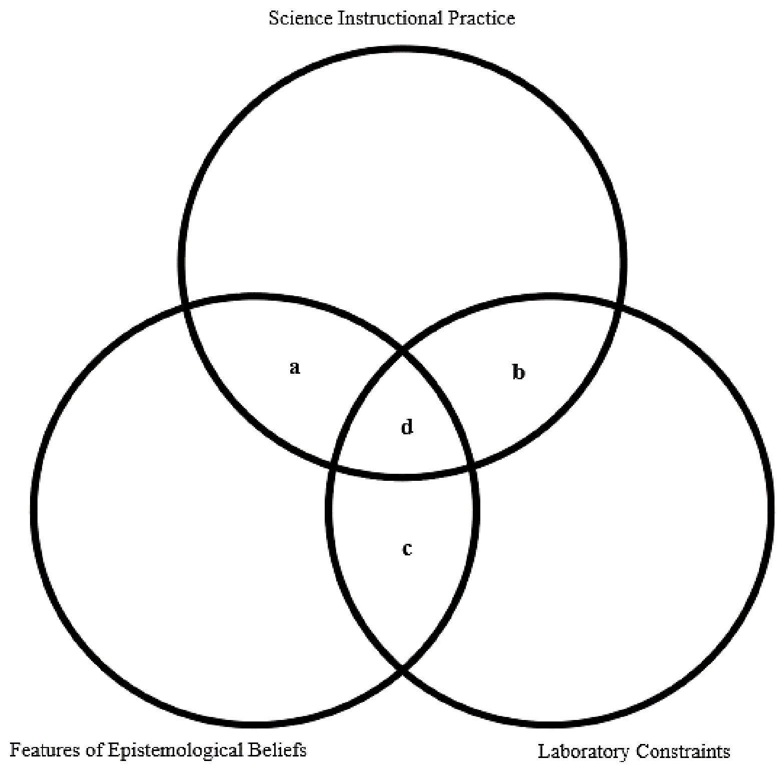
The complexity theory was used as the theoretical framework to gain a more explicit understanding of the interactions of the components of the laboratory system focusing specifically on self-organization, emergence, non-linearity, inter-connectivity, and autonomy and co-adaptability of the laboratory system. In this research, complexity theory drew significantly on ecological theory. It attached great importance to the laboratory context and how it interacts with GTAs' epistemological beliefs as well as their science instructional practice. Ecological approaches contributed to the complexity framework by emphasizing the understanding of the relationships and interconnectedness of individuals and contexts. The codes were derived using the deductive method where the codes and their descriptions were pre-determined and were based on the design and descriptions provided by this study's theoretical framework. The codes and descriptions used are shown in Table 11.

Table 11

Codes for Complexity Theory and their Descriptions

Codes	Description
Self-organization	Spontaneous organization to better cope with various internal and external perturbations and conflicts.
Emergence	The appearance of novel and coherent structures and patterns based on interactions within the system.
Non-linearity	Discrepancies between inputs and effects where small changes can have striking and unanticipated effects, whereas great stimuli may not always lead to drastic changes in a system's behavior.
Interconnectivity	Interactions between components that show connections.
Autonomy and Co-adaptation	The ability of the system to evolve and adapt to a constantly changing environment while still maintaining its independence because the interactions are not centrally controlled.

After analysis for each research question was completed and summary analyses were obtained, the researcher explored the summaries of the analyses for each component (i.e., features of epistemological beliefs, science instructional practice, and contextual constraints) to determine which of the characteristics of the complexity theory was demonstrated by the laboratory system. First, the researcher read over the summaries several times (familiarization). Second, following a deductive approach, the summary notes for each case were analyzed utilizing the following the format: (1) sorting through summary notes and categorizing them into the three components of the laboratory system (i.e., features of epistemological beliefs, science instructional practice, and laboratory constraints), and (2) investigating pairs of components to determine relationships and interconnections by looking at interactions between them. This analysis involved identifying the characteristic of the complexity theory that was displayed by the pair. Figure 9 highlights the method used for pairing and analysis.



Pairings:

a Science Instructional Practice + Features of Epistemological Beliefs
b Science Instructional Practice + Laboratory Constraints
c Features of Epistemological Beliefs + Laboratory Constraints
d Science Instructional Practice + Features of Epistemological Beliefs + Laboratory Constraints

Figure 9. Pairing pattern for analysis of components of complexity theory.

The example described in Table 12 provides an insight into the process used to determine the interactions and interconnections (ecological systems theory). To sum up the section on the connections between the research question and the theoretical framework of this study, a visual display has been provided (Figure 10).

Table 12

Example of the Analytical Process for Determining Interactions and Interconnectedness of the Components of the Laboratory System

Interacting Components	Supporting Data	Evidence	Characteristics of Complexity Theory
Instructional Practice + Laboratory Constraint	*Question One*	Do you think your students learned the biology concept regarding fermentation as you intended, and why do you think so?	Self-organization, non-linearity, and co-adaptability.
	Cleomedes' Response (VSR Interview, March 8, 2019)	I think they learned the basics of it but not in-depth. It was the time constraint. With the first lab—the bromothymol blue lab— we didn't finish it out as we should have.	
	Question Two	What approach or method would you say that you used to help your students learn about fermentation, keeping in mind the time constraint?	
	Cleomedes' Response (VSR Interview, March 8, 2019)	I use the lecture [approach] just because of the time constraint. It was just easier. If it were another time without the time constraint, I would ask more questions and give more demonstrations. But I would still use the PowerPoint as a reference for students.	

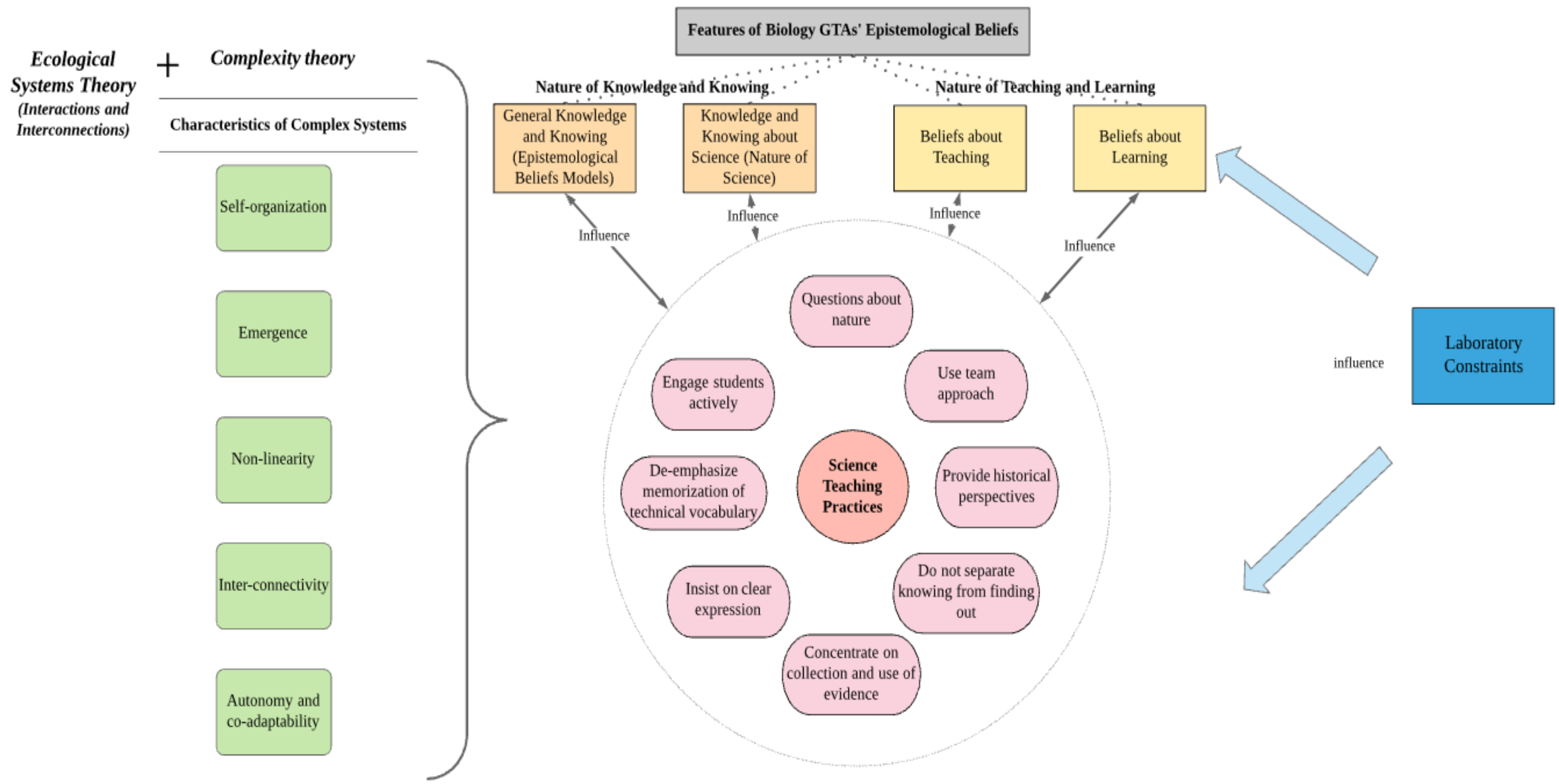


Figure 60. Schematic of the connection between research questions and theoretical framework of the study.

Delimitations of the Study

Given the qualitative, exploratory nature of this study, there were limitations to the nature of the conclusions drawn from the data. Determining the features of epistemological beliefs of GTAs and the relationship to their science instructional practice and laboratory context was an important goal. However, the qualitative nature of the study limited the possibility of generalizing the findings beyond the specific cases presented. The purpose of qualitative research, however, is not to generalize the results but rather to support their transferability (Gay, Mills, & Airasian, 2011). The use of thick, rich descriptions and details supported the transferability of the findings of this study.

Other characteristics that limited the scope of this study were under the control of the researcher and defined the boundaries of this study. First, the problem selected, the research questions, and the examination of the areas of focus with the research questions were guided by the researcher's choices. Second, the parameters of the cases, the participant selection process, and the participants were chosen directly by the researcher. The use of a specific theoretical framework as an interpretative lens of the study and the selected methodology were specially chosen due to their likely influence on the study. These factors, combined with others, including the university environment, provided specific boundaries under which the study was conducted.

Limitations of the Study

The limitations of the study included issues that were mostly out of the control of the researcher, either due to physical or contextual reasons. Physical factors such as the timeframe for the study and the volume of the report that it produced limited the study in specific ways. For example, the collection of data was confined to a period of 16 weeks; the results captured a brief and fleeting view of the phenomenon under examination and relied on four cases to situate this study's point-of-view. Additionally, the volume of data collected during this timeframe produced a thick description of the study's context, whose length limited the audience it reaches. Finally, the laboratory context in which the research was situated, particularly in its examination of four cases, further bounded the study.

Issues of Trustworthiness

The trustworthiness of this research was established mainly by its credibility or insurance that there was an examination to the full degree of the complexity of the study's context (Gay et al., 2011). This credibility was predicated on classroom observations, field notes, and interviews. These data collection methods and the data produced were used to support triangulation (Gay et al., 2011; Yin, 2014). This resulted in a complete account of the situations under examination. An example of this process was the extensive interview of biology GTAs about their perceptions of knowing and the nature of knowledge before the direct observation of their classroom practices over four weeks.

To ensure the trustworthiness of this study, the researcher relied on three additional factors: transferability, dependability, and confirmability. Transferability, or descriptions within context (Gay et al., 2011), was derived from the rich, descriptive data collected. The study's dependability or data stability (Gay et al., 2011) was supported by the overlapping methods of data collection described previously. In addition, all aspects of data generation were made transparent by producing an audit trail based on the description of the instruments and processes used to collect, analyze, and interpret the data. Finally, the study's confirmability or objectivity (Gay et al., 2011), ensured trustworthiness through the process of triangulation and the researcher's awareness of the potential biases identified in the section describing the researcher's role as an instrument and the use of a reflective journal.

Verification

For this study, several measures were taken to enhance credibility and validity and reduce bias. To increase the credibility of the study, the researcher included a description of her experiences, training and perspective, her reflective journaling (reflexivity), her potential biases, the reactions of the participants from her interactions (reactivity), and her competencies (Patton, 2015). The researcher practiced reflexivity by keeping a reflective journal to monitor and record her practices as truthfully as possible. As the investigator, the researcher did not participate in the instruction or planning of laboratory lessons, which would have "increased the potential for bias" (Schwartz, 2004, p. 112). Respondent validation of interview transcripts was conducted to enhance the validity of the findings (Shenton, 2004). That is, all transcribed interviews and episodes of practice were returned to GTAs for approval of accuracy and further validation.

Ethical Considerations

This study possessed minimal, if any, risk to participants, and even if their identities were known, it posed no foreseeable risk. Although undergraduate students were not part of the research, they were made aware of the presence of the researcher in the laboratory and the times when any data collection included them (specifically video recordings). Both the GTAs and students were administered consent forms before data collection began. The researcher, in person, administered consent forms. Students were asked to grant the researcher permission to include them in video recordings even though GTAs were the main point of focus of the study. GTAs were provided with written and verbal instructions regarding voluntary participation and the choice of terminating their participation if there was a desire to do so. All video and audio recordings, field notes, interview transcripts, and reflective writings were de-identified and kept in a secure location.

Chapter Summary

GTAs are responsible for instructing a significant proportion of undergraduate students (Gardner & Jones, 2011; Kendall & Schussler, 2012; Sundberg et al., 2005). The concepts, features of epistemological beliefs, science instructional practice, and context are areas that researchers concerned with reformed science teaching have explored (e.g., Sengul, 2018; Suh, 2016). An investigation into GTAs' epistemological beliefs—explicitly identifying the features of epistemological beliefs of GTAs—is a significant consideration in this research, particularly in the context of the laboratory since epistemological beliefs are strong predictors of instructional choices. This qualitative study utilized a case study approach to analyze multiple units of data to determine the common features among biology GTAs' professed features of epistemological beliefs and the relationship between these beliefs and GTAs' science instructional practice. Additionally, the literature identifies misalignments between beliefs and science instructional practices. This study explored the contextual constraints of the laboratory in an attempt to clarify misalignments by revealing how laboratory constraints influence GTAs' science instructional practice. Finally, the relationship between features of epistemological beliefs, science instructional practice, and laboratory context were examined using complexity theory and ecological systems theory as the underpinning theoretical framework.

CHAPTER IV: RESULTS

Introduction

Many factors contribute to an individual's epistemological beliefs, including past experiences, knowledge structures, and sociocultural contexts. These constructs also impact the effectiveness of teachers (Ernest, 1989; Pajares, 1992). The influence of teachers' epistemological beliefs, including GTAs, on their instructional practices, has been well examined in the literature (Lee, 2019; Mansour; 2013; Pajares, 1992). However, the features of science teachers' epistemological beliefs (Suh, 2016), specifically biology GTAs, have not, and therefore the interactions between the features of these beliefs and their bearing on science instructional practices in the laboratory context are not fully understood. The results of this study endeavored to illuminate the deficiency in this regard.

The literature indicated that there are inconsistencies that exist regarding the professed beliefs of instructors about their classroom practices and what they actually do in the classroom. Mansour (2013) acknowledged that an investigation of the context in which teachers work might shed more light on these misalignments, focusing primarily on constraints that the instructional environment may present. Classroom constraints can stifle the transference of certain features of teachers' epistemological beliefs. As such, these beliefs may be exhibited during a teacher's instructional practice (Mansour, 2013). The opposite is also true, where contextual constraints may facilitate certain epistemological enactments during teaching and learning.

This study first examined the features of biology GTAs' epistemological beliefs and the relationship to science instructional practice, then investigated the constraints of the laboratory context and their influence on the instructional practices of GTAs. The following research questions were addressed:

1. How are the features of biology graduate teaching assistants' professed epistemological beliefs related to their science instructional practice in the laboratory, if at all?
2. How are misalignments between the features of professed epistemological beliefs and science instructional practice influenced by laboratory constraints, if at all?

The findings from this exploration are presented in this chapter in two parts. Part one offers the findings that are specific to research question one and are described, case by case, in four subsections: (1) analysis of the features of the biology GTA's epistemological beliefs, (2) analysis of the science instructional practices of the GTA, (3) a cross-case review that includes a description of the relationship between the features of GTAs' epistemological and the GTA's science instructional practice, and (4) an analysis of the nature of the complexity of the interrelatedness between the features of the GTA's epistemological beliefs and science instructional practice. Part two addresses research question two and the results are provided case by case in four subsections: (1) an analysis of the laboratory constraints, (2) analytical results of misalignments between professed epistemological beliefs and science instructional practice for each GTA, (3) analysis of findings of the influence of laboratory constraints on misalignments between professed epistemological beliefs and science instructional practice, and (4) an analysis of the nature of the complexity of the interrelatedness between the science instructional practice and laboratory constraints, as described by this study's theoretical framework.

Description and General Characteristics of Graduate Teaching Assistants

Before presenting the main findings of the study, this section offers a description of each biology GTA, noting aspects like their personality, instructional styles and strategies, and general laboratory-teaching atmosphere. These aspects were significant in providing insight into the learning environment, that is, the laboratory teaching and learning culture, from the GTAs' perspective. Such insight is important in providing a more explicit understanding of epistemological beliefs, which is translated into their instruction (Huling, 2014; Lee, Zhang, Song, & Huang, 2016). The four-participating biology GTAs were Aesara, Batis, Cleomedes, and Diodora – three females and one male, selected via purposive sampling for this study. Table 13 shows a summary of the GTAs' demographic information and teaching experiences.

Table 13

Biology Participants' Demographic Data

	Biology GTA			
Categories	Aesara	Batis	Cleomedes	Diodora
Nationality	American	Chinese	American	American
Gender	Female	Male	Female	Female
Age (years)	30 – 39	30 – 39	30 – 39	20 – 29
Total Teaching Experience (years)	10.5	9	10	1.5
Science Teaching Experience (years)	4	1.5	10	1.5
Teaching Experience as GTA (years)	3	1.5	4	1.5
Student Status	Doctoral Candidate	Doctoral Student	Doctoral Student	Master's Student

Aesara

Aesara was the most experienced instructor of the participants and had been teaching for over ten years. However, only four were spent teaching science. Most of her experience was from working with students as an academic advisor, which, according to Aesara, had enabled her to establish more significant teacher-student relationships with her students. Aesara was very passionate about teaching science, especially to students at the undergraduate level. During her interviews, she spoke carefully and explicitly, and with an air of certainty and passion when she described her views about teaching and learning science. According to Aesara, her dedication to teaching was visible in her laboratory instruction, and she described her disposition as being patient and caring, which sometimes, in her opinion, caused her to take on a motherly role to her students. Aesara continued by explaining that, in turn, this created a dynamic class atmosphere as she tried to maintain a high energy level during each laboratory and motivated students using a variety of instructional methods and alternative strategies like singing and dancing. For example, she used very bright colored PowerPoint presentations with funny pictures or animals. Most importantly, she tried to engage students cognitively and used a variety of teaching strategies such as concept maps.

During laboratory lessons, Aesara described her primary role as listening to students' ideas and actively supporting those who had difficulty understanding a particular concept. Outside of the laboratory, Aesara continued student support by providing additional resources to students via posting content and auxiliary materials on the university's learning management system's website. At the center of Aesara's practice were student engagement and creating a learning environment that made students comfortable enough to share their ideas. According to Aesara, this made her laboratory an ideal example of a student-centered classroom.

Batis

Batis was a very active and energetic international GTA who felt that his cultural background and English as a second language negatively influenced his instructional practice. During his GTA beliefs interview, Batis explained that he tried to compensate for his perceived inadequacies in the laboratory by making lessons very lively and drawing students' attention to everyday occurrences that were tied to the laboratory activities. There was a continuous banter between Batis and his students that created a dynamic yet respectful learning atmosphere.

Batis believed that the purpose of the laboratories was to have students engaged in doing hands-on activities. He explicitly reiterated this point during his interviews, "I do not like to lecture . . . [and the] lab is not a place to lecture and instead highlighted the need for students to act on their understanding of the content learned during the lecture" (Batis, GTA beliefs interview, January 8, 2019). As such, his lessons were very student-centered, and students were often engaged in discussing, exploring, and sharing ideas while Batis took the background role of the facilitator. This atmosphere benefited Batis in that he was able to manage at a level where his knowledge of the English language did not make him too uncomfortable to teach aspects of the content that was inundated by science vocabulary with which he was not acquainted. In cases where he felt that students needed a better grasp of the content, Batis would use thoughtfully selected videos from YouTube that he felt presented the content material in a manner that was simple and easy for students to understand.

Batis tried to keep an open mind, as evidenced by the interviews. He often professed a willingness to consider new and different ideas and increase his pedagogical knowledge as well as his science content knowledge. He was particularly interested in trying new approaches to help students better understand science concepts and even divulged that he should sit in on Aesara's labs. Although Batis struggled with his ideas of teaching and his actual instruction in the laboratory, he was proficient at classroom management and continuously through questioning and dialogue encouraged students to think for themselves.

Cleomedes

Cleomedes possessed a reticent and calm personality. Cleomedes talked very carefully and rarely spoke loudly in the laboratory, even in her one-on-one exchanges with students. Cleomedes was an experienced high school teacher, and her instructional style reflected her years of working with high school students. For example, if they needed to get materials from the side benches for an experiment, the students' movement was coordinated so that there would be no crowding at the materials' stations. As another example, Cleomedes ensured that all students were familiar with or prepared for a specific laboratory activity by reading the instructions aloud.

Although students were comfortable enough to engage in discussions, there was not the energy and enthusiasm that pervaded Aesara and Batis' laboratories. Cleomedes acknowledged that she was more familiar with teaching using mini lectures because of her high school teacher experiences and experiences as an undergraduate and graduate science student. For this reason, Cleomedes' laboratory lessons could be characterized as relatively less student-centered and more teacher-guided but still retaining the essential features of the student-centered classroom such as cooperative learning groups and a high degree of student engagement and interactions.

During her interviews, Cleomedes spoke about her professional development as an instructor, which she believed was a result of the influence of being in a doctoral program. She explained that reading current literature and engaging in scholarly conversations about teaching and learning, especially in science, were causing her to rethink some of her ideas about science education.

Diodora

Diodora had the least teaching experience of the four GTAs. Her teaching experience was limited and consisted of mostly laboratory teaching. Diodora explained that she kept an open mind and was very passionate about science and confident about teaching the subject. During her interviews, Diodora shared her passion for pure science and described her teaching experience as one framed by her upbringing in a small, rural town. She was not afforded much of an experience with science outside of the classroom. The science laboratory was either not available or limited in number or scope.

Diodora emphasized that it was imperative to keep students interested in learning science because science unlocks doors. Although she saw herself as a facilitator and in her own words described herself as a “spirit guide” for students, Diodora possessed the characteristics of a traditionalist teacher who believed that she held or was the source of knowledge that students need. For example, Diodora described herself as a musician playing a song where the music was the knowledge she had and then getting the students to learn that song and music was her role as a GTA. Her idea of playing games to peak students’ interest included examples and illustrations that relied heavily on the traditional approaches to teaching and learning of biology. For example, she explained that she used a game that required students to identify the results of genetic crosses using pink and blue colored paper to help students determine what alleles were present in the genotype. At the same time, Diodora was very serious about working in the laboratory and emphasized laboratory skills or techniques. She was stern and strict about adhering to laboratory rules, procedures, and safety. However, despite her stringency in the laboratory, Diodora believed that GTAs need to be able to build trusting relationships with students in the interest of creating a safe, positive, and productive learning environment wherein students can debate and share opinions themselves. As such, she often reminded students to focus on their tasks and expressed that she empowered her students to be in charge of their own learning when it came to conceptual learning.

Research Question One

This section describes the findings specific to research question one, which discusses, as separate cases, each biology GTA's features of epistemological beliefs and science instructional practice. The relevant information is presented in the following format. The first section will be *Professed features of epistemological beliefs*. This section will describe the four main themes (i.e., epistemological beliefs in general, epistemological beliefs about science, beliefs about learning, and beliefs about teaching), which are further divided into subcategories and are explicitly discussed to highlight the features of epistemological beliefs that were specifically displayed by each case (GTA). The next section will be *Science instructional practices.* This section will discuss the findings regarding the recorded observations of four laboratory lessons and lesson structure of each case (GTA). Observations of the biology GTAs' laboratory lessons indicated which of the eight science instructional practices that were demonstrated and the frequency of the GTAs' demonstration of the science instructional practices during their laboratory lessons. The third section will be *Relationship between the features of epistemological beliefs and science instructional practices*. This will include Misalignments, or circumstances where the professed epistemological beliefs contradicted what was done during science instructional practice, that is, the science instructional practices as recommended by the AAAS (1993, 2011). It will also include alignments or circumstances where the professed epistemological beliefs of GTAs were enacted during GTAs' science instructional practice, where these science instructional practices corresponded to the practices of teaching that are consistent with the nature of inquiry as described by the AAAS (1993, 2011). The misalignments and alignments will be discussed according to the categories of epistemological beliefs under which they were found based on the data analysis. Finally, complexity theory will be used to describe the interrelatedness between the features of the biology GTAs' epistemological beliefs and science instructional practice.

Aesara: Professed Features of Epistemological Beliefs

Epistemological Beliefs in General (Knowledge and Knowing)

An individual's general epistemological beliefs are concerned with how an individual comes to know what he or she knows and the process of knowing. In this study, the features of epistemological beliefs focused on the nature of knowing and knowledge and recognized four sub-dimensions of domain-general epistemological beliefs (i.e., changeability of knowledge, the structure of knowledge, source of knowing, and justification of knowing) as the core dimensions of epistemological beliefs (Hofer & Pintrich, 2002).

Changeability of knowledge. The changeability of knowledge is concerned with whether knowledge is certain, uncertain, fixed, or changeable. Aesara held strong beliefs that knowledge did not change. She defined knowledge as information that can be acquired, passed on, or experienced in several different ways. Considering her beliefs regarding the changeability of knowledge more closely, Aesara explained that the application of knowledge could change with experiences, but that does not infer a change in knowledge. She added that instead, it is indicative of the way an individual understands a piece of knowledge. According to Aesara,

> We can gain wisdom about information or [a] piece of knowledge. So, how we use that knowledge and how we come to understand that piece of knowledge may change over time. But knowledge itself, I don't think changes. I think that we may be exposed to different aspects of knowledge, or, as I said, we may understand things differently, and that changes. How we approach things, how we perceive things change over time, but I think knowledge in and of itself does not. I think a leaf will be a leaf whether we perceive it as a leaf or not. (Aesara, GTA beliefs interview, January 8, 2019)

This quote indicated that in Aesara's view, the terms knowledge and understanding as being different and separate. She presumed that an individual's understanding of a piece of information changes with experience. This revealed that Aesara believed that knowledge was a large entity made up of many subparts where there could be changes in the subparts but not in the larger entity – knowledge.

Justification of knowledge. The justification of knowledge identifies the procedures that individuals use to evaluate and warrant knowledge claims, as well as the reliability and acceptance of any of the processes and procedures that led to the belief. For Aesara, the means of justification of knowledge were self-derived. She affirmed that the justification of her knowledge came from self and was based on her experiences, especially from what one intuits. According to Aesara, "Like I said, experience – so in the world of science, you know, if you touch it, feel it, see it, you know, it's kind of there. This justifies what you know because it is right there" (Aesara, GTA beliefs interview, January 8, 2019). In her view, the core of the justification process lies within an individual and is mostly dependent on evidence and validation drawn from one's own experiences.

Source of knowledge. The source of knowledge is concerned with where an individual believes that knowledge comes. For Aesara, the source of knowledge was a blend of authoritative figures and the experiences of an individual. She further alluded to questioning authoritarian figures if certain pieces of information did not seem clear. Aesara elaborated by saying,

> I think it's a blend between authoritative figures and experience. I think at a younger age, it was more authoritative, like parents, schoolteachers, or people that are older in my life. And then, as I grew up and began to kind of understand the way the world works a little better, I began to experience different things, and that became a little bit of my teacher as well. Now, as who I am now, sometimes I question those in authority. Like, if I was younger [Aesara], I probably wouldn't have, but at the age I am now, there may be things that don't make sense, and I may ask for clarity. Or ask, "what does that mean?" You know, they're experts. They've done this way more than I have, and they have a lot more understanding about things. But if something doesn't make sense, I feel like it shouldn't be offensive for me to ask for clarity. (Aesara, GTA beliefs interview, January 8, 2019)

As indicated from this except, Aesara believed that knowledge could be derived from multiple sources. That is, Aesara assumed that one's experiences served as a source of knowledge and experts or persons in authority could also serve a source of knowledge. This indicated that Aesara held dual views of the source of knowledge.

Structure of knowledge. The structure of knowledge deals with whether knowledge is simple or complex, inseparable, or fragmentary. In Aesara's case, she agreed that knowledge moves along a continuum from simple to more complex. Aesara expressed that,

> My gut would say the best ideas are the most simple, but I know that there's an exception to everything. I think complexity is inevitable, but I think sometimes we overlook simplicity because it's simple. And sometimes, there are very unique opportunities that are just really simple, but as we gain an understanding of big ideas, knowledge becomes more complex. (Aesara, GTA beliefs interview, January 8, 2019)

Aesara believed that in order to understand more complex ideas, students must first understand simple ideas and build on that, therefore purporting a gradual movement from simple to complex knowledge. This proclamation disclosed that Aesara perceived that knowledge grows in complexity as one's understanding increases.

Summary of Aesara's professed features of epistemological beliefs. During the GTA beliefs Interview, Aesara expressed her views regarding the four main areas of epistemological beliefs in general, as described by the literature. Table 14 highlights the features of Aesara's epistemological beliefs regarding the nature of knowledge and knowing and provides a summary of her proclamations regarding each aspect. Next is a discussion on Aesara's beliefs about the nature of science.

Table 14

Summary of Aesara's Professed Epistemological Beliefs about the Nature of Knowledge and Knowing

Feature of Epistemological Belief	Proclamation regarding belief about the nature of knowledge and knowing
Changeability of Knowledge	Knowledge does not change.
Justification of Knowledge	Knowledge is justified by self.
Source of Knowledge	Both authorities and self are sources of knowledge.
Structure of Knowledge	Knowledge structures move gradually from simple to complex.

Epistemological Beliefs about the Nature of Science (NOS)

Hurling (2014) posited that if you are studying a person's scientific epistemological beliefs, then you are studying their views of NOS. Epistemological beliefs about the study of scientific knowledge or NOS are related to the study of science as a way of knowing. All knowledge has value and belief systems that are affiliated with it, and these systems are integral to the development of knowledge. According to Lederman (1992), the NOS has its own specific set of values and beliefs that characterizes it as scientific. These characteristics of scientific knowledge set it apart from other disciplines. While specific characteristics of NOS are still a subject of dispute, academic research and educational reform movements (e.g., NGSS, 2013) have established characteristics that serve as a basis for most recent descriptions of NOS (e.g., Ackerson, Abd-El-Khalick, F., & Lederman, 2000; Abd-El-Khalick, Bell, & Lederman, 1998; Hodson, 2014). These characteristics include that scientific knowledge: 1) is a way of knowing, 2) is a human endeavor, 3) is empirically based (based on and/or derived from observations of the natural world, 4) assumes order and consistency, 5) is derived from a variety of methods, 6) is tentative and open to revision, 7) is generated from scientific models and theories, and 8) answers questions about nature. These eight characteristics were used to determine the epistemological beliefs of GTAs regarding the nature of science. The analysis for the features of epistemological beliefs about science revealed that the biology GTAs did not identify with all eight characteristics of NOS. Only the characteristics professed during the GTA beliefs interviews are discussed.

Science as a way of knowing. Science as a way of knowing describes science as a body of knowledge that is based on scientific inquiry and practices that are governed by logic, evidence, and reasoning. According to Aesara, science as a way of knowing is both systematic—allowing for inquiry methods—and chaotic – forbidding one specific method or process of investigation. Aesara explained,

> I think science is a way of knowing or understanding things about this natural world. I think it's systematic in its own chaotic way because I don't think you can put a step 1, step 2, step 3 to it. I think it's more so this causes you – this one thing or this observation may cause you to look at things differently or deeper. Or let me see if that happens again or let me go collect some more data to see if it matches this evidence. So, I think there are patterns that happen in the way that we obtain this scientific knowledge that we can isolate and say, "We collect data, we make observations, we test it out, we conclude this." But I think it's chaotic in the sense that I don't think every scientist has to do the same thing to say that they're conducting science or obtaining scientific information. It has to be something we see, smell, touch, feel – you can't go outside of that natural world. (Aesara, GTA beliefs interview, January 8, 2019)

This excerpt highlighted Aesara's perception that science, the body of knowledge, was a result of information gained about the natural world through the five senses. This disclosed that Aesara believed that generating scientific knowledge is a process of discovery that comes about through investigations that are both procedural and disorderly. Aesara also believed that the procedural aspects of scientific investigations involved the various steps of the scientific process, for example, observing, questioning, hypothesizing, predicting, etcetera. The "chaotic" aspects of science explorations, according to Aesara, involve the application of different means of testing and gaining scientific information.

Science is a human endeavor. The biology GTAs in this study acknowledged that people had been practicing science for a long time. Aesara believed that there is creativity in how scientists organize and design their experiments, as well as how they conduct investigations. Aesara expressed,

> I think [scientists] in the way that they design the experiments, their creativity and imagination may come out. I think that there's some creativity in how we even investigate things. So, scientists' creativity can come out in that. I think that they all could be looking at and investigating similar things or the same things. But the way they're investigating, their creativeness in how they're doing it, designing the experiment, and what they're doing can have different conclusions that they're drawing even when they are of different social, cultural, and ethnic backgrounds. I mean, we would hope we have faith in our scientific society that we can get some consistency on some things. (Aesara, GTA beliefs interview, January 8, 2019)

In the above excerpt, Aesara highlighted that creativity and imagination were important in science and that the endeavors of scientists influence their investigations and findings. This revealed that Aesara viewed that human endeavor in science, specifically regarding the ways that scientists work, leads to similar results even if scientists were of diverse cultural, ethnic, and social backgrounds.

Science is based on empirical evidence. This feature of the nature of science was one that all four biology GTAs noted that played a significant role in the development of scientific ideas; hence, scientists need to develop multiple lines of evidence using various methods. Aesara believed that patterns are important when generating scientific knowledge. Aesara believed that empirical evidence was necessary to make something plausible and that scientific knowledge comes about as a result of the collection of evidence. Also, she believed that evidence is necessary to build a case and make it plausible, especially if the evidence that is provided is a result of repeated testing. In the excerpt below, Aesara explained,

> I think some patterns happen in the way that we obtain this scientific knowledge that we can isolate and say, "We collect data. We make observations. We test it out; we do this." I think it [scientific knowledge] comes from a collection of kind of – a collection of evidence. Like a collection of something. Like if we say, "This pen is black." We've collected data, we've looked at it through this lens, we've looked at it through that lens and comment – like multiple people are thinking, you know, saying it's black. There are multiple amounts of evidence that lead to this pen being black, so it's probably black. So, I would say it's kind of a collection of this evidence that allows us to say that this is plausible. [The role of scientific evidence is] I think to build a case, right? To build a case to say, "This is probable. This is likely to happen because of this amount of evidence. It's been tested; it's been viewed from different angles. People have done several different experiments on it and – or observed it several times, and it holds; the information is supported." (Aesara, GTA beliefs interview, January 8, 2019)

In this excerpt, it can be inferred that Aesara acknowledged that the role of evidence in science is to justify scientific information. As stated above, Aesara believed that the amount of evidence obtained is based on the various experiments that have been done and the number of times that they have been done.

Science uses a variety of methods. Aesara believed that there are many ways to go about the process of obtaining and developing scientific knowledge. In support, Aesara claimed that there is not only one way to design an experiment. She further explained that science "is systematic in its own chaotic way because I don't think you can put a step one, step two [because] there's no one way to design the experiment" (Aesara, GTA beliefs interview, January 8, 2019). This statement disclosed that Aesara believed that there is not just one way of doing science, and investigations in science can be designed using various approaches that are not methodological.

Summary of Aesara's professed beliefs about NOS. In summation, there were four characteristics of NOS about which Aesara made explicit claims during her GTA beliefs interview. A summary of Aesara's claims regarding four of the characteristics of NOS are as follows:

- Science is a way of knowing or understanding things about the natural world.
- Science is a human endeavor, and the practice of science is seen in the way that scientists design experiments using their creativity and imagination.
- Science is based on empirical evidence, which makes scientific information plausible.
- Science uses a variety of methods, and there is not just one way of doing science and investigations in science.

The section which follows describes Aesara's beliefs about learning.

Beliefs about Learning

An instructor's beliefs about how to learn are an important aspect of their epistemological beliefs, primarily since epistemological beliefs affect instructional practices. This section describes Aesara's beliefs about learning and presents her beliefs about four aspects of learning: the ability to learn, how to learn, control of learning, and the role of students in learning.

Ability to learn. This feature addressed the question of where the ability to learn emanates. As stated by Aesara,

> I feel like everybody can learn. You may have difficulties, you may have adversities or barriers, but eventually, you just need to figure out how. You just need to figure out how it's going be done. But if that person doesn't have the motivation to do it. It's not going to happen. If you have the motivation to let you keep trying and let you just figure out the way that works for you, then I think that you can overcome those difficulties. (Aesara, GTA beliefs interview, January 8, 2019)

From this excerpt, it was evident that Aesara presumed that cognitive impairment does not hinder learning. She supported her belief by acknowledging the role and importance of the application in the learning process and expressed that, with effort, one could find the best suitable method of learning.

How to learn. Aesara believed that learning is a "process and a way of experiencing various phenomena" (Aesara, GTA beliefs interview, January 8, 2019). She further highlighted that "learning took place when students integrated new information from multiple sources and interwove what they already know with the latest information." She also acknowledged that "interactions between students were necessary for them to construct their own meaning about a concept" (Aesara, GTA beliefs interview, January 8, 2019). This disclosed that student-student communication and exchanges, as well as the involvement with various sources of information, were influential in developing what students already knew and, therefore, further enhanced the learning process.

Control of learning. Aesara believed that students oversaw their own learning and that the students needed to have the will, motivation, and the desire to put in the effort to learn. She also believed that the instructors were a significant contributor to students' learning. For example, this was illustrated in the following excerpt from Aesara.

> Instructors contribute 50%, that is, by providing the information, but the students have the other 50%. They have this half – they have to put in the effort. They have to be motivated. They have to be able to want the instructor to meet them where they are, want to seize that opportunity for learning, and [to] be able to move forward. So, I feel like it's a blend – instructors and students both. I feel like it's a dual effort in the learning process. (Aesara, GTA beliefs interview, January 8, 2019)

The above claim disclosed that Aesara believed that both students and instructors are in control of learning. However, the contribution of the instructor is mainly to serve as a source of information, a perspective that is reiterated in her discussion on the source of knowledge, where Aesara believed that authority figures serve as a source of knowledge.

Role of the student. Aesara believed that students needed to be curious about scientific information—whether they are in the classroom or outside—in an attempt to understand how the natural world works. Aesara explained as follows,

> The job of the students is just to wonder about things. In the labs specifically, I want them to be like, "What is that? Why does that happen?" And [to] be able to think about that outside of the lab when they go home and be like, "Oh, my goodness." We do a lab [activity] with UV beads. When students do the experiment, they're like, "Wait a minute. My sunblock is really not even working for me the way I think it should." So, I think that students should wonder about that outside of the lab. I think that their role is to try to figure out how this world is working. (Aesara, GTA beliefs interview, January 8, 2019)

According to this excerpt, Aesara believed that the natural curiosity of students should be what initiates the process of learning. This revealed that an individual's attempt to learn commences with simply thinking about and asking questions regarding the nature of how things work in the natural world. This idea coincided with the first aspect of the scientific process, which begins with an individual making an observation and asking a question based on that observation.

Summary of Aesara's professed beliefs about learning. During the GTA beliefs interview, Aesara indicated her beliefs regarding learning. More specifically, she made claims about her views on the ability to learn, how individuals learn, who is in control of learning, and the role of the student in learning. A summary of her claims are as follows:

- The ability to learn comes from self.
- Students learn best from both student-student interactions and student-instructor interactions, and students are engaged with multiple sources of information.
- Both the student and the instructor are in control of learning.
- The role of the student is to be curious and to wonder about how things work in the natural world.

The section which follows describes Aesara's beliefs about teaching.

Beliefs about Teaching

This section describes Aesara's beliefs about teaching regarding the role of the instructor, how to teach, and the goal of teaching. These aspects are important in providing an insight into how Aesara's science instructional practices in the laboratory reflected her conceptions about teaching.

How to teach. Aesara's views about teaching included using various activities that required group work and stressed using different strategies to increase conceptual understanding. She noted that she would observe other GTAs to determine some of the activities that worked in their laboratories so that she could incorporate them into her lessons as well. For example, one of the activities she mentioned was the carousel, which she described in the excerpt that follows:

> I adapted this from another GTA and somebody else, but I did a carousel activity where students would go around and kind of add to whatever particular topic we were going over. They would kind of add to the information on posters, on different posters. And so, they would walk around and kind of look at what other people said and add to it or make comments on it. Then we would regroup and talk first in groups and then as a whole class. The idea of piggybacking on each other's brains helps a lot. Group work helps a lot. (Aesara, GTA beliefs interview, January 8, 2019)

Aesara also mentioned using two other teaching strategies that she felt were useful in helping students gain and retain knowledge. She admitted that concept maps and think-pair-share were two such examples.

> We've done things where we've done concept maps. I would give them several terminologies and ask them how these connect. Or two big things – topics. We did cellular respiration at one time, and I asked them to make connections between aerobic and anaerobic. Like, what things were similar? What things were different? And map it out. Like, they had to draw it in some kind of way, so I brought markers and paper. And most of them enjoyed that. I also got to do some work with the lecture, and some of the students were able to kind of mimic that as a study strategy for the lecture as well. I have done turn-and-talk-to-your-neighbor kind of group activities where let's discuss this before we discuss it as a whole class. Kind of pair-share things. I have mainly a lot of group work and table work. So, I've tried to modify some of the labs to where each group member may have a role or something, and they're all responsible. And then, as I said, do a lot of drawing. They can add drawings and stuff to their In-labs. Things like that. I let them tell me what they want to – what they're thinking about or what they were having trouble with. This is important. That way, they can – they have a stake in the game. I'm not just reading questions off, and this is the answer. It's more like what did you have trouble with. Let me know, and I'll

> answer it, and so they have to speak up and tell me that. (Aesara, GTA beliefs interview, January 8, 2019)

This excerpt disclosed that Aesara regarded peer collaboration and interactions between students and instructors as significant since these types of interactions allowed students to be aware of their role in the teaching and learning process. Aesara's proclamations also implied that students' participation in the learning process, in this case, involved telling their instructor what activities they wanted to include in the lesson that they believed would be beneficial in helping them better understand the content material. These same ideas were reflected in her previous proclamations about how students learn. Also, this statement seemed to indicate teacher-centered instruction, especially the part where Aesara stated, "It's more like what did you have trouble with. Let me know, and I'll answer it" (GTA beliefs interview, January 8, 2019).

Role of the instructor. Regarding the questions concerning the role of the instructor in the learning process, Aesara described herself as a pacing guide and explained how in that role, she was able to manage laboratory lessons and steer discussions and group work in the direction that she thought they should go. Based on her discussion, Aesara pointed out that,

> I feel like I'm a pacing guide. Like I'm making sure things are on pace. Because most of the labs are a lot of information. They have a lot of content information crammed into one [lab]. So, a pacing guide and also more like a point of reference for the students. A point of reference to kind of navigate their wonder, navigate what they're thinking about, what we're talking about. And they may have some other questions that they bring to the table, so I kind of navigate that in a direction [so] that we stay on pace. (Aesara, GTA beliefs interview, January 8, 2019)

Aesara also explained that she followed a "constructivist approach and allowed her role as a facilitator to help students construct their own knowledge and understandings of scientific concepts" (GTA beliefs interview, January 8, 2019). This disclosed that Aesara believed that her role was to assist students in achieving the learning goals without intervention or controlling the activities of the learners. This meant that Aesara would grant students the space needed to allow for creativity and innovation, which requires students to get involved and actively participate in discussions and teamwork activities.

Goal of teaching. Aesara noted that her goal as a laboratory instructor was twofold and involved helping students become informed citizens which would involve a conceptual understanding of the science content and extending the desire to learn beyond the walls of the classroom. According to Aesara,

> I have two goals. I think one of them is to invoke this life-lasting curiosity about this world and how it works. And then I think the other one is to provide you with – to develop you as an informed citizen, right? To say that you have a responsibility with this knowledge now to be able to make informed decisions about how things work. I think the nature of the class is it could lend itself to that. I think there are sometimes like I said, there are a lot of things we try to cram in there, but I think I try to pull it back to what is the big picture. What is the point kind of thing? (Aesara, GTA beliefs interview, January 8, 2019)

Aesara further explained that,

> I think, as a GTA, I can have that liberty to bring them back to that big point. And sometimes that we get caught up in – like they don't have to know the stages of mitosis – you know, just memorize that. But what does that mean if it's out of whack? You know, what does that do to our body when that's out of whack. Like, let's bring it back to the big picture. So, I feel like as a GTA, I can bring them back to these big concepts that can help them become an informed citizen and help them wonder in the world. I feel like the things that either they're not getting in class – like it's just like – I don't even understand what you're talking about. Or they have the most questions about like they're most curious about. I'll target those. (Aesara, GTA beliefs interview, January 8, 2019)

These two excerpts highlighted Aesara's stance on what she believed was her overarching goals for students. This disclosed that scientific literacy was one of Aesara's teaching goals. Scientific literacy is the knowledge and understanding of scientific concepts and their associated processes. Aesara's view also disclosed that this understanding is required for an individual's decision making and participation in cultural, civic, and economic issues.

Summary of Aesara's professed beliefs about teaching. Aesara's view about teaching reflected some of the same beliefs that she held about learning, particularly regarding the aspects of how to teach and how to learn. The following provides a summary of her views about teaching:

- The most effective way to teach is through group work, where students can collaborate and interact with each other (also one of the best ways for students to learn).
- Aesara's role as an instructor is to be a facilitator and pacing guide.
- The goal of teaching is to prepare students to become scientifically literate citizens and to extend their natural curiosity into their afterschool years where they can continue to wonder about the natural world and how it works.

The section which follows provides a discussion on Aesara's science instructional practices.

Aesara: Science Instructional Practices

Since the 1960s, science education has been through a process of continual change. Advocated are changes in instructional practices that will promote the recruitment of higher numbers of students into careers in science with specific emphasis on how science is taught. This section presents the analytical results of Aesara's use of the eight science instructional practices proposed in *Science for All Americans* (AAAS, 1993, 2013). These eight practices accentuate the distinctive characteristics of the material to be learned, and the conditions under which the teaching and learning are to take place in the science classroom and include: (1) start with questions about nature, (2) engage students actively, (3) concentrate on the collection and use of evidence, (4) provide historical perspectives, (5) insist on clear expression, (6) use a team approach, (7) do not separate knowing from finding out, and (8) de-emphasize the memorization of technical vocabulary.

Aesara's Laboratory Instruction

Aesara's laboratory lessons were two hours long, and activities were distributed based on time to last for the duration of the laboratory. However, all the time was not utilized for teaching. During the first 10 minutes of every laboratory, students completed a short quiz that covered teaching material from both the last lesson as well as the lesson that they were about to do. During the laboratory, Aesara provided students with hints or clues as to some of the topics or aspects that they should expect on the upcoming quiz. During the next three to five minutes after completing the quiz, Aesara reviewed questions or aspects that students needed to clarify. This time was also used to remind students of upcoming deadlines or other general information that Aesara thought students should be aware of (e.g., formative assessment such as grading and homework and housekeeping such as important dates and holidays).

Lesson structure. Aesara's lessons were structured to follow a consistent format regardless of the topics or biology content material. Each lesson began with a review of the previous laboratory, a brief discussion of the objectives for the current lesson, a short lecture on the content that students needed to learn, and hands-on laboratory activities that supported the content. In cases where the laboratory lesson covered several different topics, Aesara conducted a short lecture before each activity as a means of transitioning from one topic to the next. In some instances, Aesara embedded worksheets or activities that were not included in the laboratory workbooks that students used for the course. She considered these as *additional activities* and acknowledged that although she would like to do some more of these types of activities with her students, time would not permit this. At the end of the laboratory, students were required to clear their tables (which were all assigned numbers), wash, throw away or replace apparatus, and complete and submit the in-labs portions of their labs. Colored folders were assigned to each table group so that students could hand in or pick up in-labs, quizzes, or homework.

Science instructional practices. Aesara's lessons were observed for the instances when her instructional practices demonstrated the eight science teaching practices as defined by the AAAS (1993, 2011). Aesara incorporated most of the science instructional practices during her lessons; that is, six out of the eight recommended science instructional practices (Table 15). The instances where her instruction demonstrated practices that countered the eight scientific practices were also noted (Table 16). In Tables 15 and 16, an 'X' indicates the instructional practice that was demonstrated during the teaching of an activity. The tables also highlight information regarding instances where certain activities were completed as a demonstration. For example, the activity on *Yeast and Gas Production* was completed as a demonstration instead of being done by the students. Also emphasized are the activities that were supposed to be completed as part of the lesson but were left out due to time constraints. For instance, the *Stages of Mitosis (Simulation with Beads)* activity from the Human

Genetics Laboratory. Finally, the tables indicate the activities that highlighted evidence and data collection.

Table 15

Science Instructional Practices Demonstrated During Aesara's Laboratory Lessons that Aligned with the Eight Science Instructional Practices Described by AAAS (1993;2011)

	Science Instructional Practice							
Lesson Associated Activities	1	2	3	4	5	6	7	8
Fermentation								
You and Gas Production[a]		X		X				X
Yeast and Gas Production[b]			X	X			X	
Quantifying Gas Production[a]	X	X					X	
DNA Extraction and Mitosis								
Strawberry DNA Extraction		X						
Stages of Mitosis (Simulation with Beads)[c]								
Stages of Mitosis (Microscope)	X	X		X				
Human Genetics								
Pipe Cleaners and Beads	X	X		X				
Human Genetics	X	X						X
Punnett Squares Worksheet		X						X
Blood Typing	X	X						X
Plant and Animal Reproduction								
Spread of STIs	X	X					X	X
Flowering Plant Dissection	X	X		X				
Male and Female Anatomy (Microscope)		X		X				

Note. The numbers in the science instructional practices columns coincide with the following: 1 – Use Team Approach; 2 – Students are Actively Engaged; 3 – Start with Questions about Nature; 4 – Do not Separate Knowledge from Finding Out; 5 – Provide Historical Perspectives; 6 – Insist on Clear Expression; 7 – Do not Emphasize the Memorization of Technical Vocabulary; 8 – Concentrate on the Collection and Use of Evidence

[a] Activity during which students collected data

[b] Activity during which Aesara conducted a demonstration

[c] Activity that Aesara skipped because of time constraint

Table 16

Science Instructional Practices Demonstrated During Aesara's Laboratory Lessons that Countered the Eight Science Instructional Practices Described by AAAS (1993;2011)

	Instructional Practice							
Lesson Associated Activities	9	10	11	12	13	14	15	16
Fermentation								
You and Gas Production[a]	X		X		X	X	X	
Yeast and Gas Production[b]	X	X			X	X		X
Quantifying Gas Production[a]			X	X	X	X		X
DNA Extraction and Mitosis								
Strawberry DNA Extraction	X		X	X	X	X	X	X
Stages of Mitosis (Simulation with Beads)[c]								
Stages of Mitosis (Microscope)			X		X	X	X	X
Human Genetics								
Pipe Cleaners and Beads			X		X	X	X	X
Human Genetics			X	X	X	X	X	
Punnett Squares Worksheet	X		X	X	X	X	X	
Blood Typing								
Plant and Animal Reproduction								
Spread of STIs			X	X	X	X		
Flowering Plant Dissection			X		X	X	X	X
Male and Female Anatomy (Microscope)	X		X	X	X	X	X	X

Note. The numbers in the science instructional practices columns coincide with the following: 9 – Do not Use Team Approach; 10 – Students are not Actively Engaged; 11 – Do not Start with Questions about Nature; 12 – Separate Knowledge from Finding Out; 13 – Do not Provide Historical Perspectives; 14 – Do not Insist on Clear Expression; 15 – Emphasize the Memorization of Technical Vocabulary; 16 – Do not Concentrate on the Collection and Use of Evidence

[a] Activity during which students collected data

[b] Activity during which Aesara conducted a demonstration

[c] Activity that Aesara skipped because of time constraint

Students are actively engaged. It was observed that students were, at most times, actively participating in various activities during Aesara's lessons. This included instances where Aesara asked her students to think, imagine, predict, or visualize, and members of certain groups were asked to share with each other. Also included as actively engaged were instances where Aesara asked her students to write, speak, or do certain things during the various laboratory lessons. For example, during the Human Genetics activity, students were asked to pick a superhero trait (super strength, ability to fly, or invisibility) and predict their offspring if they were to mate with another student in class by using the Punnett squares method of crossing genes. Students were asked to share their results with the rest of the class at the end of the exercise.

Questions about nature. Aesara introduced most of her lessons with questions. However, questions posed were not questions about nature that would introduce the content using phenomena that were interesting and familiar, although she expressly stated that "students being curious . . . [and] wondering about how the natural world works" was very important (Aesara, GTA beliefs interview, January 4, 2019). Instead, she asked content-related questions that might be outside students' range of perception or understanding, especially if they had not yet covered that information in their lecture. The following example and its accompaniment, Figure 11, is a video still and an excerpt of the coinciding narrative from the laboratory lesson on DNA Extraction and Mitosis, filmed at the introduction of the lesson: "There are some questions up here that I want you to talk to your tablemates about and then we will discuss them as a class" (Aesara, Lesson on DNA Extraction and Mitosis, March 13, 2019). Aesara acknowledged that she used these types of questions as a bridge between laboratory lessons so that students would not conclude that content material from each lab was unconnected. She also posited that in so doing, students were able to build on their existing knowledge.

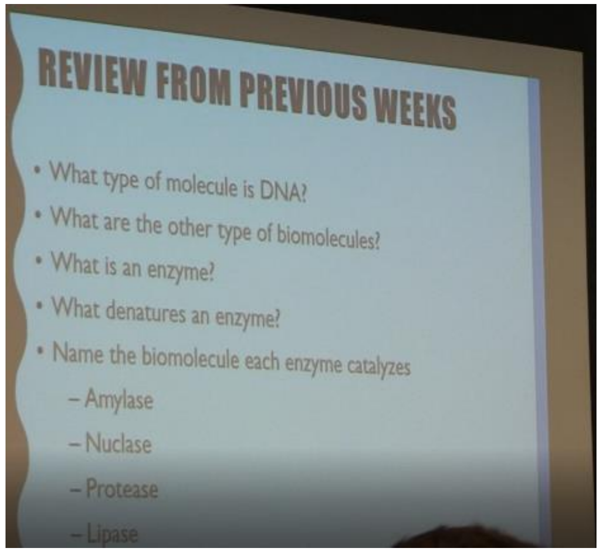


Figure 11. Video still of Aesara's introduction for the lesson on DNA extraction and mitosis.

Use a team approach. In all the lessons observed, Aesara incorporated teamwork the majority of the time. She numbered the tables and would encourage the participation of all team members during laboratory activities, as noted in the following excerpt:

> These are Punnett squares. I am assuming that you guys have seen these before. So, we're going to do some little problems on pages 83 and 84. As a table, I want you to go through and work on these problems. So, you will work together as a table to come up with the answers to these problems, and then I will work them on the board. (Aesara, Genetics Laboratory Lesson, March 27, 2019).

After group work, Aesara would bring all students together to review and highlight what she thought were important aspects of the content.

Do not emphasize the memorization of technical vocabulary. There were a few of the observed laboratory lessons where there was much emphasis on defining and learning specific biology terms. One example was the lesson on Human Genetics. Aesara noted that some lessons require to go over a lot of vocabulary before engaging students in the activities. For example, during her VSR interview on the lesson on Genetics, when asked about the various strategies that she used during the lesson, Aesara stated,

> There are some concepts that students may get hung up on about. You know, the difference between antigen and antibodies and understanding dominance and recessive and what that means in a population. Dominant and recessive alleles just trying to target areas where students may have common misconceptions or confusion about things. So that's what I take into consideration like breaking down those particular areas and I spend some time on these terms and what they mean. I find illustrations to be easier to digest. We can just take it step-by-step instead of using the chart. Often, it is just one chart with a lot of information, and you have to kind of break it down. But visually, if you start with the blank and then you just add one piece at a time, students can kind of go with you at that pace. So that's why I did that was to just kind of break it down step by step as to how these related to each other and just what the role of each term was to try to make it easier for them to memorize and understand. (Aesara, Genetics Laboratory Lesson VSR Interview, March 28, 2019)

From this except, Aesara explained her instructional practice of emphasizing the memorization of technical vocabulary. The explanation provided in this except also disclosed that Aesara believed that memorization leads to understanding and that different ways of presenting the material for memorization make it easier for students to understand various concepts.

Concentrate on the collection and use of evidence. Laboratory lessons typically involved activities associated with the content material such as experiments. Not all the activities for lessons observed included students collecting data. For example, during the laboratory lesson on Fermentation, the *Quantifying Gas Production in a Fermentation Tube* activity required data collection. Students measured the amount of gas released during the fermentation process and noted it in their laboratory manuals. Aesara briefly went through the results without input from the students and noted while pointing to the results on the whiteboard,

> So, this is what you are looking at to see. Boiled yeast did not yield anything, and the alcohol didn't yield anything. These are the results that you are looking at to see at the end of the 20 minutes how much CO_2 was actually produced and how did that affect everything using those variables. This is what you are comparing right here, and this is the evidence that you will use for the question on page 58 to explain to your neighbor– this is what I think will happen if you either add vinegar or you need to change it up by adding alcohol and maybe do something different. This is the evidence that you're using. (Aesara, Fermentation Lesson, March 27, 2019).

Aesara instructed students to write down their own interpretations and explanations and hand in the completed work. During the VSR interview on the Fermentation lesson, Aesara was asked about the decision to teach the activity in this manner, and she admitted that there was not enough time to ask students to discuss. She stated that in order to ensure that students had some understanding and make a connection between the experiment and the content, she went through the results herself. In other cases, for instance, when she was conducting a demonstration, Aesara encouraged students to provide interpretations for results. This was evident in the *Yeast and Gas Production in a Glove* activity that Aesara demonstrated in order to show students that an organism like yeast produces CO_2 as humans do, as well as during an exercise where students extracted DNA from a strawberry.

Insist on clear expression. Although Aesara engaged students in the practice of discussing results, she did not emphasize students' need for clear expression during oral presentations and discussions. Aesara acknowledged that since the students were not involved in designing their own experiments, students were not required to explain their procedures, findings, or defend their work to others. As such, Aesara did not emphasize clear expression.

Do not separate knowledge from finding out. The issue of laboratory curriculum not requiring students to design their own experiments also impacted Aesara's instructional actions regarding not separating knowing from finding out. She explained that it was challenging to help students acquire scientific habits of the mind and make them realize that in science, methodologies and procedures that lead to these conclusions and increased knowledge in science were closely related. Based on her perspectives about the laboratory curriculum, Aesara posited that it was easier to follow the teaching approach that imparted the accumulated knowledge in science to students.

Provide a historical perspective. Regarding the final science teaching practice – providing a historical perspective, Aesara was not observed enacting this instructional practice. When questioned about how she presented the content to students, Aesara posited that she was a supporter of constructivist teaching and learning but felt obligated to focus mainly on the information that was provided by the department. Aesara noted,

> I think that you know the expectation set before us is to teach the lab that we've been provided using the resources that we've been provided and to follow the sequence of that. I feel like it has to be – we have to utilize the resources and the manual and everything that's been already paid for and designed for this lab. (Aesara, Fermentation VSR Interview, March 1, 2019)

This excerpt disclosed that since the teaching materials (e.g., PowerPoint presentations) had already been prepared and followed a specific format, the expectation was that these resources be used without the need for changes. It was observed that the PowerPoints for lessons included, to some extent, content material that facilitated making connections to historical aspects. For example, during the lesson on genetics, there were aspects involving Gregor Mendel's laws of inheritance, as noted in Figure 12, a snippet of a slide from the PowerPoint provided by the biology department highlighting the content material provided. However, it was left up Aesara to highlight the historical aspects that connected to the lesson and its various activities.

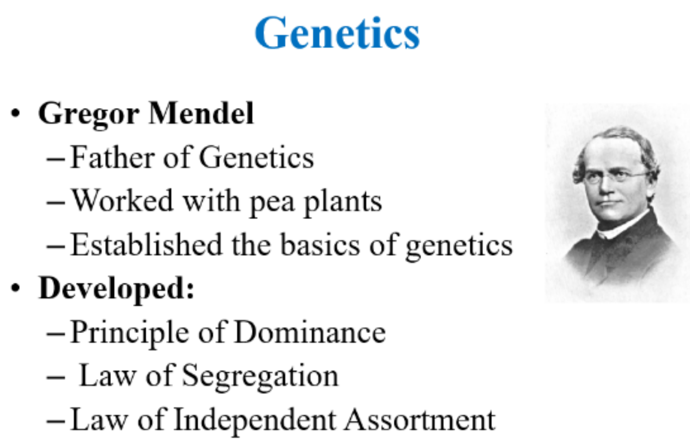


Figure 12. A video still of a selected slide of the PowerPoint presentation from Aesara's lesson on Human Genetics.

Aesara opted to briefly read the information provided in the slides without providing students with the opportunity to discuss and develop a sense of the growth of Mendel's scientific ideas and the twists and turns on the way to our current understanding of Mendel's work.

Frequency of Aesara's science instructional practices. During the four observations, Aesara completed a total of 13 activities with her students, during which time she demonstrated the use of many of the science instructional practices as recommended by the AAAS. The frequency of the use of each science instructional practice was calculated and is shown in Figure 13. Calculation of the frequency of science instructional practice was calculated by:

1. noting the science instructional practices that were demonstrated during the teaching of each activity,
2. tallying the total number of activities completed in each lesson, and
3. calculating the frequency (%) of the demonstration of each science instructional practice by dividing the sum of each science instructional practice by the total number of activities per lesson and multiplying by 100.

For example, Aesara completed a total of 12 activities during the four lessons for which she was observed. She employed the use of the science instructional practice, *do not separate knowledge from finding out*, four out of the 12 times. The frequency of demonstration of this science instructional practice was calculated as : $\frac{4}{12} \times 100 = 42\%$.

Therefore, Aesara employed the science instructional practice, do not separate knowledge from finding out, 42% of the 12 activities observed.

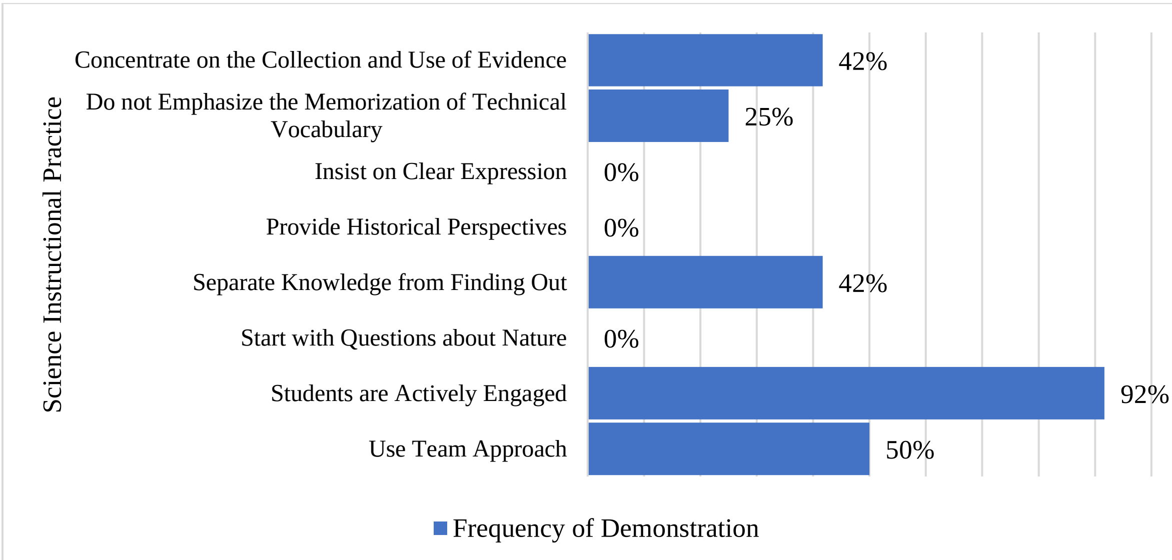


Figure 13. Frequency of the demonstration of the science instructional practices by Aesara.

The most frequently demonstrated science instructional practice was *students are actively engaged* (92%), followed by, *use a team approach* (50%), *do not separate knowledge from finding out* (42%), *concentrate on the collection and use of evidence* (42%), and lastly, *do not emphasize the memorization of technical vocabulary* (25%). Observations of Aesara's laboratory lessons showed that she did not employ three of the science instructional practices at any time during the four laboratory lessons observed. These three science instructional practices were: *start with questions about nature*, *provide historical perspectives*, and *insist on clear expression*. It must be noted, however, that although Aesara did not begin any of her observed lessons with questions about nature, she did begin each lesson with content-related questions. For example, for her lesson on DNA Extraction and Mitosis, Aesara began by asking, "Okay, table one, what type molecule is DNA?" (Aesara, DNA Extraction and Mitosis Lesson, March 13, 2019). Therefore, it can be said that questioning was a vital part of the introduction of Aesara's laboratory lessons. Following this discussion of results on Aesara's science instructional practices, the next section presents the findings that indicate the nature of the relationship between the features of her professed beliefs and science instructional practices.

Aesara: Relationship between Aesara's Features of Epistemological Beliefs and Science Instructional Practices

This section presents information regarding the instances where the professed features of Aesara's epistemological beliefs, although aligned with the recommendations of the AAAS (1993, 2011), contrasted with her science instructional practices. The data that were used to analyze for the relationship between the features of GTAs' professed epistemological beliefs and their science instructional practices included the GTAs' beliefs interviews, video recordings, and field notes from the laboratory lesson observations, and video stimulated recall interviews. Analysis of the data revealed mismatches—misalignments—between the features of Aesara's epistemological beliefs and the science instructional practices recommended by the AAAS (1993, 2011). A misalignment describes Aesara's demonstration of a science instructional practice that portrays her thoughts and actions in the laboratory that contradicted or opposed the recommendations of the AAAS (1993, 2011). That is, based on Aesara's proclamations, observations of her instruction should have reflected certain claims that aligned with the recommendations of the AAAS, but instead, these claims were not observed during her instruction. The recommendations of the AAAS (1993, 2011) highlighted eight practices of teaching that are proposed to be consistent with the nature of inquiry and provide students with the kinds of experience that will enable them to understand science as a way of thinking and doing. The sections that follow present the misalignments under the categories: epistemological beliefs in general, epistemological beliefs about the nature of science, and beliefs about teaching.

Misalignments between Features of Epistemological Beliefs and Science Instructional Practices

Epistemological beliefs in general and science instructional practices.

***Aesara's beliefs about the* changeability of knowledge *and the science instructional practice* do not separate knowledge from finding out.** The data indicated a connection between Aesara's epistemological beliefs regarding the *changeability of knowledge* and the scientific instructional practice *do not separate knowing from finding out.* According to the AAAS (1993, 2011), science instructors should not separate knowledge from finding out but, instead, should help students acquire both scientific knowledge of the world and scientific habits of mind at the same time.

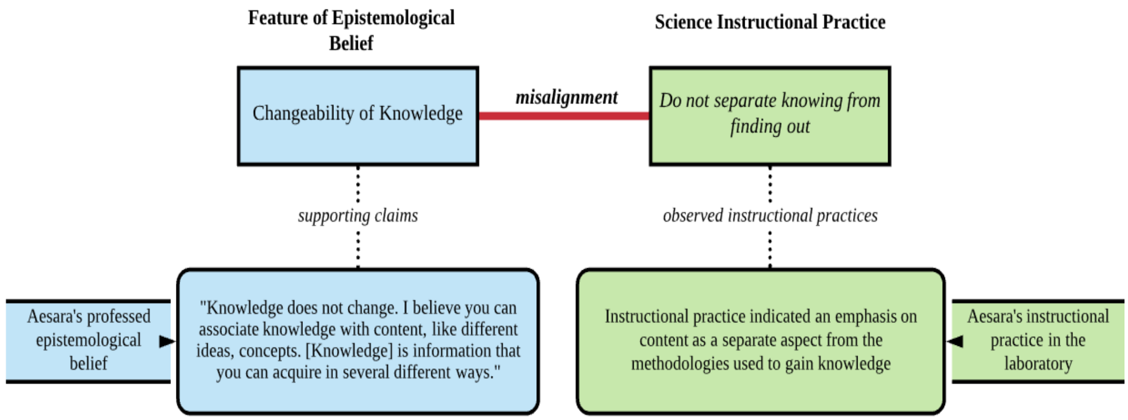


Figure 14. Relationship between Aesara's epistemological beliefs about the *changeability of knowledge* and the enactment of the scientific practice *do not separate knowing from finding out*.

Aesara believed that knowledge does not change, but rather it is an individual's understanding of a piece of knowledge that changes. She further added that students should be provided with ample opportunities in the laboratory to understand the biology content material. According to Aesara, "knowledge I believe you can associate with content, like different ideas, concepts. [Knowledge] is information that you can acquire in several different ways" (Aesara, Plant and Animal Reproduction VSR Interview, April 17, 2019). In her attempt to facilitate a deeper understanding of the biology laboratory material, Aesara separated knowledge from finding out by focusing on the content as a separate knowledge component from the methodologies that were used to gain that accumulated knowledge. Aesara used different methods to deliver the content material to students (e.g., concept maps, charts, analogies, illustrations) to ensure that students understood the concepts. However, she rarely highlighted the methods of investigations employed during the laboratory activities and how what is being investigated and what is learned depends on the methods used. Based on Aesara's beliefs regarding the changeability of knowledge, it can be inferred that Aesara viewed methodologies and the various means of scientific investigations as not being a significant aspect of the content knowledge that should be learned since scientific methods vary and change with time. This inference was supported by Aesara's claim that "knowledge does not change, but it is the understanding of a piece of knowledge is what changes." Here, the association between *changeability of knowledge* and *do not separate knowledge from finding out* represents a misalignment between epistemological belief and science instructional practice (represented by the red arrow in Figure 14).

***Aesara's beliefs about the* structure of knowledge *and the science instructional practice* de-emphasize the memorization of technical vocabulary.** Another connection that was revealed by the data analysis of relationships between features of epistemological beliefs and science instructional practices was a connection between the *structure of knowledge* and *de-emphasize the memorization of technical vocabulary*. This relationship is highlighted in Figure 15.

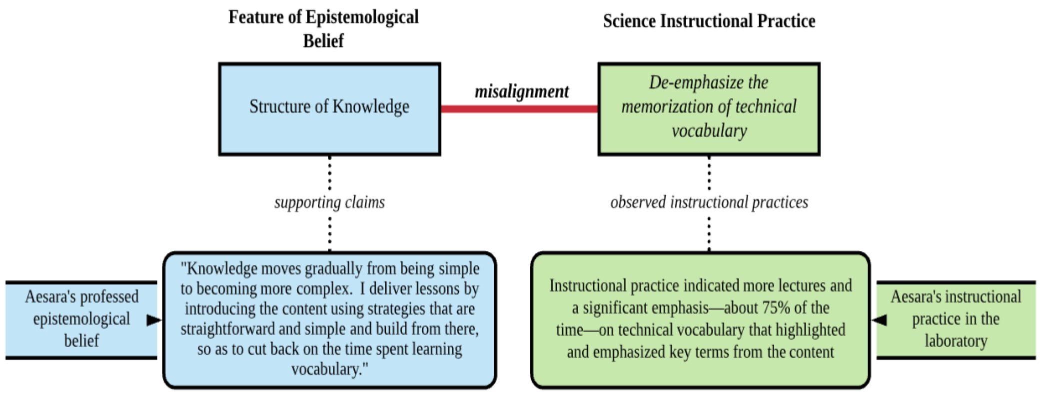


Figure 15. Relationship between Aesara's epistemological beliefs about the *structure of knowledge* and the enactment of the science instructional practice *de-emphasize the memorization of technical vocabulary*.

Aesara believed that knowledge moved gradually from being simple to becoming more complex and that some subject areas were more complex than others. For example, Aesara posited that the lesson on Human Genetics was one that was complicated and entailed a lot of technical terms that students were required to know and understand in order to be able to engage in the laboratory activities. To help facilitate understanding, Aesara acknowledged that she needed to spend more time "providing students with opportunities that would clarify thinking and conceptual understanding" (Human Genetics VSR Interview, March 28, 2019). In support of her views on the complexity of knowledge, Aesara expressed that she delivered her lessons by "introducing the content using strategies that are straightforward and simple and build from there, so as to cut back on time spent learning vocabulary" (DNA Extraction and Mitosis VSR Interview, March 13, 2019). However, Aesara's instruction indicated more lectures and a significant emphasis—about 75% of the time—on technical vocabulary that highlighted and emphasized key terms from the content. Therefore, deducing from Aesara's claims and relating these claims to her instructional practice, it was assumed that there was a misalignment between her views on the *structure of knowledge* and the science instructional practice *de-emphasize the memorization of technical vocabulary* (Figure 15).

***Aesara's beliefs about the* justification of knowledge *and the science instructional practice* concentrate on the collection and use of evidence.** Data analysis showed that there was a misalignment between Aesara's views on the *justification of knowledge* and the science instructional practice *concentrate on the collection and the use of evidence*. Aesara believed that in order for knowledge in science to be reliable and acceptable, there were procedures and means of assessments that warrant knowledge claims. Aesara noted, "I think scientific knowledge comes from a collection of evidence that makes information authentic" (Aesara, GTA beliefs interview, January 8, 2019). However, although Aesara held such strong beliefs about the role of evidence in science and how evidence was used to support scientific knowledge, her emphasis on the collection and use of evidence was only 42% of instruction time (observed) as indicated by Figure 13. This was not reflective of the vigor of her firm, professed beliefs concerning the value of evidence in science. This indicated a misalignment between beliefs about the *justification of knowledge* and the science instructional practice *concentrate on the collection and use of evidence* (Figure 16).

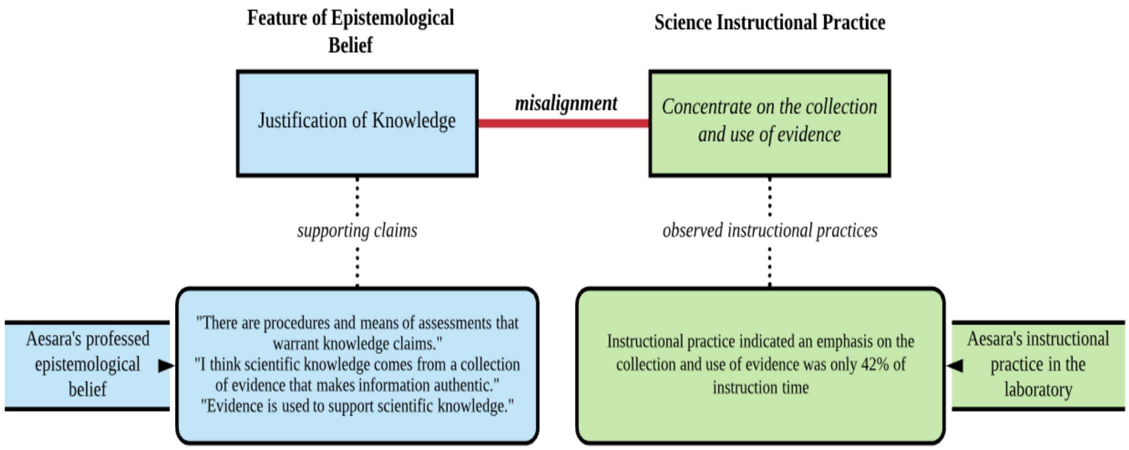


Figure 16. Relationship between Aesara's epistemological beliefs about the *justification of knowledge* and the enactment of the science instructional practice *concentrate on the collection and use of evidence*.

Epistemological beliefs about the nature of science and science instructional practices.

***Aesara's beliefs about* science is based on empirical evidence *and the science instructional practice* concentrate on the use and collection of evidence.** Data analysis showed a misalignment between the feature of epistemological beliefs about NOS, *science is based on empirical evidence* and the science instructional practice *concentrates on the collection and use of evidence* (Figure 17).

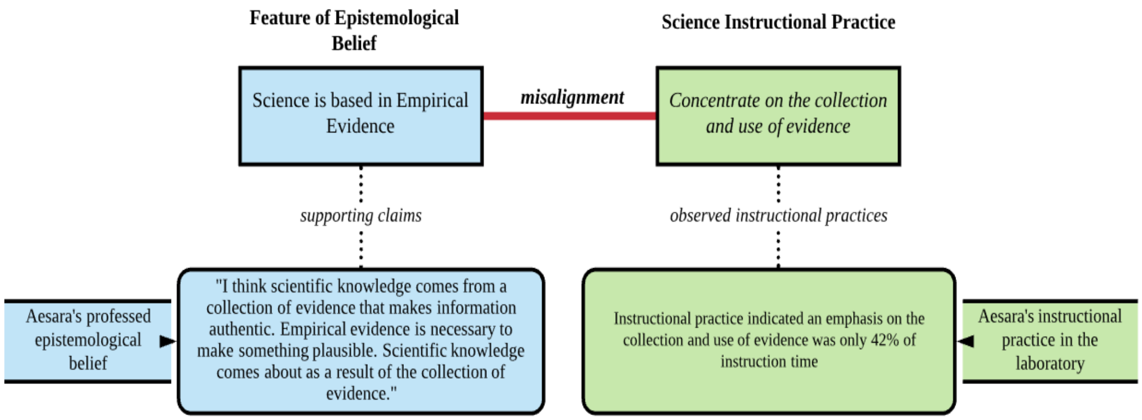


Figure 77. Aesara's epistemological beliefs about *science is based on empirical evidence* and the enactment of the science instructional practice *concentrate on the collection and use of evidence*.

As noted in the previous section, Aesara was very insistent about her epistemological beliefs concerning the role of evidence in science. This strong position was particularly prevalent during the discussion of scientific knowledge in the teaching and learning of science. Aesara noted, "I think scientific knowledge comes from a collection of evidence that makes information authentic. Empirical evidence is necessary to make something plausible. Scientific knowledge comes about as a result of the collection of evidence" (Aesara, GTA beliefs interview, January 8, 2019). However, once again, Aesara's instructional practice, in the instances where students collected data, rarely focused on the way data was collected or allowed students to decide what evidence was relevant and offer their own interpretations of what the evidence meant. As such, it was deduced that there was a misalignment between Aesara's professed epistemological beliefs regarding *science is based on empirical evidence* and the science instructional practice *concentrate on the collection and the use of evidence instructional practice*.

Beliefs about teaching and science instructional practices.

***Aesara's beliefs about* how to teach *and the science instructional practice* use a team approach.** Findings indicated a mismatch between Aesara's beliefs about *how to teach* and the science instructional practice *use a team approach*. According to Aesara, "science is all about group work" (GTA beliefs interview, January 8, 2019). Aesara indicated that as a K-12 student doing science, it was always hands-on, no textbooks, and a lot of group work. In her own words, Aesara declared,

> I think I fell in love with science in high school. It was just – it was a lot of things that I could ask questions about and explore with teammates. It wasn't – you know, English is reading, writing. Math is numbers. But science is like, you can do and wonder about so many different things both alone and together as a group, and so I kind of fell in love with that aspect of science in high school, working with others to discover things. (Aesara, GTA beliefs interview, January 8, 2019)

In this excerpt, Aesara explained how she came to fall in love with science, and one of the reasons included working with teammates to discover and learn things in science.

Regarding the aspect of *how to teach science*, Aesara also explained that she thought that group work was the better way to engage students in the teaching and learning of science. In describing the various strategies that she employed in her instruction, Aesara stated,

> I have done turn-and-talk-to-your-neighbor kind of group activities where let's discuss this before we discuss it as a whole class. Kind of pair-share things. I have mainly a lot of group work and table work. So, I've tried to modify some of the labs to where each group member may have a role or something, and they're all responsible. Because I had somebody – last semester, I had a group that had a student that was very much kind of off to himself and didn't really do a lot. So, I had to give them different roles and stuff. And so, they would all have their own responsibilities, and therefore it kind of motivates them to participate and interact with each other. (Aesara, GTA beliefs interview, January 8, 2019)

This declaration by Aesara disclosed that group work was a regular part of her instruction. However, during Aesara's instruction, this proclamation was not fulfilled. Based on the observations of four of her laboratory lessons, students were engaged in group activities for about 50% of the lesson (Figure 12). Therefore, this presented a misalignment between Aesara's beliefs about *how to teach* and the enactment of science instructional practice *use a team approach* (Figure 18).

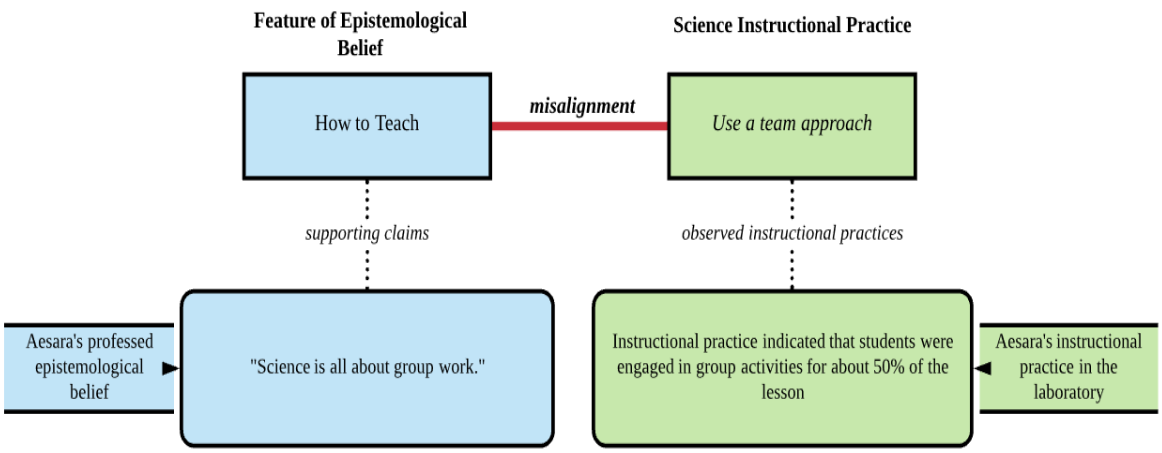


Figure 18. Aesara's epistemological beliefs about *how to teach* and the enactment of the science instructional practice *use a team approach*.

Summary of misalignments between Aesara's professed features of epistemological beliefs and science instructional practices. Regarding Aesara, the data revealed that there were four misalignments between features of epistemological beliefs and recommended science instructional practices of the AAAS (1993, 2011). Misalignments represented the instances where there was a mismatch between the features of Aesara's professed epistemological beliefs and her science instructional practices. For example, Aesara's professed epistemological beliefs aligned with the ideas of the AAAS, but these beliefs were not visible during her science instructional practices in the laboratory. The science education reform document issued by the AAAS (1993, 2011) recommended eight practices of teaching considered to be consistent with the nature of inquiry that facilitate the kinds of experience that students need to enable them to understand science as a way of thinking and doing.

According to the findings, Aesara's professed epistemological beliefs, although they harmonized with the recommendations of the AAAS (1993, 2011), were not demonstrated during her teaching episodes in the laboratory. In summation, the analysis of results specific to the features of Aesara's epistemological beliefs and her science instructional practice identified five misalignments between the two constructs. These misalignments are reiterated in Figure 19, which highlights the categories of epistemological beliefs and their respective features and the science instructional practices to which they were mismatched.

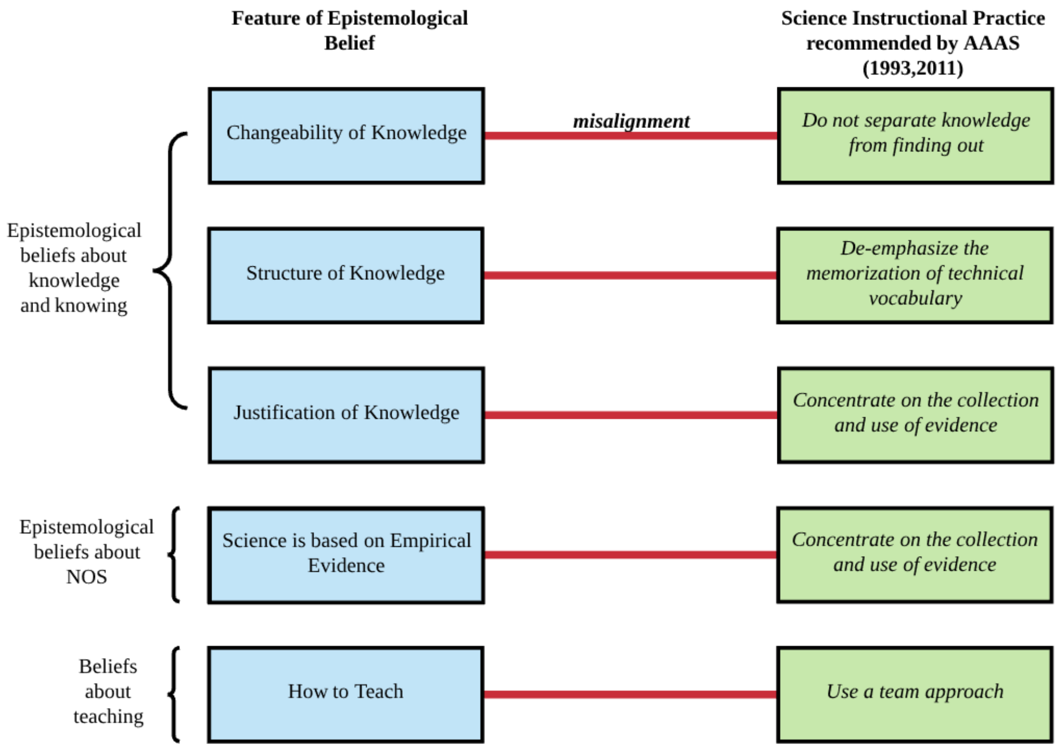


Figure 19. Misalignments between Aesara's professed features of epistemological beliefs and science instructional practices recommended by the AAAS (1993, 2011).

Alignment between the Professed Features of Epistemological Beliefs and Science Instructional Practices

The data were also analyzed to consider the alignment between the professed features of epistemological beliefs and the science instructional practices as recommended by the reform document issued by the AAAS (1993, 2011). That is, Aesara's thoughts and actions aligned with the propositions of the AAAS regarding the teaching and learning of science, and these beliefs were demonstrated during her instructional practice. Findings indicated that there was a positive association—alignment—between the features of Aesara's professed beliefs about teaching and science instructional practices. Figure 20 highlights the positive associations between Aesara's beliefs about teaching, specifically regarding the features of epistemological beliefs on *how to teach* and the science instructional practices *students are actively engaged.*

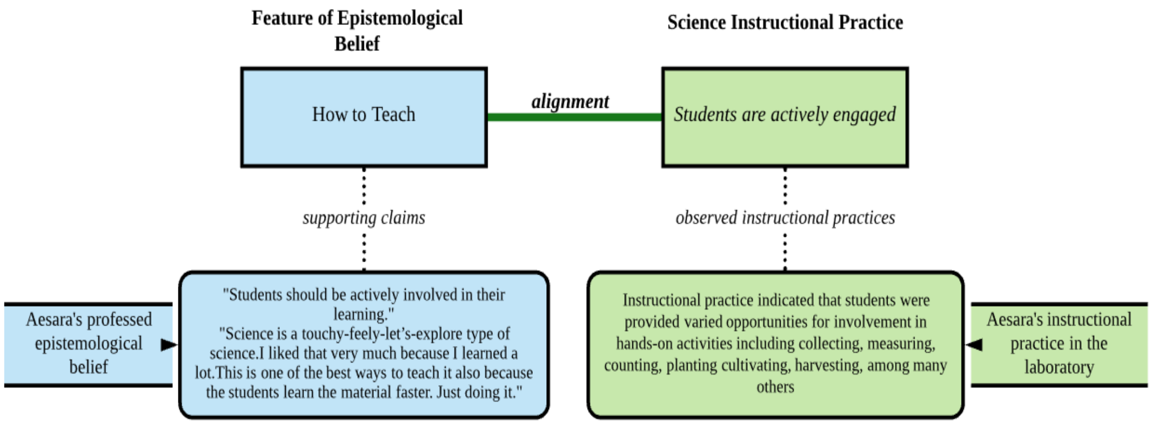


Figure 20. Relationship between Aesara's features of epistemological beliefs about *how to teach* and the enactment of the science instructional practice *students are actively engaged*.

Epistemological beliefs about teaching and science instructional practices.

How to teach and students are actively engaged. Some findings indicated a positive association between Aesara's professed epistemological beliefs regarding *how to teach* and *students are actively engaged.* Observations of Aesara's laboratory lessons showed that students were provided varied opportunities for involvement in hands-on activities including collecting, measuring, counting, planting, cultivating, harvesting, among many others. For example, Figure 21 shows a snapshot of Aesara's students counting the number of planaria that had regenerated in their petri-dishes after specific types of cuts.

Figure 21. A snapshot of a student actively engaged in counting the number of regenerated planaria in a petri-dish.

Additionally, Aesara expressed that she believed that students should be actively involved in their learning. Further, she believed in that type of teaching since this is how science was introduced to her and one of the reasons why she fell in love with the subject. According to Aesara,

> In high school my early memories are the classrooms were set up as labs – it was just one room. So, we did the experiments and the teaching part altogether. It wasn't a separate thing. Like, I didn't go to a separate lab so it was all, you know, as he was talking – one of my teachers was a male – as he was talking about things, we would do an experiment maybe later on about it. Or it was all kind of integrated into each other. It was a Paideia school. So, it was very much – we had a lab experiment, we got to dissect things: frogs, a cow heart. It was very much a touchy-feely-let's-explore type of science. I liked that very much because I learned a lot. This is one of the best ways to teach it also because the students learn the material faster. I think that going outside, doing things – I think that touching stuff, looking at weird things and asking questions about it or figuring out your human body really does that, you know? Like, I feel like all that stuff is a way that we learn and teach about science and what it is. Just doing it. Experiment. Experimenting. (Aesara, GTA beliefs interview, January 8, 2019)

This excerpt disclosed that Aesara enjoyed learning via participating in hands-on activities and also thought that this was one of the best ways to teach as well. It can also be inferred that her instructional practice reflected the teaching and learning experience that she had as a high school student.

Summary of alignments between features of Aesara's epistemological beliefs and science instructional practices. The findings of this study identified only one positive association between Aesara's professed features of epistemological beliefs and science instructional practices. This positive association was referred to as an alignment between professed epistemological beliefs and instructional practice described an occurrence where Aesara's science teaching practices reflected the recommendations of the AAAS (1993, 2011). In other words, her teaching practices incorporated some of the eight practices of teaching believed to be consistent with the nature of inquiry and will provide students with the kinds of experience that will enable them to understand science as a way of thinking and doing. The only alignment specific to Aesara was found to be between her beliefs about *how to teach* and the enactment of the science instructional practice *students are actively engaged*.

Aesara: How Complexity Theory Describes the Interrelatedness between the Features of Aesara's Epistemological Beliefs and Science Instructional Practice

Complexity theory is the study of complex systems and is defined as a collection of individual agents with freedom to act in ways that are not always totally predictable, and whose actions are interconnected so that one agent's actions changes the context for other agents. Complexity theory emphasizes relationships among the subparts of a system and the emergence of something new. One of the key ideas of complexity theory and education, which is particularly relevant to this study, is that many aspects of education, including classrooms, can be viewed and understood as a complex system. The philosophy of complexity is that complex systems such as the classroom have properties—emergent properties—that cannot be reduced to the sum of their mere parts and look at each individual component. Instead, to understand the behavior of such systems, it is more favorable to consider the components while concentrating on the interactions between the various components. Complex systems have several characteristics that typify complex systems, including self-organization, emergence, non-linearity, connectivity, and autonomy and adaptation. This section uses these characteristics to explain the connections between professed epistemological beliefs and science instructional practice specific to the data on Aesara's laboratory as a complex system. The data analysis pertaining to Aesara's classroom system, specifically regarding the features of epistemological beliefs and science instructional practices, displayed three attributes of the complexity theory: *self-organization*, *non-linearity*, and *interconnectedness*. These attributes are discussed in the sections that follow.

Self-Organization

Self-organization can be defined as the spontaneous emergence of an organized structure due to the local interactions of individual components of a complex system. Spontaneous, in this case, can mean that in a system, any individual component can be eliminated, changed, or replaced without any damage to the overall or resulting structure of the system. Self-organization creates order out of disorder, is responsible for the patterns, structures, and arrangements that are found in a system and gives rise to the emergence of new levels of organization within that system. In this case, Aesara's laboratory is considered a system.

There were instances when there was an unplanned or unexpected reorganization of Aesara's teaching. For example, during Aesara's laboratory on DNA Extraction and Mitosis, there was an activity based on the stages of mitosis where students used the microscope to look at slides showing the various phases of mitosis. Aesara noted that she had initially planned for students to work individually to look at the slides and make a drawing in their laboratory manuals of what they were seeing. However, during the activity, she discovered that there were several non-functioning microscopes. According to Aesara,

> So, I think in theory - I think it's very good for them to actually look at organisms, right for them to look at things through a microscope to get that skill set of what scientists actually do and they actually look at things that we can't see with our naked eye, right? That gives leeway to scale and so forth. I think there were a lot of difficulties like this lab this class in particular- was a lot more difficult than my other classes because there were a lot of microscopes that were hard to focus. So, there was a lot that I had to either spend a lot of time trying to focus whereas in times past, I could help them really quickly and then go to another student and help them and so forth. Whereas this one I had to spend a significant amount of time trying to help them focus and still some of them like two or three of them I didn't get focused. And so, I felt that this one was a little more difficult to navigate because of the quality of the lens. So I tried to say you know, 'if somebody at your table sees something on their slide and their microscope is working fine – like if you have an onion root [slide] and this other person has a whitefish [slide] then you go look on theirs because they had a good quality.' In that way by working together, so they can at least still see it, you know. (Aesara, DNA Extraction and Mitosis VSR Interview, March 15, 2019)

Here, the spontaneous reorganization of the activity from students working individually to working as a group indicated a change that did not reflect Aesara's belief regarding teaching and learning with the microscope, where Aesara's core belief was that students needed to work independently in order to master the laboratory skill of using the microscope. The change in instruction from working alone to working in groups did not reflect Aesara's professed and core belief and highlighted spontaneous change that was required to maintain the stability of the classroom system.

Non-linearity

Non-linearity in a complex system describes discrepancies between inputs and effects where small changes can have striking and unanticipated effects. In contrast, great stimuli may not always lead to drastic changes in a system's behavior. When effects are smaller than the causes, it is referred to as negative feedback, and the reverse is denoted as positive feedback. The dynamics of a complex system typically exhibit both negative and positive feedback.

The case of non-functional microscopes and slides during Aesara's DNA Extraction and Mitosis laboratory revealed positive feedback in her laboratory system and highlighted the aspect of non-linearity. The unexpected case of malfunctioning microscopes was a significant enough to cause a shift in Aesara's science instructional practice where she had to make the instructional decision to assign teamwork and to be uneasy about the fact that some students might never get an opportunity to work with the microscope in the way that would facilitate learning. Here, a small cause led to a large effect. The effect, in this case, also stimulated an instructional action that countered Aesara's epistemological beliefs. According to Aesara,

> Well, if I do this again then I probably would ask the students to do it to make it go quicker to ask them to clean both the lens and the thing – but it's just it's unfortunate because I know there's some students that didn't see anything and I didn't have time to get to them. Like I know for sure there was at least one student that he even traded out his microscope, and I still didn't have time to come back to him. (Aesara, DNA Extraction and Mitosis VSR Interview, March 15, 2019)

This excerpt disclosed that a few non-functional microscopes had significantly impacted teaching and learning. Aesara's laboratory circumstance showed the presence of positive feedback where a small cause (non-functional microscopes) led to the amplified effect that affected teaching and learning. The interactions between professed features of epistemological beliefs (*how students learn* and *structure of knowledge*) and science instructional practice (*use team approach*) showed fluctuations in terms of stability of the system where the last portion of Aesara's lesson seemed disrupted as she rushed to help students with their microscopes, realizing that she was not able to assist everyone. The display of non-linearity, in this case, amplified the effect of the interactions of the two components of the laboratory system – beliefs about teaching and science instructional practice.

Interconnectivity

Within complex systems, interactions between components show connections. Analysis of findings revealed the interconnections between Aesara's professed beliefs and science instructional practices, primarily in the instances where there were both misalignments and alignments between the two constructs. For example, the interconnection between professed epistemological beliefs and science instructional practice was revealed in Aesara's belief about *how to teach* and her demonstration of the science instructional practice *students are actively engaged.* Aesara's instructional practice was observed to reflect her belief about providing students with ample opportunities to be engaged and get hands-on science learning experiences.

Summary of the Complexity Theory and its Interrelatedness to the Features of Aesara's Epistemological Beliefs and Science Instructional Practice

Aesara's professed epistemological beliefs and science instructional practice were part of a complex system, the laboratory as a classroom. These two constructs, as part of any complex system, interacted with each other, and displayed characteristics that were specific to the nature and type of system. In Aesara's case, three characteristics of the complexity theory were highlighted as a result of the interactions and interrelatedness of her features of epistemological beliefs and science instructional practices. These characteristics were *self-organization, non-linearity,* and *interconnectivity*. Self-organization of the system depicted a change in the system specific to instruction while non-linearity occurred when small changes like that of the non-functional microscopes led to greater than expected effects in the teaching and learning process in the laboratory. Interconnectivity described the interaction between the components—professed epistemological beliefs and science instructional practice—and how these interactions were used to describe the nature of these interactions. That is, whether there were alignments or misalignments between the two constructs.

Batis: Professed Features of Epistemological Beliefs

Epistemological Beliefs in General (Knowledge and Knowing)

An individual's general epistemological beliefs about knowledge and knowing are concerned with how that individual comes to know what he or she knows, as well as the process of knowing. In this section, the subdimensions of domain-general epistemological beliefs that are referred to as the core dimensions of epistemological beliefs, according to Hofer and Pintrich (2002), are used to describe the features of Batis' professed epistemological beliefs. These core dimensions are the changeability of knowledge, structure of knowledge, source of knowledge, and justification of knowledge.

Changeability of knowledge. Regarding the changeability of knowledge, Batis acknowledged that knowledge could change over time, and he emphasized how the experiences of individuals are framed by existing knowledge. Although Batis recognized the place of experience in changing knowledge, his perceptions also extended to include the roles and responsibilities of an individual in society and the inception of necessary change in one's knowledge based on their societal roles and responsibilities. Batis stated,

> [Knowledge] changes. You have to be part of society. You have to be in a society, you play different roles, but over time, you require different knowledge or skills to be qualified or to be good at that role. Like a worker, like a father. So, knowledge definitely changes. (Batis, GTA beliefs interview, January 8, 2019)

In this excerpt, Batis acknowledged that the various roles of individuals in society directly influence a change in knowledge, and this is necessary for individuals to excel in these particular roles. This revealed that Batis held high regard for the influence of various roles and responsibilities and that as roles and responsibilities changed, so did knowledge. This was supported by Batis' claims that a first-time parent, more specifically a father, would gain new knowledge about how to take care and raise a baby, implying that this was new knowledge that did not exist before.

Justification of knowledge. In explaining his belief regarding how individuals evaluate and warrant knowledge claims, Batis believed that one should rely on verification from the content of textbooks and other persons who have attained degrees via higher education. From his standpoint, Batis stated,

> Well, I think if the knowledge is consistent with the textbook, it probably is right. Yes, [textbooks] still have authority for me. That's kind of like a proof. I also

> talk to my peers if I got an opportunity. I talk to the professor. So, I get justification from people around me, too. (Batis, GTA beliefs interview, January 8, 2019)

This excerpt disclosed that Batis believed that the authority and experts (e.g., the authors of textbooks) were sources on which individuals could rely to verify and justify knowledge. Batis also attributed verification of information from persons with whom he interacted. This also revealed that experts and authority were not the only ones capable of evaluating and warranting knowledge claims, but laypersons could just as well.

Source of knowledge. In his description of where knowledge comes, Batis explained that he would like to use his experiences to establish his position. Considering his knowledge-development process, Batis asserted that the sources of his knowledge were teachers and textbooks. Also, considering his cultural background, Batis described his experience as an English language learner broadened his source of knowledge to more than just teachers and books. He also identified social media and interactions with others as sources of knowledge. For Batis, social interactions were pivotal to the knowledge-construction process. Batis mentioned that "conversations with others are a valid source of information, especially since those interactions enabled me to develop my knowledge of the English language" (GTA beliefs interview, January 8, 2019). Once again, based on Batis' claims, it was disclosed that both the individual—self—and outside sources served as sources of knowledge. Batis' proclamations also implied that he did not place much importance on the credibility of the information that came from various sources. For example, Batis stated,

> My English knowledge came from so many places – so it's like watching TV – TV shows like Friends, like Big Bang Theory. And also, I interact with people,

> like going to church, like going to a class, you know. Knowledge can come from many places as I said. (Batis, GTA beliefs interview, January 8, 2019)

Structure of knowledge. Batis acknowledged that knowledge is, at times complex and can be related to an individual's search for truth. He purported that the search for truth was linked to survival and satisfaction as well as pertained to the curious nature of individuals. Batis further alleged that the inquisitive nature of individuals drives them to search for knowledge, which is not simple. According to Batis, "people are more inclined to accept simple knowledge because it is easier to understand, but their curious nature causes them to search some more and gain a more complex understanding of things" (GTA beliefs interview, January 8, 2019). Batis' claim disclosed that an individual's structure of knowledge is dependent upon what the search for what is true.

Summary of Batis' features of professed epistemological beliefs. During the GTA beliefs interview, Batis expressed his views regarding the four main areas of epistemological beliefs in general, regarding the nature of knowledge and knowing. Table 17 provides a synopsis of the features of Batis' epistemological beliefs regarding the nature of knowledge and knowing. The section which follows discusses Batis' professed beliefs about the nature of science.

Table 17

Summary of Batis' Professed Epistemological Beliefs about the Nature of Knowledge and Knowing

Feature of Epistemological Belief	Proclamation regarding belief about the nature of knowledge and knowing
Changeability of Knowledge	Knowledge changes over time.
Justification of Knowledge	Both self and others justify knowledge.
Source of Knowledge	Both authorities and self is a source of knowledge.
Structure of Knowledge	Knowledge structures are complex.

Epistemological Beliefs about the Nature of Science (NOS)

Hurling (2014) posited that if you are studying a person's scientific epistemological beliefs, then you are studying their views of NOS. Epistemological beliefs about the study of scientific knowledge or NOS are related to the study of science as a way of knowing. According to Lederman (1992), NOS has its own specific set of values and beliefs that characterizes it as scientific. These characteristics, as described by science education experts who specialize in research on NOS (e.g., Ackerson, Abd-El-Khalick, F., & Lederman, 2000; Abd-El-Khalick, Bell, & Lederman, 1998; Hodson, 2014), were used to determine Batis' epistemological beliefs regarding NOS. Only the characteristics professed during the GTA beliefs interview with Batis are discussed in the sections that follow.

Science as a way of knowing. Science as a way of knowing describes science as a body of knowledge that is based on scientific inquiry and practices that are governed by logic, evidence, and reasoning. Batis purported that science is a way of knowing that differs from religion and philosophy. From Batis' perspective, science is a way of knowing that comes about through the rigorous study of the natural world. He stressed that "the body of knowledge in science examines nature as well as humans and that this body of knowledge is derived from scientific investigations that are objective in nature" (GTA beliefs interview, January 8, 2019). Batis' claims disclosed that an understanding of the natural world separates science as a way of knowing from another way of knowing, such as religion and philosophy.

Science is a human endeavor. Batis believed that it is human nature to be curious, and humans always want to find answers, and in order to appease their curiosity, humans have to be creative. He explained that scientists need to be creative, especially in the way they investigated and disseminated information from their explorations. Batis elaborated on the aspect of creativity by providing an example of the case of Kekulé's benzene ring dream, where the benzene structure was described as an ouroboros – a snake eating its own tail. Batis also noted that,

> Scientists engage in scientific practice using scientific methods. Scientific practice includes observing and doing experiments all over the world, doing qualitative and quantitative research in different countries and different cultures. So, scientists put effort into getting ways to increase scientific knowledge from doing experiments, from discussions, from peer review, experiments, and using scientific methods. (Batis, GTA beliefs interview, January 8, 2019)

This excerpt revealed the belief that the combination of the effort and contributions of scientific investigations and research from all over the world contributed to science as a body of knowledge.

Science is based on empirical evidence. Batis thought that in science, evidence is essential, and the scientific community relied on evidence. Further, he believed that scientific knowledge is predicated on evidence. He also noted that science relies on logical and conceptual connections between evidence and explanations of findings. According to Batis, “It goes back to truth. You know it’s true when the evidence supports and is aligned with the explanations. This makes the information durable and certain” (Batis, GTA beliefs interview, January 8, 2019). Markedly, Batis believed that the certainty and durability of scientific knowledge were as a result of empirical evidence.

Science uses a variety of methods. Batis recognized that there are different ways that scientists go about doing their work. He likened the various methods and approaches that scientists use as the existing disparity between a Christian believer and a scientist. According to Batis,

> I’ll say they’re coming from different perspectives, different frameworks. And also, I would say the researchers hold different beliefs. It is like a Christian actively seeking evidence for the information in the Bible, and the other one is just like a scientist who is not a believer. Both groups use different means of finding knowledge. The Christian uses information in the Bible, but scientists may have different conclusions and use different scientific methods. Yes, scientists use many different ways to investigate and find evidence. (Batis, GTA beliefs interview, January 8, 2019)

Here, Batis explained the different approaches that individuals use to do their work. For example, he described the difference between scientists who use investigative approaches such as the scientific methods that are markedly different from Christian believers who depend on the information in the bible to support and justify their stance and the work that they do. This disclosed that Batis believed that the information from the various bodies of knowledge (specifically science and religion) are determined by their numerous yet unique ways.

Summary of Batis' professed beliefs about NOS. To recapitulate, there were four characteristics of NOS that were explicitly discussed during Batis' GTA beliefs interview. A summary of Batis' claims regarding these four characteristics of NOS is as follows:

- Science is a way of knowing that is different from religion and philosophy and comes about through the rigorous study of the natural world.
- Science is a human endeavor that is fueled by creativity because humans always want to find answers in order to appease their curiosity.
- Science is based on empirical evidence; that is, scientific knowledge is predicated on evidence.
- Science uses a variety of methods, and there are different ways that scientists go about doing their work.

The following section discusses Batis' proclamations on his beliefs about learning.

Beliefs about Learning

An instructor's beliefs about how to learn are an important aspect of their epistemological beliefs, primarily since epistemological beliefs affect instructional practices. This section describes Batis' beliefs about four aspects of learning – the ability to learn, how to learn, control of learning, and the role of students in learning.

Ability to learn. Batis acknowledged that one's natural ability to learn is no longer as relevant as one gets older. He used his language learning experience to explain that had he started learning a second language at his current age, it would be more difficult. Also, Batis stressed that he had to work harder and put in a lot more effort to learn a second language because he was not very young when he started. Batis posited, “You have to have basic learning ability, but that’s not the one that makes a big difference. An effort is very important” (Batis, GTA beliefs interview, January 8, 2019). This disclosed that Batis believed that the innate ability to learn diminishes with age. Hence, more effort is required to learn as one gets older.

How to learn. Batis noted that social interactions were fundamental and stated that, “Without an interactive environment, without social activities, people cannot learn something” (Batis, GTA beliefs interview, January 8, 2019). Batis also shared the belief that students learned best when they discussed their own claims. He described how his students learned by illustrating the process as it happened during a lesson on fermentation. From his context, the first stage was for students to think about what they already knew at the start of class by thinking about a question written on the whiteboard and discussing within their table groups. Batis identified the second stage as the one where students wrote down questions that they had regarding the process of fermentation, conducted the investigation, interpreted results, and formed conclusions. Batis mentioned that the second stage was the negotiation process, where students compared test results, challenged each other’s ideas, and identified questions that remained unanswered. The final stage, according to Batis, was assessment. He believed that assessment was essential and that it encouraged learning by enabling students to make meaning of what they had just learned. Batis’ claims disclosed that interactions among students were important to learn. However, the interactions should be structured where instructors create opportunities for students to think, discuss, as well as assess for student understanding. Overall, Batis believed that active participation involving these three stages was how students learned.

Control of learning. Batis had no qualms about who the subject was in the process of learning. In defending his certainty, Batis declared,

> You can take the students to the classroom, but they have to learn by themselves. I would say it's both. Just like you were saving somebody from drowning, and you have to make an effort to save them. They also have to make an effort to lift themselves up. I think both parts are important. (Batis, GTA beliefs interview, January 8, 2019)

Based on this statement, Batis believed that both instructors and students are in control of learning, and their role in the control of learning is equally important.

Role of the student. Batis believed that the role of students was to be active participants in the class. In his own words, Batis asserted,

> Students are the main body, I would say they are the learner, so they are not just a receiver. They are also – they should be a participant. Also, they have to be the one who's asking questions, like reflecting. And also, collaborators. So, there is definitely a collaboration between peers and students and teachers. So, I would say we are teammates. (Batis, GTA beliefs interview, January 8, 2019)

Based on this claim, it can be inferred that Batis perceived students as team members who needed to work collectively to promote their learning. Also, it can be disclosed that Batis' ideas about the role of the student as active participants were expected since he believed that it is most effective to learn via student-student interactions. Hence, Batis' view of the role of the student is an extension of his beliefs about how to learn.

Summary of Batis' professed beliefs about learning. To recapitulate, Batis' GTA beliefs interview revealed that he believed that:

- the ability to learn comes from self since one's innate ability to learn diminishes with age;

- the most effective way to learn is through interactions with peers especially if these interactions provide opportunities for engaging in thinking about concepts, discussing these concepts, and finally, being assessed; and
- the role of the student is to be an active participant in the learning process.

The next section provides a discussion on Batis' professed beliefs about teaching.

Beliefs about Teaching

This section describes Batis' beliefs about teaching and focuses explicitly on the aspects of teaching that are specific to the role of the instructor, how to teach, and the goal of teaching. These three aspects of teaching are significant in providing an insight into how Batis' conceptions of teaching are related to his science instruction.

How to teach. Batis thought that creating a comfortable and relaxing learning environment was essential. He expressed that students should be able to openly discuss their ideas as well as listen to the ideas of others, as noted in the quote, which follows:

> I would say first give [students] the opportunity to either discuss or observe and have the experience doing something or even ask some questions. Also, let them wonder first. Let them ponder on what they already know. So, they can see what they know and do not know and maybe have some questions – essential questions. Then share their big ideas which shows that they are really curious, they really want to know the answer. That's the first. And then give them the opportunity to really engage in scientific inquiry, have the opportunity to find the answers, and after that, we can have some reflection, discussion, critique each other's ideas. And turn to their professor, the experts, the textbooks to find the answers. So, the best teaching practice has a reflection, like what [students] learn, whether they found the answer or not. Then, I would say inquiry – through problem-solving. (Batis, GTA beliefs interview, January 8, 2019)

Based on this statement, it can be disclosed that Batis believed that affording students with opportunities to engage in inquiry facilitates a better understanding of science content. That is, instances which involve asking questions related to a science concept, sharing ideas or possible explanations regarding these ideas, designing investigations, collecting data and discussing results and determining whether the results reflect the ideas that were first shared, and finally using reliable sources to support, justify findings, and form conclusions. These various methods of inquiry and problem solving seem to be big ideas that Batis believes should be incorporated into teaching.

Role of the instructor. Regarding the questions concerning the role of the instructor in the learning process, Batis viewed himself as a facilitator, more specifically, a conversation facilitator. Batis also saw himself as an expert to provide the answers to students' questions. Although Batis saw himself as an expert to provide students with the required knowledge, he did not use lecture as part of instruction for two reasons: the language barrier and his belief that the laboratory is not the place for the lecture. According to Batis,

> I am sometimes the expert. I would say the expert because sometimes when [students] have problems, I answer their questions, and I don't lecture a lot. I'm not good at it because [of] the language barrier, and I also know the students that hate it. This is a lab, not the lecture part. They have enough lecture already, so I just leave that out. And also, a conversation facilitator. I organize the lesson, so I ask the questions, and they talk, and I make their talking accountable. (Batis, GTA beliefs interview, January 8, 2019)

This excerpt disclosed that Batis believed his role as the instructor was not to be an expert and a source of information for students, although sometimes he assumed this role. Also, Batis' claims reflected his idea of providing opportunities for students to ask questions and discuss with each other, a standpoint that extended his view on the importance of scientific inquiry and problem solving, which relies heavily on student-student collaborations and peer discussions.

Goal of teaching. Batis noted that although he was having difficulty communicating effectively with his students, he believed that it was important for them to leave class having learned some information that was useful in their everyday life. Batis posited, “I have to say that I prepare them for life later and also, [they] have to have some basic knowledge to be prepared for life” (Batis, GTA beliefs interview, January 8, 2019). In further support of this, Batis claimed,

> As a GTA teaching in my second language, my goal is just different. It grows, or it progresses over time. I think at first my time – when I taught my first lab, I think it’s just don’t screw up. Like, just do the job. I mean – so that the students can do their experiments well. And do not teach them something that’s wrong. But later it changed. For now, I think it is first [to] make them become interested in science and change their views. If [students] have some negative view of science I want to make them interested. And also, I want to teach them something useful. Sexually transmitted infections [STI] knowledge is quite useful, and I really like the reproduction part because STIs are very practical. The knowledge is very useful to everyday life applications. And also, change their perspective of life. Like, I show them a video of how the sperm and egg meet and how from – how that the zygotes become a baby so that they know that they’re born a winner. That’s part of my goals for this class. (Batis, GTA beliefs interview, January 8, 2019)

Batis also believed that it was important for his students to get good grades, and so one of his goals was to help students succeed in that regard. In addition, Batis believed that learning science should be fun. He declared, “It’s also fun learning something in science and that it’s helpful for the brain” (Batis, GTA beliefs interview, January 8, 2019). These claims disclosed that Batis’ goal for teaching was to prepare students as scientifically literate citizens, while at the same time to create learning environments where students will enjoy learning science.

Summary of Batis' professed beliefs about teaching. The following summarizes Batis' proclamations regarding his beliefs about three aspects of the nature of teaching:

- How to teach: using methods of inquiry and problem-solving where students can work collaboratively.
- Role of the instructor: to serve as a facilitator
- Goal of teaching: to create a learning environment where students can have fun learning science and learn the science and become scientifically literate citizens.

Next is a discussion of Batis' science instructional practices in the laboratory.

Batis: Science Instructional Practices

Since the 1960s, science education has been through a process of continual change. Advocated are changes in instructional practices that will promote the recruitment of higher numbers of students into careers in science with specific emphasis on how science is taught. This section presents the analytical results of Batis' use of the eight science instructional practices proposed by *Science for All Americans* (AAAS, 1993, 2013). These eight practices accentuate the distinctive characteristics of the material to be learned, and the conditions under which the teaching and learning are to take place in the science classroom and include: (1) start with questions about nature, (2) engage students actively, (3) concentrate on the collection and use of evidence, (4) provide historical perspectives, (5) insist on clear expression, (6) use a team approach, (7) do not separate knowing from finding out, and (8) de-emphasize the memorization of technical vocabulary.

Batis' Laboratory Instruction

Batis' laboratory lessons were two hours long. Although the laboratory time was scheduled for two hours, there were times when all activities were completed well before the two hours. Like Aesara, Batis used the first 10 minutes to quiz his students on material from both the past and present laboratories. Next, he spent a few minutes doing some housekeeping, which included reminding students about upcoming assignments and their due dates, highlighting the days that laboratory lessons would be taught by another GTA since he would be out attending conferences, and/or noting the days when there would not be laboratory, for example during the week of spring break. After students finished their quizzes and had been briefed on housekeeping matters, Batis delved straight into the laboratory lesson for the day.

Student feedback was very important to Batis. He believed that getting to know how students felt about his teaching in the laboratory presented opportunities for him to reflect on his current instructional practices and enabled him to make changes for the betterment of the teaching and learning process for students. After all, according to Batis, one of his goals for the course was that all students succeeded by getting good grades as well as left his laboratory having learned science content information to enable students to make better life choices. Because of this, Batis administered his own student evaluation halfway during the semester. After reviewing the feedback from students, Batis took some time to discuss the results of the evaluation with students, ensuring them that he had heard both their praises and their concerns and assuring them that he would work on the areas that required further development.

Lesson structure. Batis' lessons were unstructured in terms of following a consistent pattern. There were times when he spent at least 10 minutes of the time lecturing, and other times, he had students engaged in activities and spent very little time talking or lecturing. However, two things were consistent with Batis' laboratory lessons. First, he always began his lessons with a scenario and a question that was tied to the material to be taught. Second, he always embedded short YouTube videos into his lessons. After students had discussed the issue or scenario of the day within table groups and then as a whole class, Batis continued with the lesson's objectives, and then showed one or two short videos that helped clarify the content associated with the laboratory activities. During the laboratory activities, Batis walked around the room to answer students' questions. He allowed students the full responsibility to read and follow the directions for various laboratory assignments and did not feel it necessary to review any aspect of the laboratory unless, based on previous experience, he noticed that students would have had difficulty with measurements or following a step or steps correctly.
At the end of the laboratory, students cleaned up their spaces, washed or threw away apparatuses, and completed and submitted the in-labs portions of their laboratory assignments.

Science instructional practices. Batis' lessons were observed for the instances when his practices demonstrated the eight science instructional practices as recommended by the AAAS (1993, 2011). Batis incorporated most of the science instructional practices during his lessons; that is, seven out of the eight science instructional practices (Table 18). The instances where his instruction demonstrated practices that countered the eight recommended scientific practices were also noted (Table 19). In tables 18 and 19, an 'X' indicates the science instructional practice that Batis displayed during his teaching episodes. The tables also highlight information regarding the activities that required students to collect data as well as instances where certain activities that should have been completed but were left out due to the unavailability of materials or time constraints. For example, students collected data during the *Quantifying Gas Production* activity, and the *Flowering Plant Dissection* activity was not completed because the flowers for the activity were not available.

Table 18

Science Instructional Practices Demonstrated During Batis' Laboratory Lessons that Aligned with the Eight Science Instructional Practices Described by AAAS (1993,2011)

Lesson Associated Activities	Science Instructional Practice							
	1	2	3	4	5	6	7	8
Fermentation								
You and Gas Production[a]		X	X	X	X		X	X
Yeast and Gas Production	X		X	X	X		X	X
Quantifying Gas Production[a]	X	X	X	X	X		X	X
DNA Extraction and Mitosis								
Strawberry DNA Extraction		X	X	X	X		X	X
Stages of Mitosis (Simulation with Beads)[b]								
Stages of Mitosis (Microscope)		X	X	X	X			
Human Genetics								
Pipe Cleaners and Beads	X	X	X	X			X	
Human Genetics	X	X	X	X	X		X	X
Punnett Squares Worksheet	X	X		X	X		X	
Blood Typing[a]	X	X	X	X	X		X	X
Plant and Animal Reproduction								
Spread of STIs	X	X	X	X			X	X
Flowering Plant Dissection[b]								
Male and Female Anatomy (Microscope)[b]								

Note. The numbers in the science instructional practices columns coincide with the following: 1 – Use Team Approach; 2 – Students are Actively Engaged; 3 – Start with Questions about Nature; 4 – Do not Separate Knowledge from Finding Out; 5 – Provide Historical Perspectives; 6 – Insist on Clear Expression; 7 – Do not Emphasize the Memorization of Technical Vocabulary; 8 – Concentrate on the Collection and Use of Evidence

[a] Activities during which students collected data

[b] Activities that Batis skipped because of unavailability of resources or due to time constraint

Table 19

Science Instructional Practices Demonstrated During Batis' Laboratory Lessons that Countered the Eight Science Instructional Practices Described by AAAS (1993,2011)

	Instructional Practice							
Lesson Associated Activities	9	10	11	12	13	14	15	16
Fermentation								
You and Gas Production[a]	X					X		
Yeast and Gas Production		X				X		
Quantifying Gas Production[a]						X		
DNA Extraction and Mitosis								
Strawberry DNA Extraction	X					X		
Stages of Mitosis (Simulation with Beads)[b]								
Stages of Mitosis (Microscope)	X					X	X	X
Human Genetics								
Pipe Cleaners and Beads					X	X		X
Human Genetics						X		
Punnett Squares Worksheet			X			X		X
Blood Typing[a]						X		
Plant and Animal Reproduction								
Spread of STIs						X		
Flowering Plant Dissection[b]								
Male and Female Anatomy (Microscope)[b]								

Note. The numbers in the science instructional practices columns coincide with the following: 9 – Do not Use Team Approach; 10 – Students are not Actively Engaged; 11 – Do not Start with Questions about Nature; 12 – Separate Knowledge from Finding Out; 13 – Do not Provide Historical Perspectives; 14 – Do not Insist on Clear Expression; 15 – Emphasize the Memorization of Technical Vocabulary; 16 – Do not Concentrate on the Collection and Use of Evidence

[a] Activities during which students collected data

[b] Activities that Batis skipped because of unavailability of resources or due to time constraint

Students are actively engaged. Students were typically actively engaged, and most times, worked as a group. Batis posited that scientists worked collaboratively; therefore, students should work as scientists do. Also, he acknowledged that when students worked in groups, they could rely on each other for explanations and would come to him only if no one in the group knew the answers. He mentioned that this alleviated some of the discomforts that he felt as an English as a second language (ESL) instructor. Batis admitted that, most times, he found it challenging to enunciate technical vocabulary terms or explain in English and that this was one of the main reasons why he used videos to substantiate the lecturing portion of the lesson if any lecturing was necessary. As for the hands-on activities of the laboratory lessons, Batis claimed that "this is a lab, that is what they have to do, this is not a lecture, they have had that portion already" (Batis, GTA beliefs interview, January 8, 2019).

Start with questions about nature. Batis demonstrated this science instructional practice during most of his laboratory lessons. He introduced all his laboratory lessons with a question or a scenario that was, for the most part, associated with nature. For example, for the introduction to the laboratory lesson on Fermentation, Batis began with the question shown in the video still in Figure 22.

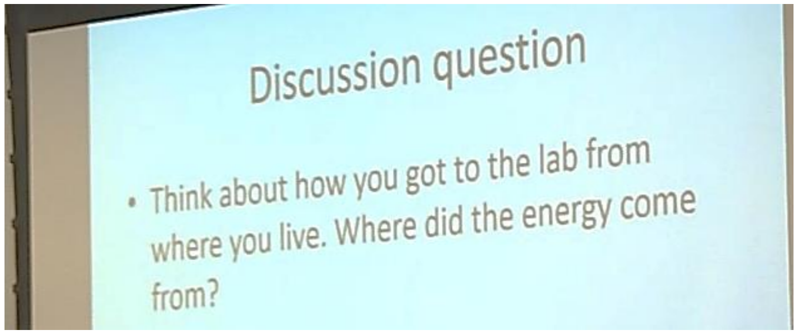


Figure 22. Video still of Batis' introduction on the lesson on fermentation.

According to Batis,

> Let's talk about this question. Thinking about from your apartment where you live until you come here [lab]. Think of all the ways – you walked, you jogged, you drive. All the ways that you used to come here. Where did the energy come from? Talk to your friends on your table. (Batis, Fermentation Laboratory Lesson, March 27, 2019)

After discussing in their groups, Batis brought all students together to talk about their responses to the question or scenario. It can be disclosed that Batis saw a need to connect the content materials with real-life events in order to pick at students' curiosity and get them thinking about the topic to be discussed using information that would be familiar and not necessarily requiring background knowledge to participate in the discussions that ensued.

Use a team approach. Batis was adamant that teaching needs to incorporate group work because "that is how scientists work" (GTA beliefs interview, January 8, 2019). Batis also stated that he liked to create a learning environment that was comfortable for students. According to him,

> Some people will not feel comfortable talking to the instructor. So, I give them an opportunity to talk to their peers. It's also about building the community

> because they work on the same table. This is like imitating the scientists. (Batis, Fermentation Laboratory Lesson, March 27, 2019)

This statement disclosed that Batis held high regard for the collaborative nature of scientific work, and he strongly reinforced this via frequent group activity in his laboratory.

Do not emphasize the memorization of technical vocabulary.

Do not emphasize the memorization of technical vocabulary. Regarding the emphasis placed on memorizing technical terms, Batis was one who thought that it was better to understand the concepts than to remember the words or phrases. Batis admitted that it was easier for him not to emphasize vocabulary due to his own inadequacy with the English terms. He felt that it was unfair for students to learn words that they could not pronounce. As a result, Batis' main aim for students was to understand rather than learn vocabulary. However, Batis stated that some laboratory lessons focused heavily on vocabulary, for example, the laboratory on Human Genetics. He felt that students needed to be familiar with the terms to clarify their thinking and understanding of genetics. More specifically, students needed to focus on some terms like alleles and genes in order to understand how genetic traits are passed from one generation to the other. In this case, Batis' view highlighted the standpoint of the AAAS, who disclosed that in certain circumstances, terminology is necessary for communication and ultimately for understanding.

Concentrate on the collection and use of evidence. For the activities that required students to collect data (Table 17), Batis concentrated on the collection of data and encouraged students to provide their own interpretations of the data. For example, this practice was demonstrated during the Fermentation laboratory when students completed the *Quantifying Gas Production* activity (Figure 23).

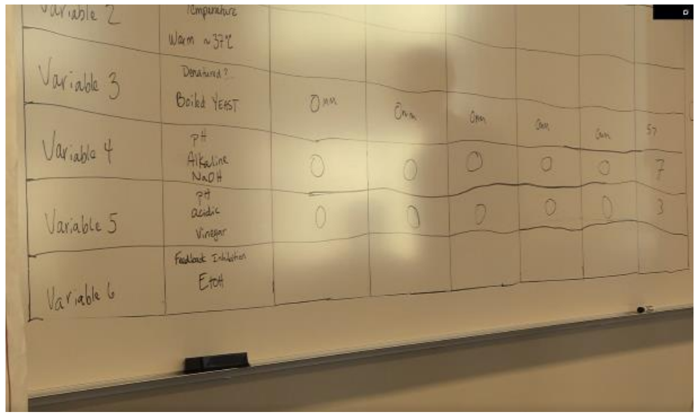


Figure 23. Video still of Batis' students' results from the quantifying gas production in a fermentation tube activity.

To facilitate a discussion about the data that students had gathered during this activity, Batis stated,

> For variable three, think about what is happening here, try to figure out the explanation, when the yeast is boiled. What happens when the yeast is boiled? Yes, they're dead, so what happens. That's correct. No fermentation happens. Can you see that from the data? Where else can you prove that no fermentation happens? Let's wait for the rest of the data to come in. (Batis, Fermentation Laboratory Lesson, March 27, 2019).

However, Batis acknowledged that he ensured that students had the correct interpretations of the data.

Insist on clear expressions. During students' explanations and interpretations of results from their investigations, Batis did not insist that students use clear expressions. Batis explained that it was difficult for him to encourage students' correct use of vocabulary when he was faced with a similar struggle. The science instructional practice, *insist on clear expressions*, was the only practice that Batis did not demonstrate during his various teaching episodes. In this instance, it was inferred that the Batis' challenge with the English language served as a constraint in the enactment of a teaching practice that was heavily recommended by major science reform documents like the AAAS (1993, 2011).

Do not separate knowledge from finding out. Batis did not separate knowing from finding out. According to Batis, it was easy for him to teach students that the methods were just as important as the results since he was not interjecting much into their work when they were completing an experiment. In so doing, students were left to develop their own intellectual independence. Batis also attributed this aspect of his scientific instruction to his discomfort with the English language and his ability to explain adequately. Hence students were left to depend on following the methods precisely, which in turn led to a better interpretation of the results. Batis explained that this helped students to both acquire scientific knowledge and reinforce their practice of the scientific method.

Provide a historical perspective. For many of the activities, Batis did not provide a historical perspective except for the exercise on the Sexually Transmitted Infections. Also, for the laboratory lesson on the Plant and Animal Reproduction, although Batis did not make his students complete two of the activities from their laboratory manuals, he did present a unique historical perspective on sexual reproduction. The historical context of human sexual reproduction was taken from a Chinese perspective, where Batis gave various representations and ideas that enabled humans to fully understand the underlying elements and function of the parts of the reproductive system. For example, Figure 24 shows the historical art that Batis showed in order to draw student's attention to the influence of society and social perspectives on the scientific enterprise.

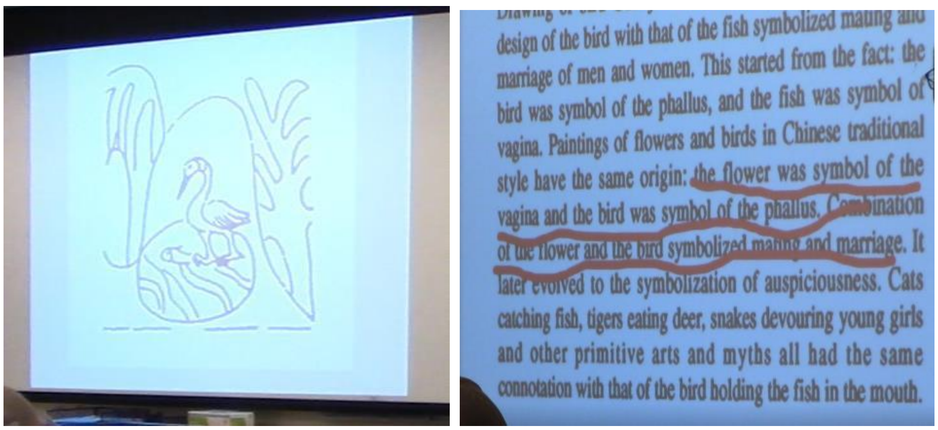


Figure 24. A video still of Batis' illustration of historical representations of the human reproductive system during the lesson on plant and animal reproduction.

Frequency of Batis' science instructional practices. During the four observations, Batis completed a total of 10 activities with his students, during which time he demonstrated the use of many of the science instructional practices (seven out of eight). The frequency of the use of each science instructional practice was calculated and is shown in Figure 25. Calculation of the frequency of science instructional practice was calculated by:

1. noting the science instructional practices that were demonstrated during the teaching of each activity;
2. tallying the total number of activities completed in each lesson; and

3. calculating the frequency (%) of the demonstration of each science instructional practice by dividing the sum of each science instructional practice by the total number of activities per lesson and multiplying by 100.

For example, Batis completed a total of 10 activities during the four lessons for which he was observed. He employed the use of the science instructional practice, *use a team approach*, seven out of the 10 times. The frequency of demonstration of this science instructional practice was calculated as : $\frac{7}{10} \times 100 = 70\%$.

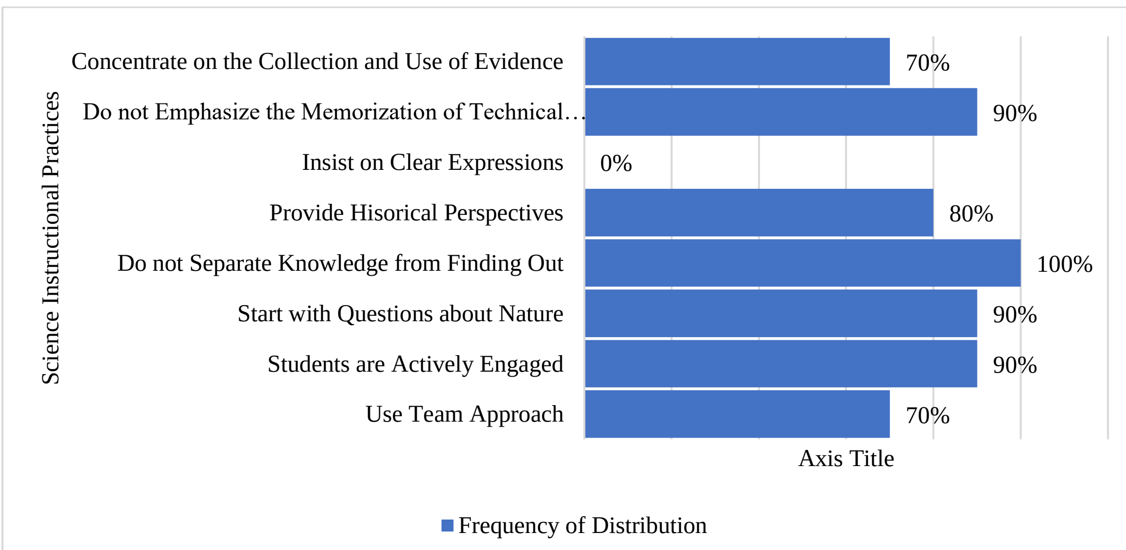


Figure 25. Frequency of the demonstration of the science instructional practices by Batis.

The most frequently demonstrated science instructional practices were *do not separate knowledge from finding out* (100%) followed by *students are actively engaged*, *start with questions about nature*, *provide a historical perspective*, and *do not emphasize the memorization of technical vocabulary*, all of which Batis demonstrated 90% of his lessons, *concentrate on the collection and use of evidence* (70%), and *use a team approach* (70%). Observations of Batis' laboratory lessons indicated that he rarely employed the science instructional practice: *insist on clear expressions*. Based on his VSR interviews, Batis noted that he had difficulty expressing some of the science content in using the English language. As such, he did not emphasize this aspect much during his teaching. Following this discussion of results on Batis science instructional practices, the next section presents the findings that indicate the nature of the relationship between the features of his professed beliefs and science instructional practices.

Batis: Relationship between Batis' Features of Epistemological Beliefs and Science Instructional Practices

The data regarding the professed features of Batis' epistemological beliefs and science instructional practices were analyzed to determine the nature of the association between these two constructs. More specifically, to determine whether there were instances of mismatches or alignments between professed epistemological beliefs and science instructional practices. A misalignment describes the demonstration of a science instructional practice that highlighted the thoughts and actions of the GTA in the laboratory that countered or opposed the eight practices of teaching recommended by the AAAS (1993, 2011). In this case, Batis' proclamations aligned with the recommendations of the AAAS, but these professed beliefs were not demonstrated during Batis' instructional practice. The propositions of the AAAS (1993, 2011) are presumably consistent with the nature of inquiry and provide students with the kinds of experience that will enable them to understand science as a way of thinking and doing. Contrarily, an alignment between professed epistemological beliefs and science instructional practice, shows a positive association between the two constructs. The results of this analysis indicated that there were no misalignments between Batis' proclamations regarding his epistemological beliefs and his science instructional practices. Alternatively, the data highlighted mostly alignments between Batis' epistemological beliefs contrasted with the science instructional practices. The information concerning these alignments is presented in this section under the categories: epistemological beliefs in general and beliefs about teaching.

Alignment between the Professed Features of Epistemological Beliefs and Science Instructional Practices

The data were analyzed to consider the alignment between the professed features of epistemological beliefs and the science instructional practices as recommended by the reform document issued by the AAAS (1993, 2011). Findings indicated that there was a positive association—alignment—between the features of Batis' professed epistemological beliefs about the nature of knowledge and knowing, the nature of science, and beliefs about teaching and learning. Batis' epistemological stance was reflected in his demonstration of science instructional practices, specifically in the instances where he started each laboratory lesson with questions about nature and allowed students to be actively engaged by minimizing lectures as much as possible.

Epistemological beliefs in general and science instructional practices.

***Batis' beliefs about the* changeability of knowledge *and the science instructional practice* start with questions about nature.** Batis posited that knowledge changed over time with new experiences and felt that it was necessary to provide students with the various experiences that could develop their knowledge and understanding about science concepts by actively engaging them in laboratory activities. According to Batis, "You gather knowledge by doing something, like through experience" (Batis, GTA beliefs interview, January 8, 2019). Batis also admitted that he provided students with the experience required to increase their knowledge and understanding during the activities by limiting his lecturing and helping them make connections between the outside world and the science content. Ninety percent of the time (Figure 25), Batis started his lessons with questions that incited thinking about phenomena that are interesting and familiar to students instead of using content-based questions that were either outside of the range students' perception, understanding, or knowledge. This positive association is highlighted in Figure 26.

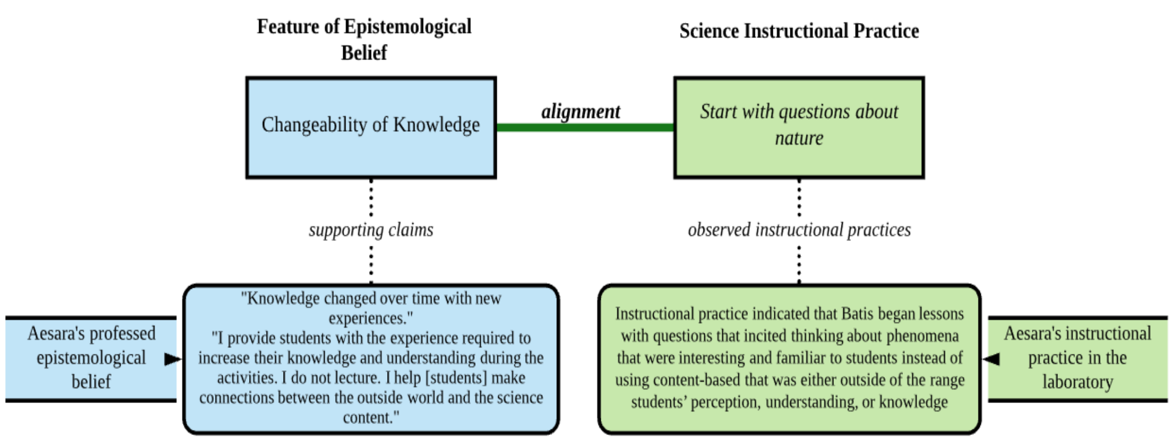


Figure 26. Relationship between Batis' epistemological beliefs about the *changeability of knowledge* and the enactment of the science instructional practice *start with questions about nature*.

The following highlights a portion of Batis' VSR interview on his lesson on fermentation:

> I chose that question to start lab because first, it is to connect. I share a personal experience about getting a ticket driving, and also that's what they do every day. They walk around, they drive around, and the early in the morning, they had breakfast. And then they move around. So, all kinds of respiration happen. In this process…, and it's amazing that all these [processes], every one of them traces back to the Sun. (Batis, Fermentation VSR Interview, March 4, 2019)

The claims made in this excerpt disclosed that Batis wanted students to make connections between what was happening in their everyday lives and the content that they were learning in the laboratory so that students would not view science content as separate and isolated information.

Other examples of Batis' questions included:

1. What do you know about your heritage? How many cells do you have in your body? (Lesson on DNA Extraction and Mitosis, March 11, 2019)
2. This photo is of pottery from about 6,000 years ago. You see two animals, fish, and a frog. So how does that relate to reproduction? (Lesson on Plant and Animal Reproduction, April 8, 2019)

A snapshot of the slide with the photograph that Batis used is shown in Figure 27.

Figure 27. Snapshot of a slide showing a picture that Batis used to introduce his lesson on Plant and Animal Reproduction.

Batis employed a variety of questions to start his lesson, including questions that reflected his culture and background. Based on this information, especially regarding the variation in the type of questions that Batis posed, it was disclosed that Batis wanted to get students acquainted with the things around them both in the immediate environment and beyond, and to become puzzled by them, ask questions about them, argue about them, and then to try to find answers to their questions.

***Batis' beliefs about the* changeability of knowledge *and the science instructional practice* students are actively engaged.** Batis became passionate when he talked about the importance of being actively engaged and not sitting down, listening to a lecture in the laboratory. According to Batis,

> I don't lecture a lot. I also know the students that hate it. This is lab, not the lecture part. They have enough so I just kind of skip the lecture part. I don't lecture a lot. That's a waste for them. (Batis, GTA beliefs interview, January 8, 2019)

Batis claimed that he encouraged students to participate actively and engage with each other. He stated that,

> I probably want to spend 15 minutes or 10 minutes. It depends on how they react to the question in the introduction. Definitely, I want to [discuss] more, I don't want to go into, into – I want to start with something really relevant, really, really, superficial but I want to dig in, but if I feel like this conversation is not going anywhere, I will just stop it. And I want to spend – I want them to spend the majority of the lab time to do the experiment. When they need the content knowledge, they – I will provide them. I will let them know about it from the PowerPoint from the videos from my lecture when they only feel the urge to learn something. But the main thing is to do, to talk with your partners at your table, to discuss the experiments. It has to come from them first, and if they do not know, then I can help them. (Batis, Fermentation VSR Interview, March 4, 2019)

This excerpt highlighted Batis' views on students figuring things out on their own by engaging with each other to discuss science investigations and findings. Figure 28 highlights the positive association—alignment—between Batis' views about the *changeability of knowledge* and the science instructional practice *students are actively engaged*.

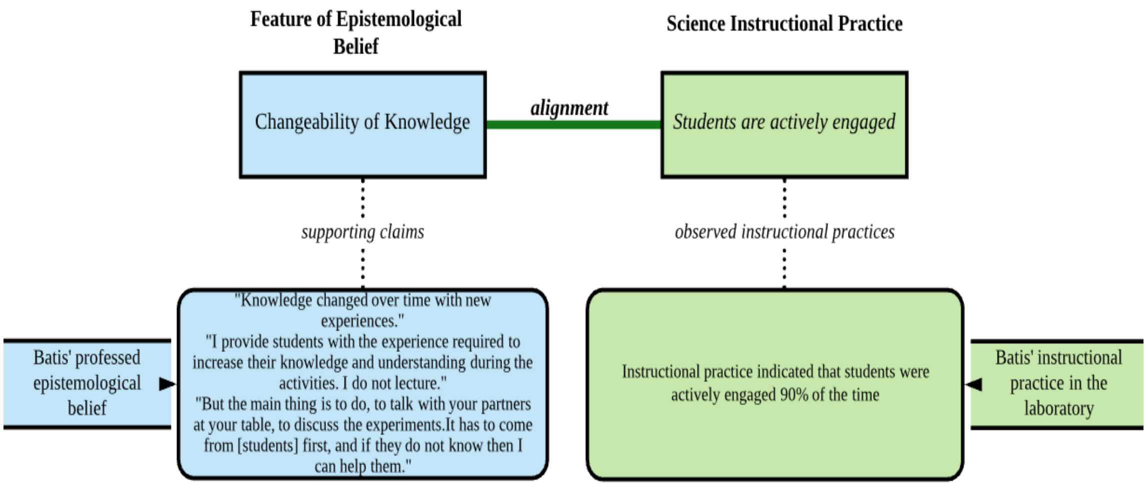


Figure 28. Relationship between Batis' epistemological beliefs about the *changeability of knowledge* and the enactment of the science instructional practice *students are actively engaged.*

Epistemological beliefs about teaching and science instructional practices.

How to teach *and* use a team approach *and* students are actively engaged.

The data revealed an affiliation between Batis' beliefs about *how to teac*h and the science instructional practices, *use a team approach* and *students are actively engaged*, which he discussed simultaneously. Batis acknowledged that he believed that,

> Learning occurs through discussions, inquiry, asking questions, and collaborating with peers, and the instructor can facilitate this type of learning by using the necessary inquiry-based methods. That's the best way to teach in the laboratory. And it's important for students to make connections with real-life situations during their discussions. (Batis GTA beliefs interview, January 8, 2019)

This statement reiterated previous discussions on Batis' stance about doing science through active participation and collaboration. This claim also disclosed that Batis believed that collaborative work that incorporates methods of inquiry is the most effective way to teach and learning science. Batis employed these two science instructional practices regularly during his laboratory lessons. For example, his instruction demonstrated the practice *students are actively engaged* in 90% of the laboratory lessons, and students were involved in teamwork 70% of the time. The alignment between Batis' beliefs about how to teach and the science instructional practices are shown in Figure 29.

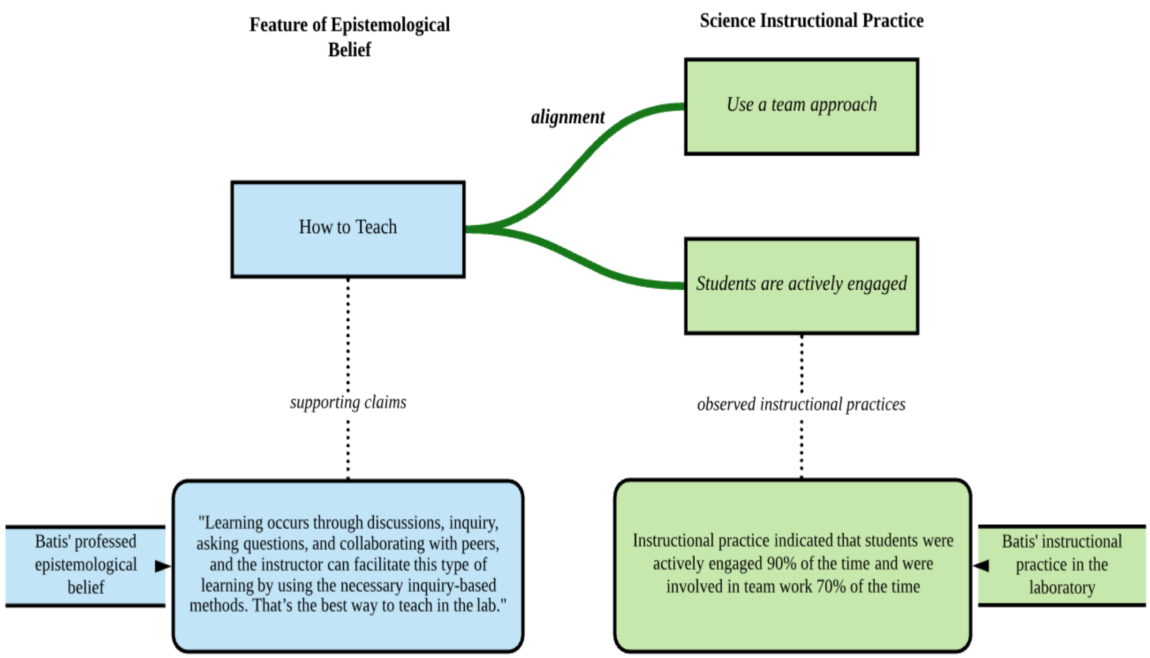


Figure 29. The relationship between Batis' belief about *how to teach* and the enactment of the science instructional practices *use a team approach* and *students are actively engaged*.

Summary of alignments between features of Batis' epistemological beliefs and science instructional practices. The findings of this study identified three positive associations or alignments between Batis' professed features of epistemological beliefs and science instructional practices. These alignments described instances where Batis' laboratory teaching practices reflected his professed beliefs, which aligned with the teaching practices as recommended by the AAAS (1993, 2011). In other words, Batis' instruction was in harmony with the AAAS' eight teaching practices which according to the AAAS (1993, 2011) are consistent with the nature of inquiry and that provide students with the kinds of experience that will enable them to understand science as a way of thinking and doing. The alignments were found to be regarding Batis epistemological beliefs in general—nature of knowledge and knowing—and his beliefs about teaching.

Batis: How Complexity Theory Describes the Interrelatedness between the Features of Batis' Epistemological Beliefs and Science Instructional Practice

Complexity theory focuses on complex systems and is characterized as a collection of individual agents with freedom to act in ways that are not always totally predictable, and whose actions are interconnected so that one agent's actions changes the context for other agents. Complexity theory emphasizes relationships among the subparts of a system and the emergence of something new. This study highlighted the laboratory as a complex system. Several attributes or characteristics typify complex systems, including *self-organization*, *emergence*, *non-linearity*, *connectivity*, and *autonomy and adaptation*. These attributes were used to explain the connections between the professed epistemological beliefs and science instructional practices specific to the data on the complexity of Batis' laboratory. The data analysis pertaining to Batis' classroom system, specifically regarding the features of epistemological beliefs and science instructional practices, displayed three attributes of the complexity theory: *self-organization*, *emergence*, and *interconnectivity*. These attributes are discussed in the sections that follow.

Self-Organization

Self-organization can be defined as the spontaneous emergence of an organized structure due to the local interactions of individual components of a complex system. Spontaneous, in this case, can mean that in a system, any individual component can be eliminated, changed, or replaced without any damage to the overall or resulting structure of the system. Self-organization creates order out of disorder; is responsible for the patterns, structures, and arrangements that are found in a system; and gives rise to the emergence of new levels of organization within that system.

There were instances when the reorganization of Batis' laboratory system was due to changes that influenced the components of the system. For example, the flower specimens for Batis' Plant and Animal Reproduction laboratory were not delivered in time for his laboratory lesson. The flower dissection activity was one of the major activities planned for that laboratory, and the unavailability of the flowers presented a significant change in Batis' science instructional practice. Batis posited that he was an avid believer of active learning in the laboratory and always highlighted that the laboratory was not a place for lecturing (GTA beliefs interview, January 8, 2019). In the case of the missing flowers, Batis chose to eliminate the activity instead of opting to supplement it with a video of the dissection. He purported that a video would not be able to replace the hands-on activity and preferred to leave it out instead. Here, Batis' instructional decision reiterated his beliefs about teaching, that students should be actively engaged. Batis used the extra class time that came about due to skipping the flower dissection activity to engage students in further discussions. The system remained stable despite the emergence of a sudden change that affected a component in the system. Furthermore, this case highlighted an interaction between two components, Batis' epistemological beliefs and science instructional practice. It indicated the interrelatedness of these two components, where Batis' epistemological beliefs strongly influenced his instructional practice or decision.

Emergence

In complex systems, emergence denotes the arising of novel and coherent structures, patterns, and properties during the process of self-organization. Emergent features are not previously observed in the complex system under observation, are not anticipated before they show themselves, and arise as complex systems evolve. Regarding the laboratory system, there was the emergence of a laboratory that was stable and comfortable for Batis as well as the students. For example, Batis (Genetics VSR Interview, March 28, 2019) admitted that he had difficulty explaining to his students some of the key aspects of the content, and that made him feel uncomfortable at times. However, Batis explained that over time, after he admitted his shortcomings to the students, his laboratory lessons began to run smoother, because the students started taking more responsibility for their learning and began to work more cooperatively, like scientists who worked with each other rather than in isolation. According to Batis (GTA beliefs interview, January 8, 2019), he urged students to work cooperatively, mainly since scientists always worked in teams. For example, there were instances when Batis noted that he allowed the students who had a good understanding of the content to "take charge and teach the others" (Batis, Genetics VSR Interview, March 28, 2019).

Batis identified his inability to deliver the content as effectively as he would like to as a laboratory constraint (GTA beliefs interview, January 8, 2019). In this case, Batis' science instructional practice (i.e., *use team approach*) and professed features of epistemological beliefs (i.e., knowledge and knowing about NOS) produced a system that evolved and highlighted the emergence of a system that was stable.

Interconnectivity

Within complex systems, interactions between components show connections. Analyses of findings revealed the interconnection between Batis' professed beliefs and science instructional practices, primarily in the instances where there were alignments between the two constructs. For example, the interconnectedness between professed epistemological beliefs and science instructional practice was revealed in Batis' beliefs about the *changeability of knowledge* and the science instructional practice *start with questions about nature.* Batis' instructional practice was observed to reflect his belief when he began each laboratory lesson with questions about natural phenomena, which served to pick at students' natural curiosity.

Summary of the Complexity Theory and its Interrelatedness to the Features of Batis' Epistemological Beliefs and Science Instructional Practice

Batis' professed epistemological beliefs and science instructional practice are part of a complex system, the laboratory. These two constructs, as part of any complex system, interacted with each other and displayed attributes or characteristics that are specific to the nature and type of system. In Batis' case, the data revealed three of the characteristics of a complex system that resulted from interactions and interrelatedness of his features of epistemological beliefs and science instructional practices. These three attributes were *self-organization, emergence,* and *interconnectivity*. Self-organization of the system depicted a change in the system specific to instruction while emergence occurred due to incidences were not anticipated before. Emergence led to the arousal of novel and coherent structures, patterns, and properties during the process of self-organization. For example, Batis left out the activity on flower dissection during the Plant and Animal Reproduction laboratory, and restructuring of the lesson led to extended class time for the other laboratory activities. Interconnectivity revealed the nature of the relationship between professed epistemological beliefs and science instructional practice.

Cleomedes: Professed Features of Epistemological Beliefs

Epistemological Beliefs in General (Knowledge and Knowing)

An individual's general epistemological beliefs are concerned with how an individual comes to know what he or she knows and the process of knowing. This section focuses on the features of epistemological beliefs about the nature of knowledge and knowing and utilizes the four sub-dimensions of domain-general epistemological beliefs, which were identified as core dimensions by Hofer and Pintrich (2002). These four sub-dimensions are the changeability of knowledge, the structure of knowledge, source of knowing, and justification of knowing.

Changeability of knowledge. Cleomedes held the belief that knowledge could change over time due to the experiences of individuals. She claimed that knowledge is capable of being altered based on experiences, especially experiences that include encounters with teachers or researchers who may add to knowledge in different ways and enhance understanding and learning.

> I think over time, knowledge can be altered slightly. Not saying that you still don't withhold those beliefs or the knowledge that you learn prior to, but it might be changed or altered due to your different experiences. Or, due to different teachers, you may encounter or different knowledge you may obtain or through research or anything like that. It doesn't change what you believed prior, but it might be slightly altered to what you believe now. (Cleomedes, GTA beliefs interview, January 10, 2019)

Justification of knowledge. To explain her beliefs about the procedures that individuals use to evaluate and warrant knowledge claims, Cleomedes demonstrated the idea that the justification of her knowledge was derived from verification from persons she considered experts in a field of study as well as textbooks. However, Cleomedes admitted that there had been some changes in her beliefs due to her time and development as a doctoral student. When asked how she justified her knowledge, Cleomedes asserted,

> Being in this program has really changed my views on a lot of things. In undergrad, I would say absolutely. Because I was like, "They're the experts. They are the professors. They are the researchers in this field. So, what they say is true." Now I think through conversations, different conversations, with either experts or people in the field that I view as being knowledgeable of certain content, just being able to hold an intellectual conversation with them. This is validation from others. (Cleomedes, GTA beliefs interview, January 10, 2019)

In the preceding quotation, Cleomedes admitted that what she knew was justified because the disseminators of knowledge, like her professors, were experts in their various fields of research. For Cleomedes, research was fundamental to the justification process and noted that there was a thin boundary between justification and the source of knowledge. She stated,

> I would say the textbook was my go-to for correct answers. Now, reading different articles that allude to things [being] incorrect in textbooks and the same textbooks haven't been updated. And so, new things and new research which is very important haven't been implemented within the textbook. So, I think a

> textbook is a resource that can verify information, but it's not the end-all, be-all. (Cleomedes, GTA beliefs interview, January 10, 2019)

This statement disclosed that Cleomedes held the view that authority serves as both the sources and verification of knowledge. Furthermore, it was inferred that Cleomedes saw experts as credible because they are engaged in research. This disclosed that the process and results of research are highly influential in the warranting and verifying of claims.

Source of knowledge. In describing from where knowledge comes, Cleomedes posited that there are many sources, authoritative figures as well as self. Cleomedes maintained that sources could be parents or caregivers because they are the ones that an individual would spend the most time with during the early stages of life. Cleomedes explained that as one grows older, the source of knowledge changes, where the classroom teacher becomes the new source now that the individual spends more of their time away from home. Cleomedes explained,

> I would say it started with my mother. My mother was a middle school teacher, and I can remember ever since maybe two years old, she just always stressed the importance of reading and writing and mathematics. And so, I think I learned first from my mother. And then also my grandmother because I didn't go to school until I was four. So, I was learning just through day-to-day activities with both my grandmother and my mother. And as I grew older, I would say in school, but still mainly at home. (Cleomedes, GTA beliefs interview, January 10, 2019)

Cleomedes also believed that the source of knowledge is self. According to Cleomedes, "I would say [knowledge is] self-constructed. Because although I learned from my mother, grandmother, or teachers, I had my own mind and my own beliefs in the way I wanted to do things. And so, I would say it was self-constructed" (GTA beliefs interview, January 10, 2019).

Also, Cleomedes discussed her views on experts as a source of knowledge. She expressed that being a graduate student allowed her to read more widely on various topics that were written by experts. However, as she became a critical consumer of information, Cleomedes posited that she had started to question the work of experts, especially as sound sources of knowledge. Cleomedes stated,

> As an undergrad, I would say that they are the experts, and that is why they are the professors. They are the researchers in this field. So, what they say is true. I question their positions, sometimes to a fault. I do this because a lot of people in my family have had cancer. And so, just reading up on different things about cancer and the treatments, everything is suspect to me. (Cleomedes, GTA beliefs interview, January 10, 2019)

The claims made by Cleomedes disclosed struggle between whom she views as the source of knowledge. Cleomedes believed that authority figures and experts can both be sources of knowing. However, she stated that there are times when their claims are questionable, and then she reverted back to self and experiences as a credible source.

Structure of knowledge. Cleomedes believed that the structure of knowledge is complex. She asserted that the complexity of knowledge was more apparent in some disciplines than in others. Using her experience as a high school teacher who taught various courses led to her having the perspective that some disciplines entail more sophisticated knowledge than others do. According to Cleomedes,

> I was teaching high school at different levels. So, AP Biology, I would say, is more complex. Because to prepare students for that test at the end, I have to go into a lot of depth, and it has to be complex and more difficult versus a Physical Science course, which is non-tested. It is basically the first science course that students have. So, transitioning them from middle school to high school, going to them with more complex ideas and thoughts, in the beginning, is hard. So, for them, I kind of go into it slowly, more simplistic, and then we go to the more complex ideas towards the second semester. So, I think everybody can start off their knowledge as simplistic and then gradually go into more complex. (Cleomedes, GTA beliefs interview, January 10, 2019)

This excerpt revealed that Cleomedes believed that knowledge is simple at first but gradually becomes more complex as more information becomes available and accumulates over time. Her explanation of the structure of knowledge was like baking a cake where you first add a single ingredient, and then you keep adding more ingredients until the batter becomes a complex mixture of various ingredients.

Summary of Cleomedes' features of professed epistemological beliefs. The GTA beliefs interview revealed Cleomedes' conceptions regarding the four main areas of epistemological beliefs in general, as described by the literature. Table 20 presents a synopsis of the features of Cleomedes' epistemological beliefs regarding the nature of knowledge and knowing and provides a summary of her proclamations regarding each aspect. Next is a discussion on Cleomedes' beliefs about the nature of science.

Table 20

Summary of Cleomedes' Professed Epistemological Beliefs about the Nature of Knowledge and Knowing

Feature of Epistemological Belief	Proclamation regarding belief about the nature of knowledge and knowing
Changeability of Knowledge	Knowledge changes over time.
Justification of Knowledge	Knowledge is justified by others (e.g., experts and authority).
Source of Knowledge	Both others and self are sources of knowledge.
Structure of Knowledge	Knowledge structures move gradually from simple to complex.

Epistemological Beliefs about the Nature of Science (NOS)

Hurling (2014) posited that if you are studying a person's scientific epistemological beliefs, then you are studying their views of NOS. Epistemological beliefs about the study of scientific knowledge or NOS are related to the study of science as a way of knowing. Lederman (1992) purported the NOS has its own specific set of values and beliefs that characterizes it as scientific and sets it apart from other disciplines. Although specific characteristics of NOS are still a subject of dispute, academic research and educational reform movements (e.g., NGSS Lead States, 2013) have established characteristics that serve as a basis for most recent descriptions of NOS (e.g., Ackerson, Abd-El-Khalick, F., & Lederman, 2000; Abd-El-Khalick, Bell, & Lederman, 1998; Hodson, 2014). These characteristics include that scientific knowledge: 1) is a way of knowing, 2) is a human endeavor, 3) is empirically based (based on and/or derived from observations of the natural world, 4) assumes order and consistency, 5) is derived from a variety of methods, 6) is tentative and open to revision, 7) is generated from scientific models and theories, and 8) answers questions about nature. These eight characteristics were used to determine the epistemological beliefs of GTAs regarding the nature of science. The analysis for the features of epistemological beliefs about science revealed that the biology GTAs did not identify with all eight characteristics of NOS. Only those characteristics revealed in Cleomedes' proclamations during the GTA beliefs interviews are discussed in the sections which follow.

Science as a way of knowing. Cleomedes described science as a way of knowing that differed from other ways of knowing because of the means by which that information was obtained. Cleomedes believed that as a body of knowledge, science has more evidence-based documentation than other ways of knowing, such as religion. Cleomedes stated,

> I think with science researchers, [they] have better-tested documentation versus philosophy or religion, only because [science] dates just as far back as philosophical beliefs or religious beliefs. So, it's not a lot of evidence from those versus science. [Science] is more evidence-based knowledge that can be considered to be somewhat factual versus philosophical or religious artifacts. (Cleomedes, GTA beliefs interview, January 10, 2019)

This statement insinuated that apart from science, there are various ways of knowing and science differs from these other ways of knowing because scientific knowledge is derived from documented evidence.

Science is a human endeavor. Cleomedes declared that people make contributions to the scientific body of knowledge from many nations and cultures and that human endeavor influences the nature of scientific findings. She equated human endeavor to the creativity and imagination of members of the scientific community. Cleomedes explained that the efforts of scientists influenced their investigations and highlighted the amount of work that scientists put into their research. She admitted that habits of mind and openness guide scientists to new ideas. According to Cleomedes,

> So, I know some scientists read up on how experiments have been done in the past and then try to mimic that and also try to find new things from that. They are skeptics. And so, I guess if they find new things, then they are somewhat using new knowledge or new inventions or something like that. But they do have a baseline to fall back on. (Cleomedes, GTA beliefs interview, January 10, 2019)

Cleomedes identified scientists as skeptics and believed that, as a result, they would be open to new ideas or new ways of conducting investigations. These claims disclosed that Cleomedes viewed the work of scientists as imaginative, creative, and driven by scientists' persistence.

Science is based on empirical evidence. In Cleomedes' view, "scientific evidence makes people more accepting of scientific knowledge and its development" (GTA beliefs interview, January 10, 2019). She proposed that evidence makes people feel more comfortable with validity. According to Cleomedes (GTA beliefs interview, January 10, 2019), "If you have evidence to back up what you're saying as truthful or new scientific knowledge, then that evidence is your proof of people validating what you're saying is to be true." Notably, Cleomedes assumed that this characteristic was primarily essential for the development of the body of knowledge in science as well.

Science uses a variety of methods. Cleomedes believed that in the process of gaining scientific knowledge, science researchers used a variety of different methods and techniques during their investigations. However, she explained that based on the nature of the investigation, the emphasis was placed on methodology. According to Cleomedes,

> I think it depends on what they're looking for. They use different methods and ways to investigate, and this depends on what they are trying to find. Like if they are trying to prove something that was already proven or to add to that information. You know to extend on that information. So, it depends. But a scientist uses a variety of methods. (Cleomedes, GTA beliefs interview, January 10, 2019)

This statement asserted that Cleomedes believed that science uses a variety of methods and that the methods used are determined by the nature of the investigation and the discovery of new information.

Summary of Cleomedes' professed beliefs about NOS. In summation, Cleomedes' GTA interview highlighted four characteristics of NOS about which she made explicit claims. A summary of Cleomedes' claims regarding four of the characteristics of NOS are as follows:

- Science is a way of knowing that is different from other ways of knowing because it is supported by evidence.
- Science is a human endeavor, and the practice of science is seen in the way that scientists design experiments using their creativity and imagination.
- Science is based on empirical evidence.
- Science uses a variety of methods, and these methods are influenced by what is being investigated.

The following section describes Cleomedes' beliefs about learning.

Beliefs about Learning

An instructor's beliefs about how to learn are an essential aspect of their epistemological beliefs, primarily since epistemological beliefs affect instructional practices. This section discusses Cleomedes' beliefs about learning specific to these four aspects: the ability to learn, how to learn, control of learning, and the role of students in learning.

Ability to learn. Cleomedes believed that effort was one of the essential agents of influence on a student's ability to learn and that every individual can construct knowledge if a certain level of diligent effort is made. For example, when asked about where students' ability to learn comes from, Cleomedes stated,

> I think learning ability comes from the student. So, if you are determined to learn and you're determined to overcome any type of hurdle that you may encounter, you're gonna be able to succeed. When I'm determined to do something, I'm gonna go above and beyond to achieve whatever goal that I set for myself. And then as far as innate and inborn ability, I think I used that ability when I was younger. But now that I'm older, I really have to work hard to learn certain concepts and things like that. I have to make an effort. (Cleomedes, GTA beliefs interview, January 10, 2019)

How to learn. Cleomedes acknowledged that interactions between students were necessary for them to construct their own meaning about a concept. According to Cleomedes, this is how students learn. In support, she explained, "I think the knowledge that [students] gain is learned through hands-on and group activities. So, incorporating active learning exercises where students can interact and work in groups is the best way to learn science" (Cleomedes, GTA beliefs interview, January 10, 2019). In addition, Cleomedes asserted that everybody learns differently and that there were variations in the ways that students constructed knowledge. Cleomedes supported her belief by positing that every student is different, and their understanding comes about in various ways based on their experiences and ways of learning. To further explain, Cleomedes purported that,

> I think that everybody learns differently. I don't think it's one-way. I don't think one person is like 'I'm an auditory learner, or I'm a visual learner.' I think that it is a combination of two or three things. However, I do believe that people do learn differently and benefit from different styles of teaching. (Cleomedes, Genetics VSR Interview, April 2, 2019)

Cleomedes' claims implied that learning is best if students are engaged in hands-on learning activities that promoted the construction of their own knowledge. Also implied from these claims is an interrelatedness in Cleomedes' views about how to learn and how to teach. This was noted in her explanation of providing students with opportunities to engage in hands-on and group activities.

Control of learning and the role of students. Cleomedes did not believe that there was a difference between the role of students and the person in control of the learning process. Therefore, for Cleomedes, these two aspects of the nature and process of learning were comingled. In continuation, Cleomedes acknowledged that students should have an active role in the classroom. According to Cleomedes,

> What I mean is that most of the things in a science classroom is particularly hands-on. So, [students] should be actively engaged in the lesson and the activities within the classroom in order for them to learn. That is what their role is, to be active participants in their own learning. (Cleomedes, GTA beliefs interview, January 10, 2019)

Cleomedes further explained that students should apply themselves and make an effort in order to learn. She stated that,

> I think the first and most important thing is effort because if a student doesn't put forth the effort or doesn't even care about the content that they're learning, then everything else kind of falls by the wayside. So, they're not going to be willing to learn if they're not putting forth that effort, then they will not succeed. (Cleomedes, GTA beliefs interview, January 10, 2019)

These claims implied that Cleomedes believed that students are active participants in their own learning and that learning occurs through students' endeavors. This idea seemed to be an extension of her views on how to learn.

Summary of Cleomedes' professed beliefs about learning. During the GTA beliefs interview, Cleomedes made proclamations regarding her beliefs about learning. More specifically, she made claims about her views on the ability to learn, how individuals learn, who is in control of learning, and the role of the student in learning. A summary of her claims are as follows:

- The ability to learn comes from self and is driven by setting goals and making an effort.
- Students learn best by engaging in hands-on activities that promote the construction of their knowledge.
- The role of the student is to be active participants in charge of their own learning, and effort is an integral part of the learning process.

The section which follows describes Cleomedes' beliefs about teaching.

Beliefs about Teaching

This section describes the Cleomedes' beliefs about teaching, specifically her beliefs about the role of the instructor, how to teach, and the goal of teaching. These aspects of teaching provide an insight into how Cleomedes' science instruction in the laboratory is associated with her conceptions of teaching.

How to teach. Cleomedes held the belief that instructors need to create a learning environment that promotes the acquisition of knowledge and accentuates the need for differentiated teaching methods. Cleomedes also acknowledged that a teacher needed to teach using strategies of which he or she is both familiar and comfortable. Her description of her views on how she used differentiated teaching strategies was premised on her experience teaching as a GTA. Her description is as follows:

> I do short lectures and then the lab activities. I really haven't incorporated any new teaching strategies within the lab, but I use different visuals and have different things incorporated. Sometimes I would incorporate a short video if [students] weren't understanding the content and try to just break it down for them. I think lecturing [is] what was familiar to me. But I felt that students felt more comfortable when I interacted with them. And so, that's why I choose to do more than just [lecture]. So, what I mean as far as the lecture part, that's what I was used to in my undergrad and my graduate experience. I'm thinking of maybe incorporating something else this semester. It's best to teach the ways you're comfortable with. I really don't know what, but I know that last semester [lecture] did work for my students. I also include discussions. And then when we're done with the content component, then I'm constantly walking around asking questions to students, and I'm kind of just in there with them helping them where they need help in the lab. And so, for me, it would just be to make sure everybody understands what we're doing as far as the lab by using different strategies. I ask questions like, "Why is it important? What are we actually looking for?" Not necessarily saying, "Okay. These are all the definitions. Memorize this. This is going to be on the quiz." I want them to know why we're doing what we're doing and how it is important for them. (Cleomedes, GTA beliefs interview, January 10, 2019)

From this excerpt, it is apparent that Cleomedes believed that an instructor should vary his or her instruction to include lectures as well as discussions and interactions. However, she also felt that an instructor needs to teach using the teaching approach that makes him or her comfortable. Her claims disclosed that she preferred the traditional method of lecturing (e.g., using PowerPoints with few words) because she was comfortable with this style of teaching.

These claims on *how to teach* contradicted her previous claims regarding *how to learn* (discussed in the previous section). In her conversation on how to learn, Cleomedes posited that students learned best by engaging in hands-on activities that allowed them to construct their own learning. However, in her proclamations about *how to teach*, she explained that it is best to employ the teaching style that you feel is most comfortable. In her case, the most comfortable teaching style was lecturing, a style that did not provide the opportunities for hands-on learning and student-student interactions. Cleomedes supported her need for a lecture by positing that students needed to learn the various content knowledge before engaging in the hands-on activities. This insinuates that she viewed hands-on activities as ways of supporting what students had already learned instead of ways of facilitating the learning of science content. Cleomedes also claimed that she would like to try other strategies during her instructions. However, she believed that her current science instructional practices work. Therefore, there was not an immediate need to make any changes.

Role of the instructor. Cleomedes considered herself a facilitator in the classroom. She stated, “I am the facilitator and the lecturer, not the dictator in the laboratory” (GTA beliefs interview, January 10, 2019). She also claimed that she wanted lessons to be an open discussion. So, she did not just sit and talk down to the students like a teacher in the traditional classroom setting would do. “My job is to make students want to have a conversation with me as well as their peers” (Cleomedes, GTA beliefs interview, January 10, 2019). Cleomedes explained that her role as facilitator was to encourage learning by promoting more conversations in the classroom. However, Cleomedes’ claims once again indicated a struggle between various beliefs in her belief system. For example, she asserted that she used the traditionalist approach (lecturing) and the constructivist approach (facilitating) simultaneously to promote teaching and learning in the laboratory. These claims revealed a conflict between Cleomedes’ beliefs, more specifically, between her core and peripheral beliefs about teaching and learning.

Goal of teaching. Cleomedes believed that a knowledge of science would encourage individuals to have a better understanding of the world and how it works. She noted that she used this perception to guide her teaching. According to Cleomedes,

> I think we need to learn science, so we know about the world around us. So, I think that’s the most important. And then also some careers you have to have a science background. But I think really just to be aware of the world around you, be aware of your body, be aware of what you’re consuming, and how you’re treating the environment. I would say I agree with them. Teaching an Intro to Bio course similar to this one, I think my goal would just be for everyone to be aware of their environment and what they consume and then how they’re treating the environment.

This excerpt divulged that Cleomedes’ goal of teaching was to increase students’ awareness of the natural world and how it works.

Summary of Cleomedes’ proclamations about her beliefs about teaching. Cleomedes’ view about teaching revealed some issues that indicate d contradictions between her beliefs about *how to teach* and *how to learn*. Although the two constructs were discussed separately, they are related. In this instance, Cleomedes' proclamations on *how to teach* did not extend on her beliefs about *how to learn*. The following provides a summary of her views about teaching.

- The most effective way to teach is to engage students in hands-on activities that encourage them to construct their own knowledge.
- Cleomedes' role as an instructor is to be a facilitator and lecturer.
- Her goal of teaching is to increase students' awareness of the natural environment and how things work in the natural world.

The section which follows provides a discussion on Cleomedes' science instructional practices.

Cleomedes: Science Instructional Practices

Since the 1960s, science education has been advocating changes in science instructional practices that will promote the recruitment of higher numbers of students into careers in science. Specific emphasis has been on how science is taught. This section presents the analytical results of Cleomedes' use of the eight science instructional practices proposed by *Science for All Americans* (AAAS, 1996, 2013). These eight practices accentuate the distinctive characteristics of the material to be learned, and the conditions under which the teaching and learning are to take place in the science classroom. These practices were: (1) start with questions about nature, (2) engage students actively, (3) concentrate on the collection and use of evidence, (4) provide historical perspectives, (5) insist on clear expression, (6) use a team approach, (7) do not separate knowing from finding out, and (8) de-emphasize the memorization of technical vocabulary.

Cleomedes' Laboratory Instruction

Lesson structure. Cleomedes had a small-sized laboratory group of about 13 students. She was very regimented and methodological as an instructor and pre-planned for factors that would impact teaching and learning like time constraints. She ascribed her highly structured instructional behavior to her time spent as a high school science teacher preparing students for state exams. As a result, she had a tightly organized and methodical laboratory design, in that, during each laboratory, although each lesson covered different content, Cleomedes delivered the content material and assigned activities in a similar sequence. She started with a quiz, briefly reviewed assignments and other information on which students needed to be aware, briefly lectured, and finally started laboratory activities. According to Cleomedes, she preferred to conduct her laboratory similarly to how she was taught in high school. For example, she insisted that students followed the step-by-step instructions from the laboratory manual. Procedures were reinforced at the beginning of each experiment, where student volunteers read the procedures out loud to the class while the others followed along in their laboratory manuals. Cleomedes believed that this strategy reduced the chance of student errors during the laboratory.

Furthermore, Cleomedes emphasized the lecture portions of the laboratory because she believed that students needed to gain an understanding before delving into the hands-on activities. Therefore, she gave a brief lecture or review before engaging in the activities for the lesson. Cleomedes covered most of the activities that were listed in the students' laboratory manual, even doing some of the laboratory exercises that other GTAs did not. A strategy that was unique to Cleomedes was asking students to use their own words to explain some of the things they had learned during an activity before moving on to the next activity. At the end of the laboratory period, students cleaned up their spaces, washed and replaced apparatuses, and worked on completing and submitting their in-lab paperwork.

Science instructional practices. Cleomedes' lessons were observed for the instances when her instructional practices demonstrated the eight science teaching principles as defined by the AAAS (1993, 2011). Cleomedes incorporated many of the science instructional practices during her lessons; that is, five out of the eight recommended science instructional practices (Table 21). The instances where her instruction demonstrated practices that countered the eight recommended scientific practices are noted (Table 22). In tables 21 and 22, an 'X' indicates the science instructional practice that Cleomedes employed during her teaching episodes in the laboratory. The tables also highlight information regarding the activities that required students to collect data as well as instances where Cleomedes conducted demonstrations of certain activities while the students paid attention to what she was doing. For example, students collected data during the *Blood Typing* activity, and Cleomedes conducted a demonstration for students to observe during the *Yeast and Gas Production* activity.

Table 21

Science Instructional Practices Demonstrated During Cleomedes' Laboratory Lessons that Aligned with the Eight Science Instructional Practices Described by AAAS (1993,2011)

	Science Instructional Practice							
Lesson Associated Activities	1	2	3	4	5	6	7	8
Fermentation								
You and Gas Production[a]		X						X
Yeast and Gas Production[b]							X	X
Quantifying Gas Production[a]	X	X				X	X	X
DNA Extraction and Mitosis								
Strawberry DNA Extraction		X						X
Stages of Mitosis (Simulation with Beads)	X	X						
Stages of Mitosis (Microscope)		X						
Human Genetics								
Pipe Cleaners and Beads	X	X						
Human Genetics	X	X			X			X
Punnett Squares Worksheet		X						
Blood Typing[a]	X	X						X
Plant and Animal Reproduction								
Spread of STIs	X	X					X	
Flowering Plant Dissection	X	X						
Male and Female Anatomy (Microscope)		X						
Parts of a Seed	X	X						

Note. The numbers in the science instructional practices columns coincide with the following: 1 – Use Team Approach; 2 – Students are Actively Engaged; 3 – Start with Questions about Nature; 4 – Do not Separate Knowledge from Finding Out; 5 – Provide Historical Perspectives; 6 – Insist on Clear Expression; 7 – Do not Emphasize the Memorization of Technical Vocabulary; 8 – Concentrate on the Collection and Use of Evidence

[a] Activities during which students collected data

[b] Activity during which Cleomedes conducted a demonstration

Table 22

Science Instructional Practices Demonstrated During Cleomedes' Laboratory Lessons that Countered the Eight Science Instructional Practices Described by AAAS (1993,2011)

	Instructional Practice							
Lesson Associated Activities	9	10	11	12	13	14	15	16
Fermentation								
You and Gas Production[a]	X		X	X	X	X	X	
Yeast and Gas Production[b]	X		X	X	X	X		
Quantifying Gas Production[a]			X	X	X			
DNA Extraction and Mitosis								
Strawberry DNA Extraction	X		X	X	X	X	X	
Stages of Mitosis (Simulation with Beads)			X	X	X	X	X	X
Stages of Mitosis (Microscope)	X		X	X	X	X	X	X
Human Genetics								
Pipe Cleaners and Beads			X	X	X	X	X	X
Human Genetics			X	X		X	X	
Punnett Squares Worksheet	X		X	X	X	X	X	X
Blood Typing[a]			X	X	X	X	X	
Plant and Animal Reproduction								
Spread of STIs			X	X	X	X		X
Flowering Plant Dissection			X	X	X	X	X	X
Male and Female Anatomy (Microscope)	X		X	X	X	X	X	X
Parts of a Seed			X	X	X	X	X	X

Note. The numbers in the science instructional practices columns coincide with the following: 9 – Do not Use Team Approach; 10 – Students are not Actively Engaged; 11 – Do not Start with Questions about Nature; 12 – Separate Knowledge from Finding Out; 13 – Do not Provide Historical Perspectives; 14 – Do not Insist on Clear Expression; 15 – Emphasize the Memorization of Technical Vocabulary; 16 – Do not Concentrate on the Collection and Use of Evidence

[a] Activities during which students collected data

[b] Activity during which Cleomedes conducted a demonstration

Students are actively engaged. During the laboratory lessons, students were actively engaged most of the time. There was only one activity during her lesson on fermentation, where students only observed Cleomedes conduct a demonstration on gas production in yeast. Even after the demonstration, students were involved in discussions of the process of gas production and how it was connected to the process of cellular production in organisms. Cleomedes ensured that students had many and varied opportunities to engage in hands-on activities such as observing, note-taking, using microscopes, measuring, and computing, among other activities. Even if she spent a lot of time lecturing, she also found it important for students to be actively engaged. This instructional practice reflected Cleomedes' view on how to teach and how to learn. These two views indicated a struggle in Cleomedes' instructional actions that showed a back-and-forth between a teacher-centered teaching approach (i.e., lecturing) and a student-centered approach (i.e., students engaged in hands-on and inquiry). Cleomedes' claims revealed a conflict between her core and peripheral beliefs about teaching and learning.

Start with questions about nature. Cleomedes started her lessons with a lecture that included the review of some of the content material that students had learned in the previous laboratory. During these lectures, Cleomedes asked questions and probed students' recollections to highlight what she considered to be important. However, questions were not about phenomena that would foster the curiosity of students. The questions were based on the content material that was covered during the previous laboratory. For example, Cleomedes began the Fermentation laboratory lesson with the following question: "So today's lab we're talking about fermentation, but also we're also going to be talking about cellular respiration. So, is everybody familiar with cellular respiration, and if so, can somebody tell me what that is?" (Cleomedes, Lesson on Fermentation, February 28, 2019). This last claim disclosed that Cleomedes was using questioning as a means of connecting the content material of the different laboratory lessons so that students did not think that science content for each laboratory was isolated and separate.

Use a team approach. Most of Cleomedes' lessons involved students working together as a team, actively engaged in hands-on activities. Cleomedes ensured that her students worked in groups and encouraged everyone's full participation, including that of the students joining her class for makeup labs. She cautioned groups about chemicals and ensured that each one looked out for each other and followed directions because procedure and methodology were highly regarded in Cleomedes' laboratory. These actions reflected her regimented instruction. Even when students followed directions as they should, there were some instances when they did not obtain the anticipated results. She encouraged students to repeat the experiment to obtain the expected results.

Do not emphasize the memorization of technical vocabulary. The opposite of this science instructional practice was employed during Cleomedes' laboratory teaching episodes. That is, Cleomedes ensured that she emphasized the memorization of technical vocabulary (Table 21). For example, there was only one activity during which technical terms were not highlighted. Cleomedes believed that students needed the necessary background information in order to be able to complete laboratory activities. As a result, she emphasized the memorization of terms and words. For example, during the Human

Genetics laboratory lesson, Cleomedes reinforced some of the genetics terminologies by stating,

> A couple of more terms just to get us started. We talked about what a chromosome is. So, it's a condensed strand of DNA. We also talked about the gene being the hereditary unit in the last couple of labs. And then, we also talked about alleles, which are a variation of a gene. So, these terms are just reviewing some of what we have talked about for the last couple of labs. But on page 82, you can write the definitions again if you like. (Cleomedes, Lesson on Human Genetics, March 28, 2019)

These claims disclosed that Cleomedes conceptualized student understanding as having the ability to define technical terms. Her assertions also revealed her use of traditional teaching approaches considering that her lecturing strategies supplied information that students might have already known rather than soliciting their input to provide background.

Concentrate on the collection and use of evidence. For the activities that required students to collect evidence, Cleomedes did not provide students with the opportunity to express their interpretations of what the evidence meant verbally. According to Cleomedes, there was not much time for lengthy discussions, since there were so many things to cover in just two hours. Instead, she focused on ensuring that data collection was conducted appropriately. To compensate for this shortcoming, Cleomedes acknowledged that she reviewed some of the expected results before students engaged in the various activities. The following excerpt from Cleomedes' lesson on Fermentation is an example that she verified during her VSR interview as an instance where she provided students with information about the activity in advance so that she would have more time to complete other laboratory exercises.

> So, with this lab, we're going to see if, in fact, you are breathing out carbon dioxide and we're gonna use bromothymol blue as our indicator. So, does anybody know what an indicator is like what does an indicator tells us? So, if you indicate something what does that mean? Pointing it out, making it known, or making it visible. So, of course, you can't really see your carbon dioxide when you exhale. Only if you live like in a cold climate you can kind of see the carbon dioxide. But we can't really visibly see the carbon dioxide. But with this activity, we're gonna actually see the color change of the bromothymol blue when you're blowing into the test-tube. (Cleomedes, Lesson on Fermentation, February 28, 2019)

This excerpt highlighted teacher-centered instruction and depicted content knowledge acquisition as a one-way transmission process from teacher to student. This statement revealed that Cleomedes ensured that students were aware in advance that they would be collecting evidence that was important and should be on the lookout for specific observations or findings. As a result, Cleomedes' instruction seemed to involve some pseudo-concentration on the use and collection of evidence. Hence, Cleomedes' desire to move through all the material to complete all of the lesson's activities outweighed her need to follow recommended instructional practices. The term *pseudo*, in this case, stood for imitation and disclosed that Cleomedes' science instructional practice reflected imitation of the instructional practice recommended by the AAAS rather than the actual instructional practice.

Insist on clear expression. Although her lessons always engaged students in discussions, Cleomedes did not emphasize the need for clarity and clear expression. Based on observations of Cleomedes' lessons, it was noted that when students struggled to explain their findings or could not orally communicate their claims or arguments, Cleomedes would step in and present the information herself or call upon another student whom she knew would be able to be present the information more clearly and succinctly.

Cleomedes' instruction always included moments at the conclusion of an activity where she asked students to use their own words to explain some of the things they had learned during the activity. This action further supported the observed inconsistencies in Cleomedes' instruction, which involved a back-and-forth instruction between traditional and constructivist approaches.

Cleomedes was probed about an instructional decision of an instance when she called a specific student whom she believed to have mastered the knowledge of using Punnett squares to complete the questions on the whiteboard. Cleomedes acknowledged that she did not have enough time to ensure that all students could explain with clarity (Cleomedes, Genetics VSR interview, April 2, 2019) and, therefore, this type of review enabled students to "catch up by following the example that the student had written on the whiteboard" (Cleomedes, Genetics VSR interview, April 2, 2019). This claim indicated time constraints impacted Cleomedes' actions and negatively influenced her demonstration of the science instructional practice, *insist on clear expression*.

Do not separate knowledge from finding out. Cleomedes separated knowledge from finding out. Her lessons highlighted knowing about the accumulated knowledge in science without much emphasis on the understanding of the development of that knowledge. When asked about her approach in this regard, Cleomedes admitted that most of her training was as a high school science teacher, where she spent most of her time preparing students for standardized tests. She added that although her high school students were engaged in hands-on activities, they memorized and reproduced scientific information that was tested. Therefore, this revealed that Cleomedes was more comfortable teaching science in that way that she was taught at the undergraduate level and that she valued memorization over the development of higher-order thinking skills of her students.

Provide a historical perspective. Based on Cleomedes' laboratory observations, there were very few instances during which Cleomedes provided students with a historical context of the content material being taught. For example, the only instance was during the Genetics lesson when students were learning about Gregor Mendel's laws of inheritance. The historical aspect of this lesson was predetermined and was embedded in the PowerPoint presentation that was issued by the biology department. Therefore, this single case in which Cleomedes *provided a historical perspective* on the father of genetics was not an accurate or verified enactment of this science instructional practice.

Frequency of Cleomedes' science instructional practices. During the four observations, Cleomedes completed a total of 14 activities with her students, during which time she demonstrated the use of many of the science instructional practices. The frequency of the use of each science instructional practice was calculated and is shown in Figure 30. Calculation of the frequency of science instructional practice was calculated by:

1. noting the science instructional practices that were demonstrated during the teaching of each activity;
2. tallying the total number of activities completed in each lesson; and
3. calculating the frequency (%) of the demonstration of each science instructional practice by dividing the sum of each science instructional practice by the total number of activities per lesson and multiplying by 100.

For example, Cleomedes completed a total of 14 activities during the four lessons in which she was observed. She employed the use of the science instructional practice, *use a team approach*, eight out of the 14 times. The frequency of demonstration of this science instructional practice was calculated as : $\frac{8}{14} \times 100 = 57\%$.

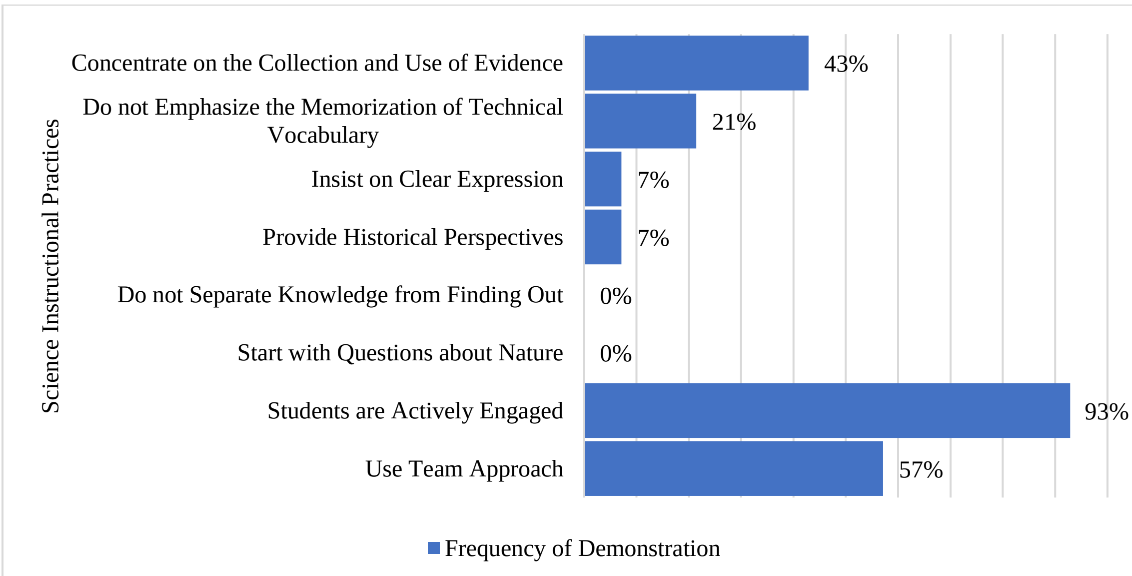


Figure 30. Frequency of the demonstration of the science instructional practices by Cleomedes.

The most frequently demonstrated science instructional practice was *students are actively engaged* (93%), followed by *use a team approach* (57%), *concentrate on the collection and use of evidence* (43%), *do not emphasize the memorization of technical vocabulary* (21%), and *insist on clear expression* and *provide a historical perspective,* both which were seven percent. Observations of Cleomedes' laboratory lessons showed that she did not employ two of the science instructional practices at any time during the four laboratory lessons observed. These two science instructional practices were: *start with questions about nature* and *do not separate knowledge from finding out*. Regarding the instructional practice *start with questions about nature,* it must be noted, though, that although Cleomedes did not begin any of her observed lessons with questions about nature, she did begin each lesson with content-related questions, more specifically, questions about the content information taught during the previous laboratory. For example, for her lesson on Plant and Animal Reproduction, Cleomedes began by asking, “So asexual and sexual, who remembers what asexual is?” (Cleomedes, Plant and Animal Reproduction Lesson, April 11, 2019). This inferred that questioning was an important aspect of Cleomedes’ laboratory lesson introduction. Following this discussion of results on Cleomedes’ science instructional practices, the next section presents the findings that indicate the nature of the relationship between the features of her professed beliefs and science instructional practices.

Cleomedes: Relationship between Cleomedes’ Features of Epistemological Beliefs and Science Instructional Practices

This section presents information regarding the instances where the features of Cleomedes’ epistemological beliefs contrasted with the science instructional practices presented and recommended by the AAAS (1993, 2011). Analysis of the data revealed mismatches—misalignments—between the features of Cleomedes’ epistemological beliefs and the science instructional practice recommended by the AAAS (1993, 2011). A misalignment describes Cleomedes’ demonstration of a science instructional practice that highlighted her thoughts and actions in the laboratory but countered the recommendations of the AAAS (1993, 2011). In this case, Cleomedes’ proclamations aligned with the recommendations of the AAAS, but these professed beliefs were not demonstrated during her instructional practice. The recommendations of the AAAS (1993, 2011) underlined eight teaching practices believed to be consistent with the nature of inquiry and provide students with the kinds of experience that will enable them to understand science as a way of thinking and doing. The results regarding the relationship between the features of Cleomedes' professed epistemological beliefs and science instructional practices are presented under the categories: epistemological beliefs in general, epistemological beliefs about the nature of science, and beliefs about teaching.

Misalignments between Features of Epistemological Beliefs and Science Instructional Practices

Epistemological beliefs in general and science instructional practices.

***Cleomedes' beliefs about the* justification of knowledge *and the science instructional practice* concentrate on the collection and use of evidence.** The data indicated a connection between biology Cleomedes' feature of epistemological beliefs regarding the *justification of knowledge* and the scientific instructional practice *concentrate on the collection and use of evidence* (Figure 31). According to the AAAS (1993, 2011), students should engage in problem-solving activities that require them to decide what evidence is relevant and to offer their own interpretations of what the evidence means.

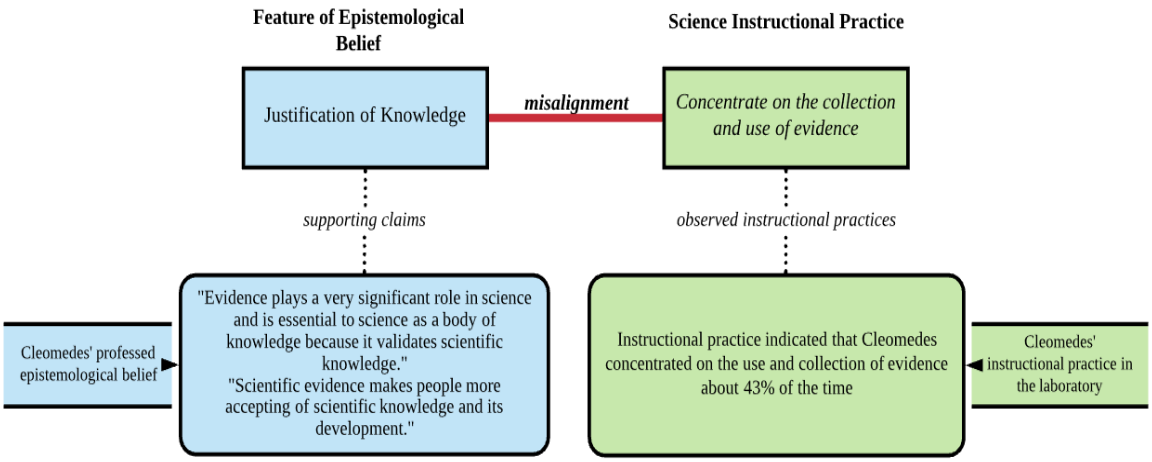


Figure 31. Relationship between Cleomedes' epistemological beliefs about the *justification of knowledge* and the enactment of the scientific practice *concentrate on the use and collection of evidence*.

Cleomedes acknowledged that "evidence plays a very significant role in science and is essential to science as a body of knowledge because it validates scientific knowledge" and that "scientific evidence makes people more accepting of scientific knowledge and its development" (GTA beliefs interview, January 10, 2019). However, although Cleomedes held this belief about the role of evidence in science and how evidence is used to support scientific knowledge, her science instruction did not place great emphasis on the collection and use of evidence. Observations of her lessons indicated that she concentrated on the use and collection of evidence about 43% of the time (Figure 29). This indicated a misalignment between Cleomedes' professed feature of epistemological belief and science instructional practice (Figure 31).

Epistemological beliefs about the nature of science and science instructional practices.

***Cleomedes' beliefs about* science as a way of knowing *and the science instructional practice* provide historical perspective.** Data analysis showed a misalignment between the feature of epistemological beliefs about the nature of science, *science as a way of knowing,* and the science instructional practice *provide historical perspectives* (Figure 32).

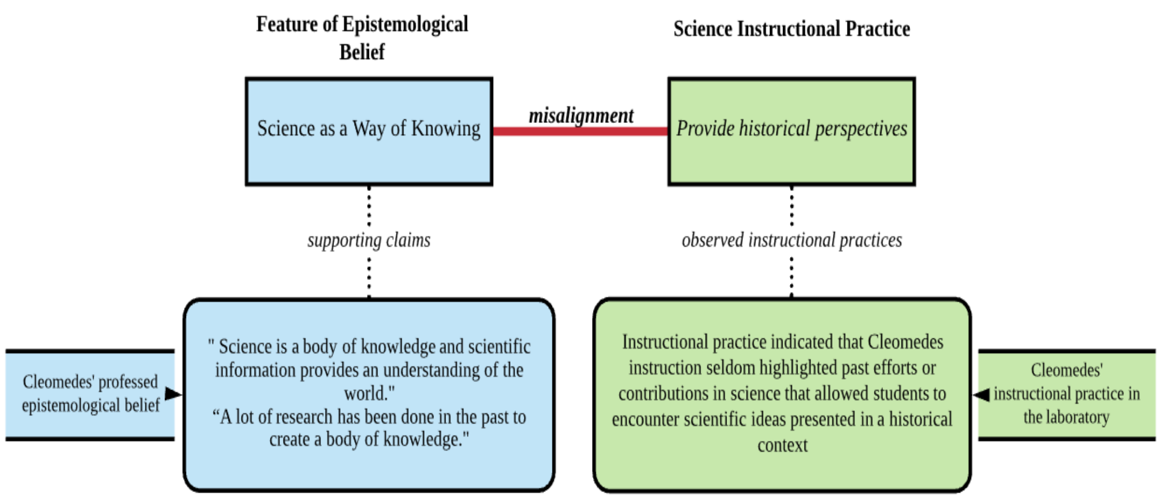


Figure 32. Cleomedes' epistemological beliefs about *science as a way of knowing* and the enactment of the science instructional practice *provide historical perspectives*.

Cleomedes stated that she recognized science as a body of knowledge and that scientific information provides an understanding of the world. Cleomedes noted that "a lot of research has been done in the past to create a body of knowledge" (GTA beliefs interview, January 10, 2019). This statement disclosed that there is a wealth of information based on contributions from past investigations in science and revealed a historical context associated with science as a body of knowledge. Although Cleomedes recognized this historical perspective, her instructional practice seldom highlighted past efforts or contributions in science that allowed students to encounter scientific ideas presented in a historical context nor emphasized the diversity and scope of the scientific enterprise, which includes century-old accomplishments. Observations indicated that there was only one instance when Cleomedes employed the science instructional practice, *provides historical perspectives*, during her lesson on Genetics, specifically Mendel's laws of inheritance. Hence, this revealed a misalignment between Cleomedes' professed epistemological beliefs and science instructional practice (Figure 32).

***Cleomedes' beliefs about* science is based on empirical evidence *and the science instructional practice* concentrate on the collection and use of evidence.** Data analysis showed a misalignment between Cleomedes' professed epistemological beliefs on *science is based on empirical evidence* and the science instructional practice *concentrates on the collection and use of evidence* (Figure 33).

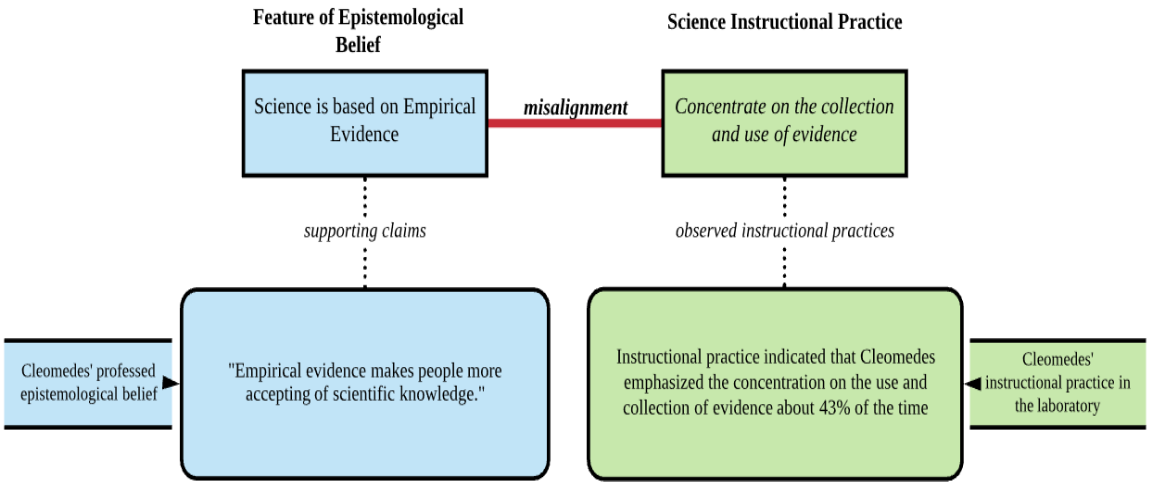


Figure 33. Cleomedes' epistemological beliefs *science is based on empirical evidence* and the enactment of the science instructional practice *concentrate on the collection and use of evidence*.

As previously noted, Cleomedes was very clear regarding her position on the role of evidence in science. Cleomedes purported that "empirical evidence makes people more accepting of scientific knowledge" (GTA beliefs interview, January 10, 2019). There were many opportunities in Cleomedes' laboratory, where students conducted experiments and collected data. For example, lesson observations showed three instances where students engaged in activities that required them to collect data (i.e., *You and Gas Production*, *Quantifying Gas Production*, and *Blood Typing*; Table 20), and there was some degree of focus on the evidence that was collected during these three activities. However, although the other activities did not require students to collect and interpret data, these activities still called for students to carry out investigations, interpret and discuss findings, and form conclusions. Based on observations of Cleomedes' lessons, Cleomedes called on volunteers or sometimes selected a student to present a review of what was done rather than emphasizing how the evidence that was collected was relevant and allowing students to offer their own interpretations of what the evidence meant. According to Cleomedes, this review was important to highlight the results to explain how these findings supported the conclusions. Students were not allowed to decide what evidence was relevant in their investigations and to offer their own interpretations of what the evidence meant.

Analysis of the data indicated that Cleomedes emphasized the science instructional practice *concentrate on the use and collection of evidence* approximately 43% of the time, and this did not include the times when she provided students with the expected results in advance. Based on Cleomedes' proclamations regarding the role of evidence in science, this indicated a misalignment between her professed epistemological belief and science instructional practice.

Summary of misalignments between features of Cleomedes' epistemological beliefs and science instructional practices. Regarding Cleomedes, the data revealed that there were three misalignments between her professed features of epistemological beliefs and the recommended science instructional practices of the AAAS (1993, 2011). Misalignments represented the instances where Cleomedes' professed epistemological beliefs that, although reflected the ideas recommended by the AAAS (1993, 2011), were not reflected in her instruction in the laboratory. The science education reform document issued by the AAAS (1993, 2011) recommends eight practices of teaching that are proposed to be consistent with the nature of scientific inquiry. The aim of these science instructional practices is to facilitate the kinds of experience that students need to enable them to understand science as a way of thinking and doing.

According to the findings, Cleomedes' professed epistemological beliefs, although they harmonized with the recommendations of the AAAS (1993, 2011), were not demonstrated during her teaching episodes in the laboratory. The analysis of results specific to the features of Cleomedes' epistemological beliefs and her science instructional practice identified three misalignments between the two constructs. These misalignments are summarized in Figure 34.

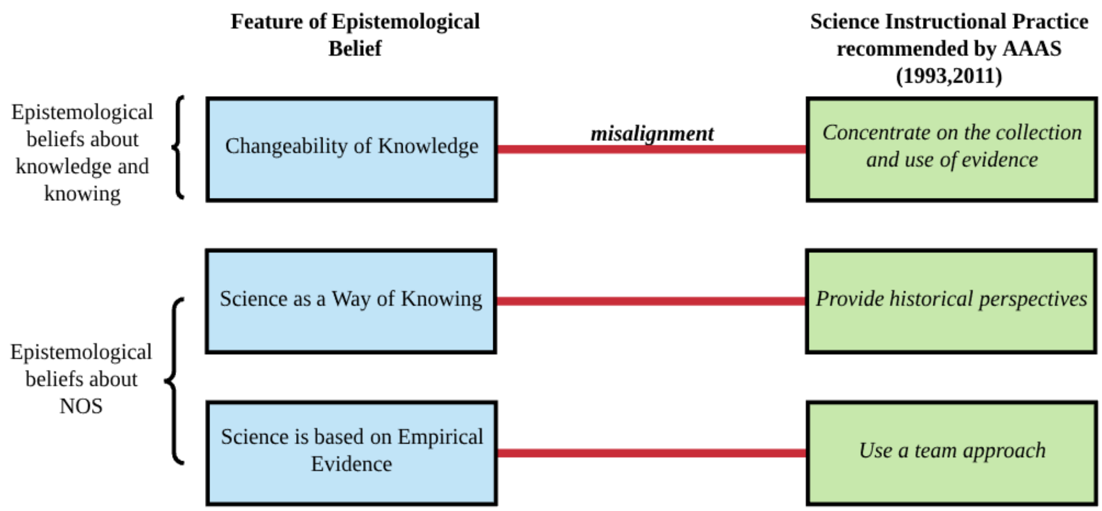


Figure 34. Misalignments between Cleomedes' professed features of epistemological beliefs and science instructional practices recommended by the AAAS (1993, 2011).

Alignment between the Professed Features of Epistemological Beliefs and Science Instructional Practices

The data were also analyzed to consider the alignment between Cleomedes' features of professed epistemological beliefs and the science instructional practices as posited by the recommendations in the reform document issued by the AAAS (1993, 2011). Findings indicated that there was a positive association—alignment—between the features of Cleomedes' professed epistemological beliefs about knowledge in general (the nature of knowledge and knowing) and the science instructional practice *changeability of knowledge*.

Cleomedes' beliefs about the *changeability of knowledge* and the science instructional practice *students are actively engaged.* Cleomedes believed that knowledge changed over time with new experiences. She also explained that it was beneficial to provide students with opportunities where they could gain new knowledge by engaging in hands-on activities. Cleomedes claimed that,

> I think, over time, knowledge can be altered slightly. Not saying that you still don't withhold those beliefs or the knowledge that you learn prior to [that], but it might be changed or altered due to your different experiences. Or, due to different teachers, you may encounter or different knowledge you may obtain or through hands-on experiences or something like that. (Cleomedes, GTA beliefs interview, January 10, 2019)

This claim disclosed that one's knowledge structure could change as a result of exposure to various types of experiences. As a result, Cleomedes believed that instructors should employ different ways of presenting the content to the students in order to facilitate an increase in student understanding. She also stated, "I think the knowledge that [students] gain is learned through hands-on and group activities. So, incorporating active learning exercises where students can interact and work in groups is the best way to learn science" (Cleomedes, GTA beliefs interview, January 10, 2019). Observations of Cleomedes' lessons showed that her science instructional practices supported her beliefs in this regard. Students were actively engaged about 93% of the time (Figure 30). Cleomedes' laboratory lessons involved a total of 14 activities. The alignment between Cleomedes' epistemological beliefs in general, specifically regarding *the changeability of knowledge* and the science instructional practice *students are actively engaged* is highlighted in Figure 35.

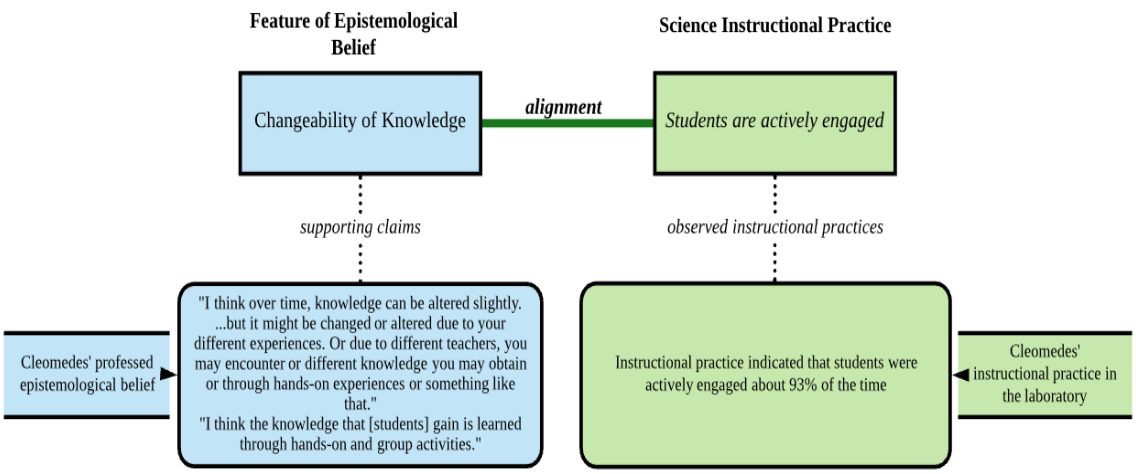


Figure 35. Relationship between Cleomedes' epistemological beliefs about the *changeability of knowledge* and science instructional practice *students are actively engaged*.

Summary of alignments between features of Cleomedes' epistemological beliefs about science instructional practices. The findings of this study identified only one positive association—alignment—between Cleomedes' professed features of epistemological beliefs and science instructional practice. An alignment, in this case, described an instance where Cleomedes' science teaching practices reflected the recommendations of the AAAS (1993, 2011), which are believed to be consistent with the nature of inquiry and that provide students with the kinds of experience that will enable them to understand science as a way of thinking and doing. The only alignment specific to Cleomedes was found to be between her beliefs about *the changeability of* *knowledge* and the enactment of the science instructional practice *students are actively engaged*.

Cleomedes: How Complexity Theory Describes the Interrelatedness between the Features of Cleomedes' Epistemological Beliefs and Science Instructional Practice

Complexity theory is the study of complex systems and is defined as a collection of individual agents with freedom to act in ways that are not always totally predictable, and whose actions are interconnected so that one agent's actions changes the context for other agents. Complexity theory emphasizes relationships among the subparts of a system and the emergence of something new. One of the critical ideas of complexity theory and education, which is particularly relevant to this study, is that many aspects of education, including classrooms, can be seen and understood as a complex system. The philosophy of complexity is that complex systems such as the classroom have properties—emergent properties—that cannot be reduced to the sum of their mere parts and look at each individual component. Instead, to understand the behavior of such systems, it is more favorable to consider the components while concentrating on the interactions between the various components. Complex systems have several characteristics that typify complex systems, including *self-organization*, *emergence*, *non-linearity*, *interconnectivity*, and *autonomy and adaptation*. This section identifies one of these five characteristics—interconnectivity—which explained the connections between the components of focus (i.e., Cleomedes' professed epistemological beliefs and science instructional practices).

The data also revealed that the other attributes of complex systems used in this study could not be applied to describe the complex nature of Cleomedes' laboratory. For example, spontaneous and unanticipated occurrences in the laboratory, like a significant number of malfunctioning microscopes and missing flowers for the dissection activity, were changes that influenced evolution and adaptability in the classroom system of some of the other GTAs. These unforeseen changes stimulated the arousal of *emergence*, *self-organization*, and *non-linearity* within the systems and revealed the nature of interactions that took place between professed epistemological beliefs and science instructional practice. However, as a regimented and meticulous instructor who had a rigid adherence to schedule/agenda and a small group of approximately 13 students in a laboratory meant to house 24 students, Cleomedes did not encounter any of the unexpected internal or external perturbations that incited unanticipated effects on either her professed beliefs or science instructional practices. Events that typically appeared as perturbations or agitations in the other GTAs' laboratory systems that initiated the rise of self-organization, emergence, autonomy and co-adaptation, and non-linearity were not observed in Cleomedes' laboratory system. The only attribute of complex systems revealed was the interconnectivity between her professed beliefs and science instructional practices where her professed beliefs were either demonstrated or not demonstrated during instructional practice.

Interconnectivity

Within complex systems, interactions between components show connections. Analysis of findings revealed the interconnection between Cleomedes' professed beliefs and science instructional practices, primarily in the instances where there were alignments and misalignments between the two constructs. For example, her belief about the changeability of knowledge, where she believed that different experiences led to changes in one's knowledge, aligned with her instructional practice, in that this aspect of her belief was observed during her instruction when she provided students with diverse opportunities to be actively engaged.

Summary of the Complexity Theory and its Interrelatedness to the Features of Cleomedes' Epistemological Beliefs and Science Instructional Practice

Cleomedes' professed epistemological beliefs and science instructional practice are part of a complex system, the laboratory. These two constructs, as part of any complex system, interacted with each other, and displayed characteristics that are specific to the nature and type of system. In Cleomedes' case, the data revealed the interconnectivity that resulted from interactions and interrelatedness of the features of her professed epistemological beliefs and science instructional practices. Interconnectivity is a characteristic of complex systems that highlights the interactions between components that show the type of connections between components. As a regimented and highly structured instructor, Cleomedes typically pre-planned for changes that would affect her laboratory system. As a result of her strict adherence to the lesson plan, Cleomedes sacrificed student-centered instruction to complete all of the intended activities, supposedly to benefit the students. As such, this complex system remained in a stable state most of the time.

Diodora: Professed Features of Epistemological Beliefs

Epistemological Beliefs in General (Knowledge and Knowing)

An individual's general epistemological beliefs are concerned with how an individual comes to know what he or she knows and the process of knowing. In this study, the features of epistemological beliefs focused on the nature of knowing and knowledge and recognized four sub-dimensions of domain-general epistemological beliefs (i.e., changeability of knowledge, the structure of knowledge, source of knowing, and justification of knowing) as the core dimensions of epistemological beliefs (Hofer & Pintrich, 2002).

Changeability of knowledge. Diodora expressed that she was sure that knowledge did not change. She purported that understanding is based on an individual's knowledge, and it is that understanding that changes. This revealed that Diodora considered the understanding of a concept and knowledge of a concept as being different and separate. She also stated that an individual's perception of a piece of knowledge could change, and this can lead to learning. According to Diodora,

> I'd say that knowledge stays the same, but [the] understanding and use of that knowledge change. So, maybe [one's] perception of that knowledge changes. I think, if you have incoming freshmen who are 17 and 19 years old and they're learning something, their life experiences aren't as in-depth as say 24-, 25-, 26-year-olds. As they get older, maybe how they understand what they've learned changes. But I don't think the nature of that knowledge changes – just how they use that material. (Diodora, GTA beliefs interview, January 29, 2019)

To further explain her standpoint, Diodora defined knowledge as information, a collective of ideas, or accepted truths that are based on one's external environment, educational contexts like school, and even contexts that encompass one's way of life or means of survival (e.g., street life) that characterize the nature of an individual's knowledge. She further added that knowledge is analogous to iCloud storage and can be accessed when needed. However, the information in storage is fixed and unchangeable. These claims revealed that Diodora considered knowledge as being a large body of information that remains unchangeable.

Justification of knowledge. Diodora's perception of the justification of knowledge included the verification of knowledge that she felt was necessary for the validation of any knowledge. According to Diodora,

> I always question everything. That's just nature. If you don't question – if you're always accepting what someone tells you, then are you ever learning? There's a difference between learning and understanding. But if an expert says something and you say, well, I wonder, is that true? Then you're going to go and do that research and look it up, and you're going to then transform that information in a way that you can understand it. And then you can create your own personal opinion on whether you believe it or not. (Diodora, GTA beliefs interview, January 29, 2019)

Diodora also identified scientific literature as a source of verification and claimed that she was willing to accept scientific information even if she believed that there were instances in scientific literature where there were disagreements among scientists and their research comrades. These statements implied that Diodora believed that an individual justifies his or her own knowledge, but that verification depends on other sources such as research-based studies.

Source of knowledge. The source of knowledge is concerned with where an individual believes that knowledge originated. Diodora asserted that knowledge fundamentally came from self-construction. However, she also acknowledged the role of authority as contributors to academic knowledge. Diodora maintained that her background in psychology supported her position in saying that knowledge is self-constructed. She referred to the African proverb, "It takes a village to raise a child," and expressed, "I'd say I probably – myself went out looking for [knowledge] and did not learn because of what was passed on from older people or experts" (Diodora, GTA beliefs interview, January 29, 2019). Also, Diodora presumed that experts are persons who had a lot of knowledge and understanding of a subject matter and included the internet (e.g., Google) as possible experts. Altogether, Diodora retained that the information from experts served as a basis for one to construct his or her own knowledge. Further, she stressed that students should not rely only on one source, especially their instructor, and should feel empowered to build their knowledge. For example, Diodora accentuated her view by saying,

> So, part mostly because I want [students] to empower themselves and have them take hold of their own knowledge. They have their cellphones. I know they have their cell phones – they're minicomputers. They can go and look up prophase, metaphase, anaphase, telophase. You know you give a man a fish feed him for a day. Teach a man to fish feed him for a lifetime. So, if they know these students know that they can go online if they have a question, they can build their own knowledge on mitosis. (Diodora, Genetics VSR Interview, March 27, 2019)

These claims revealed that Diodora believed that an individual is his or her own source of knowledge, and in cases where the individual lacks certain knowledge, he or she can use other sources such as the internet.

Structure of knowledge. In Diodora's perspective, the best knowledge can be either simple or complex. She claimed that it depends on how much knowledge an individual gains from a circumstance. Diodora explained,

> I think the best ideas are the ideas or the processes that teach you the most. So, knowledge can be simple or can be complex. I think – I've heard the adage KISS – Keep It Simple, Stupid. So, I think sometimes, the simple solutions are great. But I think, if you try to understand something complex like an abundance of evidence from an experiment, you will also learn from that. I'd say it really is whatever teaches you the most. (Diodora, GTA beliefs interview, January 29, 2019)

Diodora indicated that while an individual's initial knowledge is simple, it becomes more complex and increases as you are exposed to more knowledge. This disclosed that Diodora believed knowledge could be both simple and complex.

Summary of Diodora's professed features of epistemological beliefs. During the GTA beliefs interview, Diodora expressed her views regarding the four main areas of epistemological beliefs in general. Table 23 provides an overview of the features of Diodora's epistemological beliefs regarding the nature of knowledge and knowing. The section which follows discusses Diodora's professed beliefs about the nature of science.

Table 23

Summary of Diodora's Professed Epistemological Beliefs about the Nature of Knowledge and Knowing

Feature of Epistemological Belief	Proclamation regarding belief about the nature of knowledge and knowing
Changeability of Knowledge	Knowledge is fixed and does not change
Justification of Knowledge	Both self and others justify knowledge
Source of Knowledge	Self and others (e.g., research-based sources) are sources of knowledge
Structure of Knowledge	Knowledge structures are both simple and complex

Epistemological Beliefs about the Nature of Science (NOS)

Hurling (2014) posited that if you are studying a person's scientific epistemological beliefs, then you are studying their views of NOS. Epistemological beliefs about the study of scientific knowledge or the NOS are related to the study of science as a way of knowing. Lederman (1992) posited that the NOS has its own specific set of values and beliefs that characterizes it as scientific. The characteristics of NOS were used to determine Diodora's epistemological beliefs regarding NOS. Only those characteristics of NOS professed during the GTA beliefs interview are discussed in the sections that follow.

Science as a way of knowing. Diodora's explanation of science as a way of knowing demonstrated her view of science as being able to answer questions by pointing out falsehoods and not necessarily justifying or proving information. She noted,

> If seeing is believing, then that's not how it is in science. I'd say, in science, we can never say something is. We can only say it is not. Like you learn that a proton and a neutron – this is what a proton and a neutron is, or this is what an electron is. But as you get older and you learn more – you get up on a collegiate level – you learn that maybe it's not necessarily that way. I'd say within science there are some things that are true, that just are inherent. Whereas, like with religion, I'd say personally for me, you can't prove it. (Diodora, GTA beliefs interview, January 29, 2019)

This statement affirmed that Diodora held the firm belief that science adds to the body of knowledge by confirming what it is not, and that scientific knowledge differs from other bodies of knowledge where individuals have difficulty providing supporting evidence for their claims.

Science is a human endeavor. Diodora was the only GTA who believed that scientific knowledge has not increased due to the creativity of scientists. According to Diodora,

> I think that [scientists] are afraid to be wrong or to go against the grain. Scientists believe that if this is how it's done, this is how it's supposed to be done. I'd say, as a whole, I don't think scientists tend to be very creative. (Diodora, GTA beliefs interview, January 29, 2019)

Diodora believed that the scientific community was governed by principles that hinder scientists' ability to exercise creativity in their investigations. Diodora's claims disclosed that scientists are suppressed in their ability to fully maximize the amount of information that they can add to the body of knowledge in science.

Science is based on empirical evidence. Diodora noted that evidence played a significant role in the development of scientific ideas and discussed circumstances that promoted learning, especially in the scientific community. She held that scientific knowledge is probabilistic and is generated to support what is not because there are things that cannot be observed. She further posited that scientific knowledge might be uncertain at times because there is not enough evidence to support some scientific claims and this provides an opportunity for investigators to reconsider their hypothesis based on the evidence that they have. In the excerpt below, Diodora explained that evidence is vital in learning.

> Sometimes your results aren't always correct. I think that scientific knowledge or knowledge, in general, is driven by data. So, what does evidence do? Evidence gives us an opportunity to teach or to learn. And so, that's one of those mistakes in quotations, it is a learning experience. So, if your results—your evidence—doesn't agree with your hypothesis, that gives you a whole opportunity to go and learn, to find out what did you do? Did you goof up? How did you goof up? Or, is this something new or is it not new, is it supported? Is it common? Then you can go and repeat that experiment and compare the multiple sources of results to find patterns. I think [that's] science – that's how we learn as students and scientists. Students need to be aware of how their results is important, especially with respect to what they are investigating. (Diodora, GTA beliefs interview, January 29, 2019)

Diodora's claims disclosed that science is based on empirical evidence where the results of findings can confirm the validity of scientific information or highlight whether or not there are errors in the steps or procedures.

Summary of Diodora's professed beliefs about NOS. To recapitulate, there were three characteristics of NOS that were explicitly discussed during Diodora's GTA beliefs interview. A summary of Diodora's claims regarding these three characteristics of NOS are as follows:

- Science is a way of knowing that is based on the justification of scientific information;
- Science is a human endeavor that lacks creativity because the work of scientists is often suppressed; and
- Science is based on empirical evidence where the findings of investigations can confirm the validity of scientific information or highlight the need for revision because of errors in the steps or procedures.

The following section discusses Diodora's proclamations on his beliefs about learning.

Beliefs about Learning

An instructor's beliefs about how to learn are an essential aspect of their epistemological beliefs, primarily since epistemological beliefs affect instructional practices. This section describes Diodora's beliefs about four aspects of learning: the ability to learn, how to learn, control of learning, and the role of students in learning.

Ability to learn. Regarding the question from where the ability to learn comes, Diodora stressed that learning begins with effort and is not dependent on one's natural ability. To explain her view, Diodora used a concept in chemistry. She thought the molecular structure and bonding of compounds would be particularly challenging for students overall. Diodora noted,

> I'd say that it definitely starts with an effort. Like wanting to, being willing to put in that effort. It is not determined by natural ability. I'd say that hard work can compensate for learning difficulties, but I think some learning difficulties can't be overcome. I'm thinking [about] organic chemistry and how things are – bonds are in three-dimensional space. There are molecular modeling kits and things that help, but if you can't visualize it, then you can't get to an understanding of the material, and you don't actually learn the material. (Diodora, GTA beliefs interview, January 29, 2019)

This statement revealed that the ability to learn is as a result of self-motivation not dependent on one's natural or innate abilities.

How to learn. Diodora believed that the exchange of ideas during student-student interactions enabled students to reconstruct their conceptual framework by enabling them to make their own meaning about a concept. Diodora stressed that interactions and questions promoted students' learning, especially if they are in a comfortable learning environment. In her own words, Diodora expressed, "Students need to engage in conversations and be asked questions" (Diodora, GTA beliefs interview, January 29, 2019). Diodora's claims proposed that students learn best when they are in a comfortable learning environment that permitted productive discourse and the sharing of ideas.

Control of learning and role of students. Diodora believed that the role of students was to be in control of their own learning. This meant that Diodora viewed the control of learning and the role of students as being the same. Diodora also maintained that the role of the student was to try to understand their instructor. Her explanation of this belief was connected to her description of the role of the instructor as a "musician playing a tune in his head that the students must try to figure out" (Diodora, GTA beliefs interview, January 29, 2019). Diodora's claims indicated a teacher-centered environment where the teacher is depicted as a musician or a disseminator of information.

Summary of Diodora's professed beliefs about learning. Diodora's beliefs regarding how to learn are summarized as follows:

- the ability to learn comes from self and is not dependent on one's natural ability;

- the most effective way to learn is through interaction and engaging in argumentative discourse in a comfortable learning environment; and
- the role of the student is to be in charge of his or her own learning.

Beliefs about Teaching

This section describes Diodora's beliefs about teaching and focuses explicitly on the aspects of teaching that are specific to how to teach, the role of the instructor, and the goal of teaching. These three aspects of teaching were significant in providing an understanding of how Diodora's conceptions of teaching are related to her science instruction.

How to teach. Considering the best ways to teach, Diodora posited that a learning environment that made students feel comfortable enough to participate and ask questions was of foremost importance. This statement indicated similarities between Diodora's views about how to learn and how to teach, specifically the need to have a comfortable learning environment. Diodora also explained that during her lesson preparation and instructional practice, she often placed herself in the shoes of the students because she was "also a student and [was] aware of some of the students' challenges in the classroom" (Diodora, Diodora, GTA beliefs interview, January 29, 2019. She highlighted that students were more comfortable when she used the "each one teach one" strategy which enabled students could use non-complex means to explain the content material to each other. Diodora also noted that she believed that the instructor needs to provide content materials to students using simplified approaches, which in turn will get students excited and motivated to learn. According to Diodora,

> If you can break it down very simple for them and get them excited about it and get them excited and want them to come to class, want them to learn, want them to read – I think that's really how you can teach and how students will learn. If you're teaching somebody a topic and you're a professional or have a lot of knowledge about that, you can't just make them – you drink from a fire hydrant – you can't just turn that on. You have to layer it so that way they understand it. Keep it simple. I ask questions. So, a lot of times – and I'd say sometimes they sneak past me and I don't know if they're understanding – but what I like to do is, when I'm asking questions, I'll say, okay, see one, do one, teach one. I'll show them how. I'll have them do one. And then sometimes I'll volunteer a student, and I'll have them teach the class. I try to put myself in a Biology 1031 student's mindset and say if I'm asked to do this, what are the things that the lab manual assumes that I know that I may not know how to do? I am and was a student. I know how they feel. And I try to foster an environment where, if you goof up, it's fine. It's totally okay. Like I'm going to pick on you a little bit about it, but it's all in good humor. And I try to make an environment that they want to be in. I think that, if you make an environment where students are excited to come, where they feel comfortable with making mistakes – because if you're not making mistakes – in quotations – or learning experiences, then you're really not learning. That's how I would want to learn. That's the kind of environment that I'd like to be in. Give them background information, check their understanding – but do it in a way that has them learn in a way that they don't realize they're learning. (Diodora, GTA beliefs interview, January 29, 2019)

These statements highlighted Diodora's views about her wanting to be an instructor that can relate to the students' learning challenges and can create a learning environment that will eliminate these difficulties. Diodora's claims also disclosed Diodora's assumption that her students encounter the same challenges that she faced in her role as a student.

Furthermore, Diodora used an occurrence regarding the case of missing resources to further elucidate her thoughts about how to teach. Diodora explained that the flowers that were needed for the dissection activity during the lesson on Plant and Animal Reproduction were missing. Since she believed that learning is best when students are engaged in hands-on activities, she said, "So the flowers had been ordered last – the week before, and they didn't come in till after. So, I on the fly did a flower dissection online" (Plant and Animal Reproduction VSR Interview, April 16, 2019). Diodora added that she was not happy that the students could not do the activity themselves. She stated that the absence of the flowers had "put me off, and I had to think of something at the last minute that would replace the dissection activity but would still meet the learning outcomes of that activity" (Plant and Animal VSR Interview, April 16, 2019). Therefore, she opted to show them a video of the dissection of a flower that was closely related to the actual activity. She posited that,

> So, we have a plastic flower [model] that I went over, but then I wanted them to see it. Personally, if it was me, I don't really care much about flowers, but I think this is an instance where my druthers don't get to win, don't win over, and I don't have a justification not to do it. So, I used the video so that they could still get some experience and discuss the parts of the flower. (Diodora, Plant and Animal VSR Interview, April 16, 2019)

This claim imparted that Diodora, although faced with constraints that influenced her science instructional practice and decision-making, still held on to the belief that laboratory work should provide students with hands-on experiences. This also indicated that Diodora's belief about how to teach involved using strategies that involve students engaging in discourse and hands-on activities. This was identified as one of Diodora's core beliefs.

Role of the instructor. Regarding the questions concerning the role of the instructor in the learning process, Diodora described herself as a facilitator. She envisioned herself and her role as the instructor, like that of a musician playing music—the source or disseminator of knowledge—where her students must try to figure out and learn the music. This description of herself using the analogy of the musician disclosed a teacher-centered mindset. Diodora called herself a *spirit guide*. The following excerpt describes Diodora's views:

> I feel like I'm more just kind of like a spirit guide, and I just try to guide. The students have access to all the PowerPoints, their lab manuals, textbooks, the internet – all kinds of things – and I'm here more to guide them. If they have questions – to fill them in – and to provide them that background knowledge. I'd say that an instructor is there to clarify information and to provide the scaffolding for that song. (Diodora, GTA beliefs interview, January 29, 2019)

Based on these claims, although Diodora viewed herself as a facilitator and guide during student learning, her proclamations indicated a teacher-centered perspective. This quote revealed that she viewed herself as a transferrer of knowledge from the instructor or expert to the student. This disclosed an absolutist or relativist view of teaching and learning that conformed to the traditional instruction epistemology.

Goal of teaching. Diodora claimed that her goal of teaching was to prepare students for the world outside of the laboratory. Diodora also explained that her goal of teaching was to increase students' interest in science. She also believed that she needed to provide many opportunities for students to be successful because doing well in science meant that the students would be able to meet and achieve their future goals. According to Diodora, "Science unlocks doors" (Diodora, GTA beliefs interview, January 29, 2019). These claims revealed that Diodora's goals were concerned with increasing students' interest in science to a point where they become scientifically literate citizens.

Summary of Diodora's proclamations on her beliefs about teaching. The following summarizes Diodora's proclamations regarding her beliefs about three aspects of the nature of teaching:

- How to teach: creating a comfortable learning environment and presenting the content to students using simple approaches;
- Role of the instructor: to be a facilitator; and

- Goal of teaching: to create a learning environment where students can have fun learning science and learn the science and become scientifically literate citizens.

The next section presents a discussion of Diodora's science instructional practices in the laboratory.

Science Instructional Practices

Since the 1960s, science education has been through a process of continual change. Advocated are changes in instructional practices that will promote the recruitment of higher numbers of students into careers in science with specific emphasis on how science is taught. This section presents the analytical results of Diodora's demonstration of the eight science instructional practices proposed in *Science for All Americans* (AAAS, 1993, 2013). These eight practices accentuate the distinctive characteristics of the material to be learned. The conditions under which the teaching and learning are to take place in the science classroom include: (1) start with questions about nature, (2) engage students actively, (3) concentrate on the collection and use of evidence, (4) provide historical perspectives, (5) insist on clear expression, (6) use a team approach, (7) do not separate knowing from finding out, and (8) de-emphasize the memorization of technical vocabulary.

Diodora's Laboratory Instruction

Diodora's laboratory section for which she was observed was scheduled for eight o'clock on Monday mornings. Her laboratory lessons were two hours long, and she utilized every minute of these two hours. According to Diodora, time was always a factor to consider when teaching this laboratory course. She felt that she always had to rush to get students to complete the various activities and was not confident that they were actually learning what they were supposed to. Diodora was a big proponent of students learning laboratory skills such as how to use a pipette, how to take readings from a biuret or mearing cylinder, or how to use the microscope correctly. Apart from laboratory skills, Diodora placed much emphasis on safety in the laboratory. Therefore, during most of her teaching, Diodora would remind the students to wear their goggles and gloves and to review notes from their laboratory manuals that explained how to take readings or use the microscope.

Lesson structure. Diodora's laboratory lessons began with a short quiz that lasted for about 10 minutes. Next, Diodora spent a few minutes interacting with the students and asking them about their weekend before beginning the laboratory lessons. Diodora explained that this was necessary to help students make the transition from the "weekend mode into work mode" (Diodora, VSR Interview on Fermentation Lesson, February 26, 2019). At the end of the quiz, Diodora reviewed upcoming assignments and important dates or provided students with information that she deemed important. Before each lesson, Diodora reminded students of the laboratory rules. For example, she reminded them that no food or liquids were allowed in the laboratory and ensured that all students were attired correctly for the laboratory (i.e., wearing the correct footwear and long hairstyles were pulled back in a ponytail). Following this, Diodora went through an outline of what students would be doing for the laboratory. This outline was always written on the left-hand corner of the whiteboard, and she checked off items as she completed them. An example is provided in Figure 36 of a video still of Diodora's introduction of the laboratory lesson on fermentation.

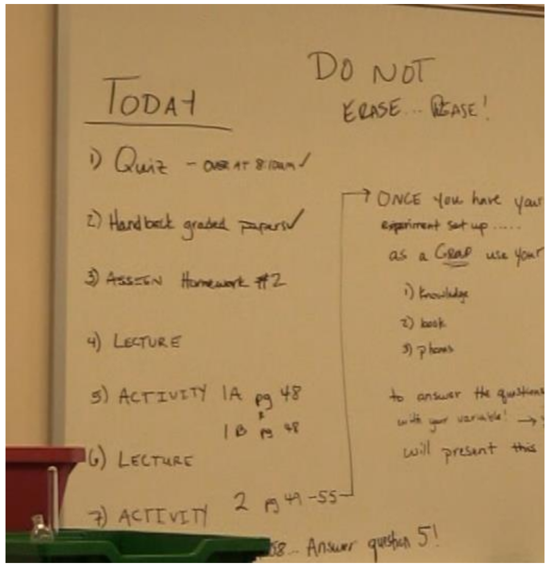


Figure 36. A video still of the outline for Diodora's lesson on fermentation.

Diodora explained that she thought students needed to know what they would be doing and the sequence of the activities. She believed seeing the activities checked off upon completion kept students engaged. Diodora acknowledged that,

> So, I studied psychology in college, and what I learned is people are more likely to finish a survey or something if they have feedback on how far they've progressed. Kind of like when you're taking a quiz or survey, you know, on the bar it says like uh 30% done, 40% done, 50%. Those kinds of things. And so, what I am trying to do here is give [students] an idea of everything that we're gonna do today – detailed. So that way, they know what's next. They know exactly what's coming and how we're gonna do it and will be motivated to do it. (Diodora, VSR Interview on Fermentation Lesson, February 26, 2019)

Although she provided an outline for the day's lesson, Diodora's laboratories were anything but methodological. She believed in giving students opportunities to make choices that influence their learning. Diodora often asked students whether they would like to conduct some of the activities themselves or would prefer that she demonstrated while they paid attention and were quizzed on it later. Therefore, Diodora's students did not conduct some of the hands-on activities themselves but instead observed and took notes while Diodora completed the exercises as demonstrations. At the end of the laboratory, Diodora directed students to clean up their workspaces and complete and submit their in-lab assignments.

Science instructional practices. Diodora's lessons were observed for the instances when her instructional practices demonstrated the eight science teaching principles as defined by the AAAS (1993, 2011). Diodora incorporated most of the science instructional practices during her lessons; that is, six out of eight of them (Table 24). The instances where her instruction demonstrated practices that countered the eight recommended scientific practices are noted (Table 25). In tables 24 and 25, an 'X' indicates the science instructional practice that Diodora employed during her teaching episodes in the laboratory. The tables also highlight information regarding the activities that required students to collect data as well as instances where Diodora conducted demonstrations of certain activities while the students paid attention to what she was doing. For example, students collected data during the *You and Gas Production* activity, and Diodora conducted a demonstration for students to observe during the *Strawberry and DNA Extraction* activity.

Table 24

Science Instructional Practices Demonstrated During Diodora's Laboratory Lessons that Aligned with the Eight Science Instructional Practices Described by AAAS (1993, 2011)

Lesson Associated Activities	Science Instructional Practice							
	1	2	3	4	5	6	7	8
Fermentation								
You and Gas Production[a]		X				X		X
Yeast and Gas Production[c]								
Quantifying Gas Production[a]	X	X				X		X
DNA Extraction and Mitosis								
Strawberry DNA Extraction[b]						X		
Stages of Mitosis (Simulation with Beads)[c]								
Stages of Mitosis (Microscope)		X				X		
Human Genetics								
Pipe Cleaners and Beads[c]								
Human Genetics	X	X			X			X
Punnett Squares Worksheet		X						
Blood Typing[a]	X	X						X
Plant and Animal Reproduction								
Spread of STIs	X	X		X			X	X
Flowering Plant Dissection[c]								
Male and Female Anatomy (Microscope)		X		X				X
Parts of a Seed[b]				X		X		X

Note. The numbers in the science instructional practices columns coincide with the following: 1 – Use Team Approach; 2 – Students are Actively Engaged; 3 – Start with Questions about Nature; 4 – Do not Separate Knowledge from Finding Out; 5 – Provide Historical Perspectives; 6 – Insist on Clear Expression; 7 – Do not Emphasize the Memorization of Technical Vocabulary; 8 – Concentrate on the Collection and Use of Evidence

[a] Activities during which students collected data

[b] Activities that Diodora demonstrated

[c] Activities that Diodora skipped because of time constraint

Table 25

Science Instructional Practices Demonstrated During Diodora's Laboratory Lessons that Countered the Eight Science Instructional Practices Described by AAAS (1993, 2011)

Activity	Instructional Practice							
	9	10	11	12	13	14	15	16
Fermentation								
You and Gas Production[a]	X		X	X	X		X	
Yeast and Gas Production[c]								
Quantifying Gas Production[a]			X	X	X		X	
DNA Extraction and Mitosis								
Strawberry DNA Extraction[b]	X	X	X	X	X		X	X
Stages of Mitosis (Simulation with Beads)[c]			X	X	X	X	X	X
Stages of Mitosis (Microscope)	X		X	X	X		X	X
Human Genetics								
Pipe Cleaners and Beads[c]								
Human Genetics			X	X			X	
Punnett Squares Worksheet	X		X	X	X		X	
Blood Typing[a]			X	X	X	X	X	
Plant and Animal Reproduction								
Spread of STIs			X		X	X		
Flowering Plant Dissection[c]								
Male and Female Anatomy (Microscope)	X		X		X	X	X	
Parts of a Seed[b]	X	X	X		X		X	

Note. The numbers in the science instructional practices columns coincide with the following: 9 – Do not Use Team Approach; 10 – Students are not Actively Engaged; 11 – Do not Start with Questions about Nature; 12 – Separate Knowledge from Finding Out; 13 – Do not Provide Historical Perspectives; 14 – Do not Insist on Clear Expression; 15 – Emphasize the Memorization of Technical Vocabulary; 16 – Do not Concentrate on the Collection and Use of Evidence
[a] Activities during which students collected data
[b] Activities that Diodora demonstrated
[c] Activities that Diodora skipped because of time constraint

Students are actively engaged. Students were typically actively engaged during Diodora's lessons, excluding instances when they were observing Diodora as she conducted demonstrations of activities. These demonstrations included activities on *Strawberry DNA Extraction* and the *Parts of a Seed* (Tables 22 and 23). Students were usually engaged in observing, note-taking, and using hand lenses, microscopes, thermometers, and other standard instruments. Diodora expressed that it was important for students to learn various laboratory skills. Therefore, she tried to provide opportunities for them to engage in the activities in order to acquire these skills. Diodora also stated,

> This semester that I did something a little different. Instead of showing them the actual slides on the PowerPoint of what each stage looks like, I encourage them to look it up on their cell phones. And I think that for me what I realized last semester when I taught a separate subject, is if these students look up things by themselves, they're engaged in acquiring their own understanding, they're more likely to learn it and retain that information. So, what I wanted them to do was to look it up and find those answers for themselves. (Diodora, DNA Extraction and Mitosis VSR Interview, March 12, 2019)

Diodora's claims disclosed that it was important for students to find the relevant information on their own because their active engagement with the content enabled them to understand the science content more efficiently than if she was to relate the information to the students herself.

Start with questions about nature. Diodora did not introduce her lessons with questions about nature or any other type of questions. Instead, she delved straight into her lecture for the laboratory by starting with the lesson's objectives, followed by short lectures. During her brief lectures, Diodora asked questions and solicited responses from students. For example, she posed questions like, "What is a genotype?" (Diodora, Human

Genetics Laboratory Lesson, March 25, 2019) and “At the end of this lab, you should be able to set up a germination experiment. What is germination?” (Diodora, Lesson on Plant and Animal Reproduction, April 8, 2019). Diodora explained that she liked to engage students in the lecture aspect of the laboratory so that students would not feel like she was “talking at them” (GTA beliefs interview, January 29, 2019).

Use a team approach. Students often worked in groups and presented their findings as a team. Diodora admitted that working in groups was significant because that is the typical behavior of scientists. However, she believed that some of the material covered during the laboratory was at the high school level and that her students became disengaged or even offended when they had to do work that they thought as below their level as undergraduates. Therefore, Diodora posited that she demonstrated some of these group activities for the students and, in some cases, skipped them altogether.

Do not emphasize the memorization of technical vocabulary. Diodora emphasized the memorization of technical vocabulary. Diodora believed that if students understood the various terms, it would be easier for them to explain and reason. Diodora introduced the essential terms during her lectures and sometimes used short videos, songs from YouTube, and/or illustrations to support learning science vocabulary. For example, Figure 37 shows an illustration that Diodora used with colored paper to help students differentiate between the vocabulary terms homozygous dominant, homozygous recessive, and heterozygous.

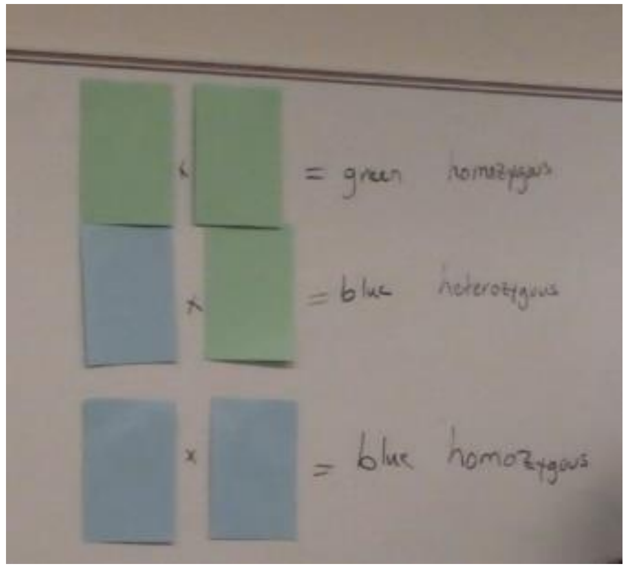


Figure 37. A snapshot of an illustration that Diodora used to help students learn genetics vocabulary terms.

Concentrate on the collection and use of evidence. The steps of the scientific process were very important for Diodora. She highlighted how crucial evidence was and admitted that she spent extra time teaching students the difference between the independent, dependent, confounding, and control variables. According to Diodora,

> So, when I'm looking at the material, what I try to do is I look at – okay, so, this is the stuff we're asking our students to do. What background information do they need to accomplish that? when I'm prepping to teach – I try to put myself in a Biology 1031 student's mindset and say, if I'm asked to do this, what are the things that the lab manual assumes that I know that I may not know how to do. [Students] have to learn the experimental variables and what they are before they can conduct experiments. This is an important aspect because they need to know this to be able to interpret their results. (Diodora, GTA beliefs interview, January 29, 2019)

This excerpt disclosed that the collection and use of the results from investigations were an important aspect of learning science and that being able to interpret, and form conclusions was necessary to indicate whether students made errors in following the procedures. According to Diodora,

> If you goof up, it's fine. It's totally okay. So, what does evidence do? Evidence gives us an opportunity to teach or to learn. And so, that's one of those mistakes in quotations – it's a learning experience. So, if your results – your evidence – doesn't agree with your hypothesis, that gives you a whole opportunity to go and learn. What did you do? Did you goof up? How did you goof up? Or, okay, is this something new, or is it not new? Is it common? I think [in] science – that's how we learn. (Diodora, GTA beliefs interview, January 29, 2019)

This statement suggested that the collection and use of evidence is important in that concentrating on the evidence does not only allow students to learn content but also opens opportunities for gaining related knowledge in science, especially knowledge related to results that do not seem to support the hypothesis of an investigation.

Insist on clear expressions. Observations of Diodora's laboratory indicated that she insisted on students using clear expressions to communicate results or support their claims during argumentative discourse less than half of the time. Diodora spent most of her laboratory time, assuring that students gained the necessary science laboratory skills like learning how to use a microscope or measuring the length of regenerating planaria and germinating seedling correctly. During Diodora's VSR on her DNA Extraction and Mitosis lesson, Diodora was asked to explain her decision to move on to the next activity without allowing students to practice using the vocabulary terms they had learned. According to Diodora,

> I chose that because I would rather them spend more time working with microscopes and [doing] work that I think is at a college level. So, a lot of the students are still focusing on either the glass slide or the coverslip, and so they're looking at edges of the glass and think that they're looking at objects. But I think once I showed them how to find [a chromosome], they were pretty good about finding more. I rather them leaving the lab knowing how to correctly use a

> microscope than know how to use words that they probably will never hear about or use in the future. (Diodora, DNA Extraction and Mitosis VSR Interview)

This excerpt disclosed that for Diodora, acquiring laboratory skills is of higher priority than effective oral and written communication.

Do not separate knowledge from finding out. Diodora did not separate knowing from finding out. Diodora explained that one of her goals for students was to learn basic laboratory skills. She also purported that students may not get another chance in their lives to engage in science activities after completing this laboratory and felt that it was her responsibility to impart some critical skills that they may be able to use in the future, especially with their own children (Diodora, GTA beliefs interview, January 29, 2019). Diodora explained that because of this, she made sure that students made the connection between the hypothesis, methods, and conclusions and encouraged reasoning to interpret, explain, and ultimately learn. During discussions, Diodora stressed the need for clear expression, especially when, according to Diodora, “students goofed up” (Diodora, GTA beliefs interview, January 29, 2019).

Provide a historical perspective. This was one of the science instructional practices that observations indicated were least employed during Diodora’s laboratory lessons. There was only one instance where Diodora spent time providing students with a historical context. This was during the Human Genetics laboratory when Diodora explained the work of Gregor Mendel and his contributions to the current understanding of the inheritance of genetic traits. This historical context was embedded in the PowerPoint presentation that was issued by the biology department. Therefore, the one-time demonstration of this science instructional practice was not a true reflection of a science instructional practice employed by Diodora that was based on recommendations of the AAAS. As a result, this revealed that providing students with historical perspectives was not a frequent occurrence in Diodora's science instructional practice.

Frequency of Diodora's science instructional practices. During the four observations, Diodora completed a total of 11 activities with her students, during which time she did not demonstrate the use of a greater part of the eight science instructional practices. For example, *concentrate on the use and collection of evidence* and *students are actively engaged* were the only two science instructional practices that Diodora demonstrated over 50% of the time. The frequency of the use of each science instructional practice was calculated and is shown in Figure 38. The frequency of science instructional practice was calculated by:

1. noting the science instructional practices that were demonstrated during the teaching of each activity;
2. tallying the total number of activities completed in each lesson; and
3. calculating the frequency (%) of the demonstration of each science instructional practice by dividing the sum of each science instructional practice by the total number of activities per lesson and multiplying by 100.

For example, Diodora completed a total of 11 activities during the four lessons for which she was observed. She employed the use of the science instructional practice, *students are actively engaged*, eight out of the 11 times. The frequency of demonstration of this science instructional practice was calculated as : $\frac{8}{11} \times 100 = 73\%$.

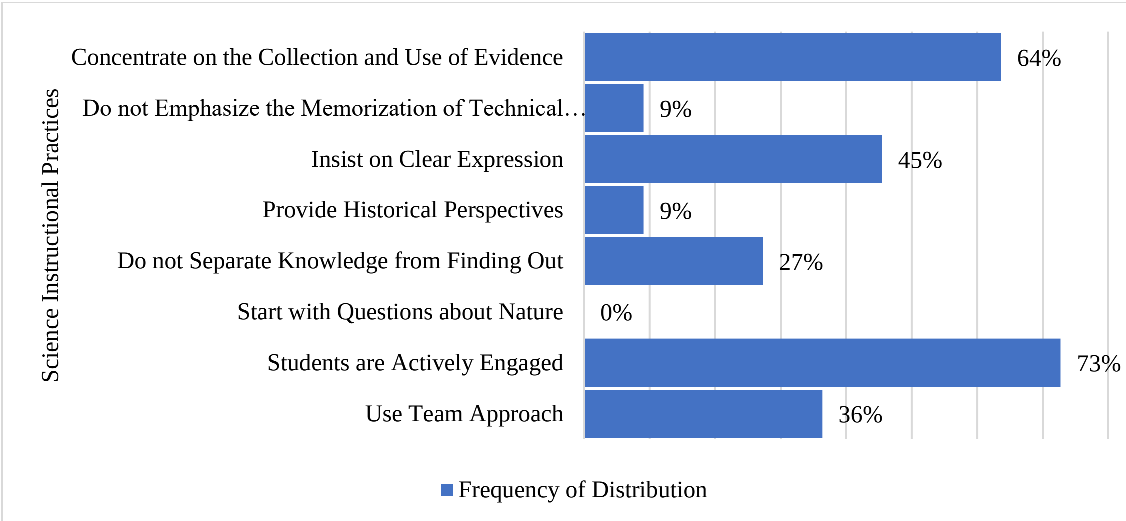


Figure 38. Frequency of the demonstration of the science instructional practices by Diodora.

The most frequently demonstrated science instructional practice was *students are actively engaged* (73%), followed by *concentrate on the collection and use of evidence* (64%), *insist on clear expression* (45%), *use a team approach* (36%), *do not separate knowledge from finding out* (27%), and *do not emphasize the memorization of technical vocabulary* and *provide historical perspectives* both at nine percent.

Observations of Diodora's laboratory lessons showed that she did not employ one of the science instructional practices at any time during the four laboratory lessons observed, that is, *start with questions about nature.* Regarding this instructional practice, it must be noted, however, that although Diodora did not begin any of her observed lessons with questions about nature or any questioning, on the whole, she embedded questioning strategies during her lessons. For example, at the start of her laboratory lesson on Human Genetics lesson, during her brief lecture, Diodora asked, “So phenotype and genotype, these words are not new to you. What is genotype?" (Diodora, Lesson on Human Genetics, March 25, 2019). The fact that Diodora used questioning as part of her instruction disclosed that questioning was still an important aspect of Diodora's laboratory lessons even if questions were not at the start of the lesson or based on natural phenomena. Following this discussion of results on Diodora's science instructional practices, the next section presents the findings that indicate the nature of the relationship between the features of her professed beliefs and science instructional practices.

Diodora: Relationship between Diodora's Features of Epistemological Beliefs and Science Instructional Practices

This section presents information regarding the instances where the professed features of Diodora's epistemological beliefs contrasted with the science instructional practices recommended by the AAAS (1993, 2011). Analysis of the data revealed mismatches—misalignments—between the features of Diodora's epistemological beliefs and the science instructional practice recommended by the AAAS. A misalignment in the analysis described Diodora's demonstration of a science instructional practice that highlighted her thoughts and actions in the laboratory that contradicted or opposed the recommendations of the AAAS (1993, 2011). That is, based on Diodora's proclamations, observations should have reflected specific claims that aligned with the recommendations of the AAAS, but instead, these claims were not observed.

Misalignments between Features of Epistemological Beliefs and Science Instructional Practices

Epistemological beliefs in general and science instructional practices.

***Diodora's beliefs about the* changeability of knowledge *and the science instructional practice* do not separate knowledge from finding out.** Diodora believed that "knowledge does not change, but rather it is an individual's understanding of a piece of knowledge that changes" (GTA beliefs interview, January 29, 2019). Consequently, she declared that "students should be provided with ample opportunities in the laboratory to understand the biology content material" (GTA beliefs interview, January 29, 2019). Diodora noted that "understanding is what needs to be changed because once students gain the necessary understanding, they would have gained the knowledge you want them to learn" (Diodora, Fermentation VSR Interview, February 26, 2019).

In an attempt to facilitate a deeper understanding of the biology laboratory material, Diodora posited that she sought to draw students' attention to conclusions and the methods so that students could be aware of the connection between the two. According to Diodora,

> For the fermentation experiment, I wanted them to learn about how the methods led to the conclusions, and if they goofed up, then I want them to know that their results could help them figure out where they went wrong. (Diodora, Fermentation VSR Interview, February 26, 2019)

Diodora's claims disclosed that science laboratory instructors should provide students with opportunities that will help them form connections between the content information and science investigation methods and see that they are tightly coupled. This view was supported by the recommendations of the AAAS who opposes the teaching of science content as a separate component from the methodologies that are used to gain scientific knowledge. However, observations of Diodora's instructional practices in the laboratory did not reflect her proclamations. Instead, only 27% of all her observed lesson activities showed her demonstrating the science instructional practice *do not separate knowledge from finding out* as recommended by the AAAS (Figure 38). Observations of her instruction revealed that she dedicated much of her instruction time to emphasizing laboratory skills and methods or procedures, a science instructional practice that highlighted the process of transmitting knowledge and skills and the separation of knowledge and practice. Here, the association between the *changeability of knowledge* and *do not separate knowledge from finding out* represented a misalignment between epistemological belief

and science instructional practice (Figure 39).

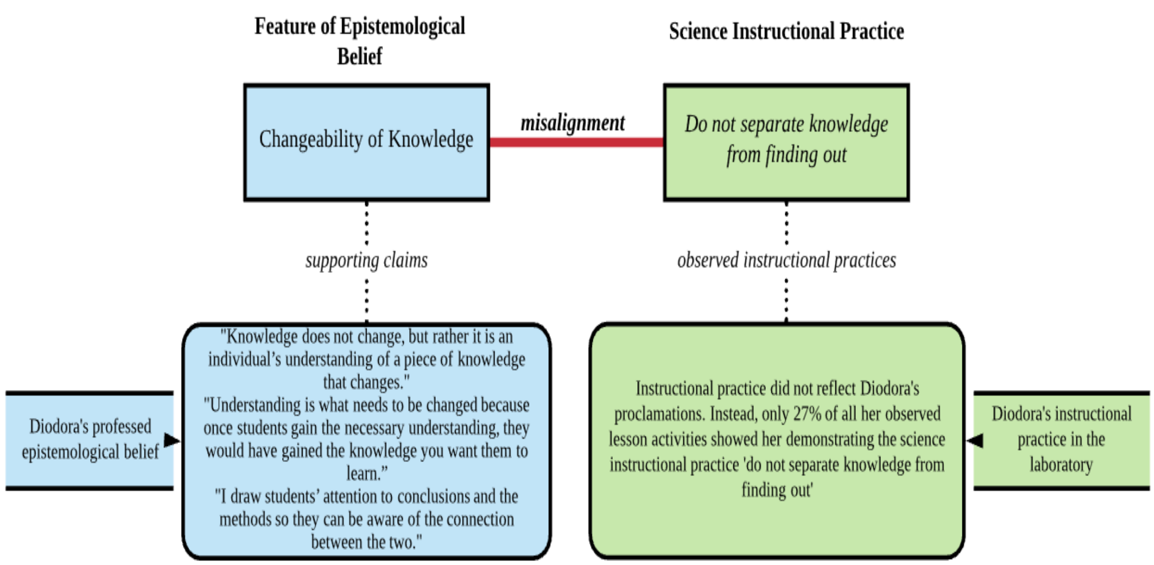


Figure 39. Relationship between Diodora's epistemological beliefs about *the changeability of knowledge* and the enactment of science instructional practice *do not separate knowledge from finding out*.

Beliefs about teaching and science instructional practices.

***Diodora's beliefs about* how to teach *and the science instructional practice* use a team approach.** The data revealed a misalignment between Diodora's beliefs *about how to teach* and the science instructional practices *use a team approach*. Observations of her laboratory lessons indicated that this science instructional practice was employed only 36% of the time for which she was observed (Figure 38). However, Diodora claimed that teamwork was very important and was one of her *go-to* strategies in the laboratory. Diodora expressed that "discussions among peers were important" (GTA beliefs interview, January 29, 2019). She also posited that "students work in teams not only to collaborate on an experiment and its results but also to discuss in-lab questions" (GTA beliefs interview, January 29, 2019). Diodora explained that she relied on the "each one teach one" teaching strategy and encouraged teamwork where students benefited from breaking down the complex content material for each other as they worked in groups. However, this proclamation was not as frequent in her science instructional practice. There was a disparity between the degree to which Diodora believed in group work and the number of times she demonstrated the use of this strategy during her instruction, which was only about 36% of the time (Figure 40).

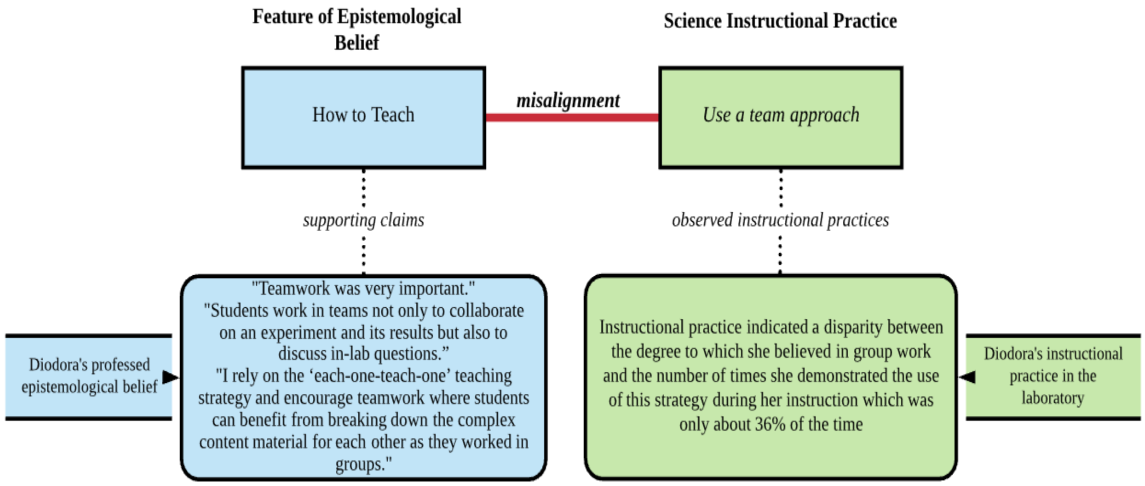


Figure 80. Relationship between Diodora's beliefs about *how to teach* and the enactment of the science instructional practice *use a team approach.*

Summary of misalignments between features of Diodora's epistemological beliefs and science instructional practices. The data analysis revealed that there were two misalignments between Diodora's features of professed epistemological beliefs and the recommended science instructional practices of the AAAS (1993, 2011) specific to science reform. Misalignments in this study represented the instances where Diodora's science instructional practices did not reflect the features of her professed epistemological beliefs that aligned with the standpoint of the AAAS. The science education reform document issued by the AAAS (1993, 2011) recommended eight teaching practices considered to be consistent with the nature of inquiry and would facilitate the kinds of experience that students need to enable them to understand science as a way of thinking and doing.

According to the findings, Diodora's professed epistemological beliefs regarding aspects of the nature of knowledge and knowing and beliefs about teaching, although they harmonized with the recommendations of the AAAS (1993, 2011), were not demonstrated during her teaching episodes in the laboratory. These misalignments are reiterated in Figure 41, which highlights the categories of epistemological beliefs and their respective features of epistemological beliefs and the science instructional practices to which they were mismatched.

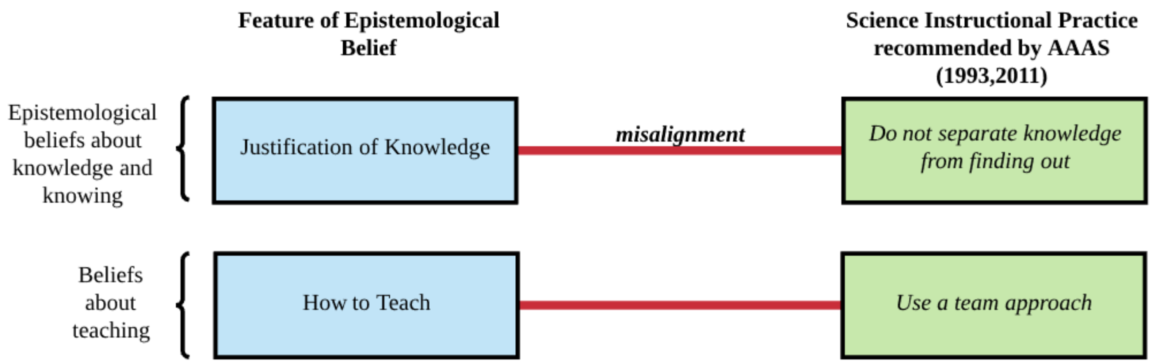


Figure 41. Misalignments between Diodora's professed features of epistemological beliefs and science instructional practices recommended by the AAAS (1993, 2011).

Alignment between the Professed Features of Epistemological Beliefs and Science Instructional Practices

The data were also analyzed to consider the alignment between Diodora's features of professed epistemological beliefs and the science instructional practices as posited by the recommendations of the AAAS (1993, 2011). Findings indicated that there was a positive association—alignment—between the features of Diodora's professed epistemological beliefs about the nature of science and science instructional practice. More specifically, Diodora's beliefs about *science is based on empirical evidence*.

Epistemological beliefs about the nature of science and science instructional practices.

***Diodora's beliefs about* science is based on empirical evidence *and the science instructional practice* concentrate on the use and collection of evidence.** Data analysis showed an alignment between Diodora's professed epistemological beliefs about *science is based on empirical evidence* and the science instructional practice *concentrate on the collection and use of evidence* (Figure 42).

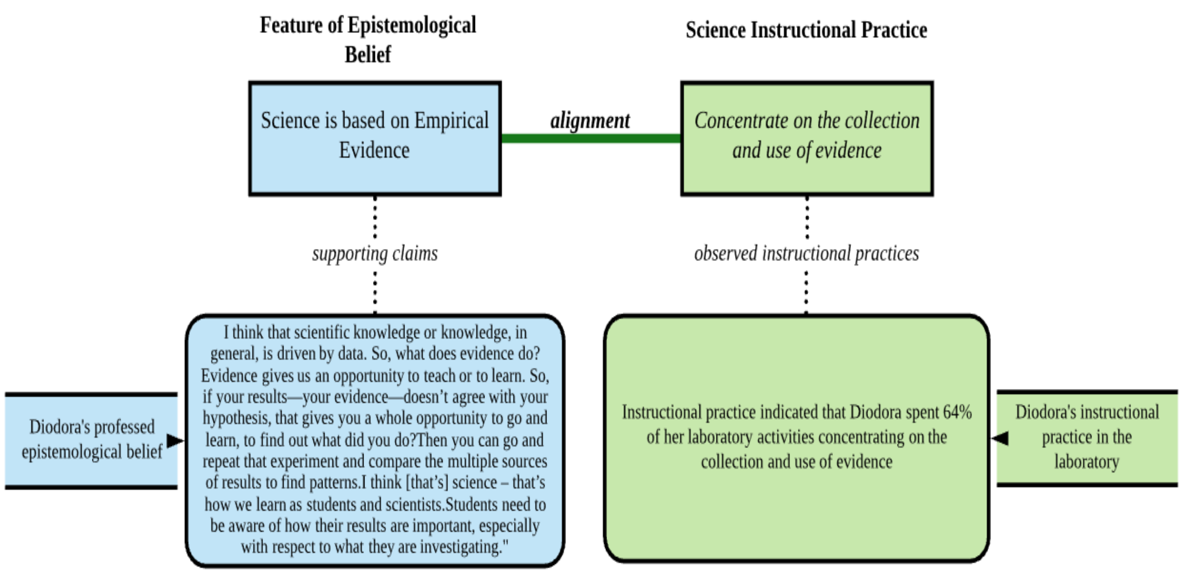


Figure 42. Relationship between Diodora's epistemological beliefs about *science is based on empirical evidence* and the enactment of the science instructional practice *concentrate on the collection and use of evidence*.

As noted in the previous section, Diodora was very clear about the role of evidence in science. She stated,

> I think that scientific knowledge or knowledge, in general, is driven by data. So, what does evidence do? Evidence gives us an opportunity to teach or to learn. And so, that's one of those mistakes in quotations, it's a learning experience. So, if your results—your evidence—doesn't agree with your hypothesis, that gives you a whole opportunity to go and learn, to find out what did you do? Did you goof up? How did you goof up? Or, is this something new or is it not new, is it supported? Is it common? Then you can go and repeat that experiment and compare the multiple sources of results to find patterns. I think [that's] science – that's how we learn as students and scientists. Students need to be aware of how their results are important, especially with respect to what they are investigating. (Diodora, GTA beliefs interview, January 29, 2019)

This excerpt disclosed that Diodora had an appreciation for the role of evidence in science, and she wanted her students to become familiar with how important evidence is in science investigations. She spent 64% of her laboratory activities, concentrating on the collection and use of evidence (Figure 38). Diodora's beliefs and practice highlighted the recommendations of the AAAS and promoted that instructors need to put a premium, just as science does, on careful observation and thoughtful analysis and discussion of results.

Diodora also acknowledged that given the number of activities squeezed into the time allocated for the laboratory, she "didn't have enough time for the students to discuss the results and see where they goofed up" (GTA beliefs interview, January 29, 2019). This revealed that if time was not a constraint, maybe there would be a greater percentage of demonstrations or this science instructional practice.

Summary of alignments between features of Diodora's epistemological beliefs and science instructional practices. The findings of this study identified only one positive association between Diodora's professed features of epistemological beliefs and science instructional practices. This positive association also referred to as an alignment, described instances where Diodora's teaching practices reflected the recommendations of the AAAS (1993, 2011). In other words, the teaching practices of the GTA demonstrated the eight teaching practices considered to be consistent with the nature of inquiry and that provide students with the kinds of experience that will enable them to understand science as a way of thinking and doing. The only alignment specific to Diodora was found to be between her beliefs about NOS (i.e., *science is based on the empirical evidence*), and the enactment of the science instructional practice *concentrates on the collection and use of evidence*.

Diodora: How Complexity Theory Describes the Interrelatedness between the Features of Diodora's Epistemological Beliefs and Science Instructional Practice

Complex systems contain a collection of individual agents with freedom to act in ways that are not always totally predictable, and whose actions are interconnected so that one agent's actions change the context for other agents. Complexity theory emphasizes relationships among the subparts of a system and the emergence of something new. One of the key ideas of complexity theory and education, which is particularly relevant to this study, is that many aspects of education, including classrooms, can be viewed and understood as a complex system. The philosophy of complexity is that complex systems such as the classroom have properties—emergent properties—that cannot be reduced to the sum of their mere parts and look at each individual component. To understand the behavior of such systems, it is more favorable to consider the components while concentrating on the interactions between the various components. Complex systems have several characteristics that typify complex systems, including s*elf-organization*, *emergence*, *non-linearity*, *interconnectivity*, and *autonomy and co-adaptation*. This section uses these characteristics to explain the connections between the components (i.e., professed epistemological beliefs and science instructional practice) specific to Diodora's laboratory as a complex system.

Self-Organization

Self-organization is the spontaneous emergence of an organized structure due to the local interactions of individual components of a complex system. Spontaneity can mean that in a system, any individual component can be eliminated, changed, or replaced without any damage to the overall or resulting structure of the system. Self-organization creates order out of disorder and is responsible for the patterns, structures, and arrangements that are found in a system and gives rise to the emergence of new levels of organization.

There were instances when sudden and unexpected events in Diodora's laboratory caused the reorganization of her laboratory classroom system. An example of an unexpected or spontaneous occurrence was the missing flower specimens for Diodora's dissection activity. The flower dissection activity was one of the major activities planned for that laboratory, and the unavailability of the flowers presented a constraint. Diodora admitted that the absence of the flowers had "put me off, and I had to think of something at the last minute that would replace the dissection activity but would still meet the learning outcomes of that activity" (Plant and Animal VSR Interview, April 16, 2019). Diodora believed that students needed the hands-on experience of the exercise, but a YouTube video of a flower dissection would be just as useful in helping students learn the parts of a dicotyledon flower. Here, there was a spontaneous reorganization in the laboratory system where there were slight changes in Diodora's beliefs (i.e., the role of active-learning in increasing students' knowledge in science; beliefs about teaching) and instructional practices (i.e., engage students actively) in order to maintain a stable and reorganized system due to a laboratory constraint (i.e., laboratory resources).

Autonomy and Co-Adaptation

Within complex systems, components have varying degrees of autonomy through their capacity to adapt to their local environment. The laboratory system was found to be continually adapting to contextual changes in the laboratory and showed internal changes via the process of adaptation. Diodora held the belief that knowledge can increase by accessing information, and increasing knowledge was more productive when students were engaged and learning the required laboratory and science process skills. However, due to time constraints as well as her beliefs about the nature of the complexity of activity (i.e., not rigorous enough for undergraduate students), Diodora explained how she "demonstrated many of the activities" (GTA beliefs interview, January 29, 2019). Diodora also posited that by doing that, she had more time to focus on the other activities. Diodora supposed that her actions "kind of eliminated the time constraint because students now had more time for the different activities and did not feel like they were wasting their time" (GTA beliefs interview, January 29, 2019). Here, it was noted that Diodora adapted her science instructional practice to provide a teaching and learning experience for students that did not align with her own core beliefs. Diodora was able to adapt her instructional practice to facilitate her beliefs about teaching and learning. This denoted autonomy and co-adaptation, which highlights a system's ability to evolve and adapt to changes while still maintaining its independence.

Interconnectivity

Within complex systems, interactions between components show connections. Analysis of findings revealed the interconnections between Diodora's professed beliefs and science instructional practices, primarily in the instances where there were both misalignments and alignments between the two constructs. For example, the interconnection between professed epistemological beliefs and science instructional practice was revealed in her belief about *how to teach* and her demonstration of the science instructional practice *use a team approach.* Diodora's instructional practice was observed to counter her belief about students working in teams, where she professed that she likes using the "each-one-teach-one" strategy. Instead, students were engaged in collaborative work less than half of the time for which Diodora's lesson activities were observed.

Summary of the Complexity Theory and its Interrelatedness to the Features of Diodora's Epistemological Beliefs and Science Instructional Practice

Diodora's professed epistemological beliefs and science instructional practice were part of a complex system, the laboratory as a classroom. These two constructs, as part of any complex system, interacted with each other, and displayed characteristics that were specific to the nature and type of system. In Diodora's case, three out of the five characteristics of the complexity theory were displayed based on interactions and interrelatedness of her professed epistemological beliefs and science instructional practices. These characteristics were *self-organization*, *autonomy and co-adaptation*, and *interconnectivity*. The self-organization of the system depicted a change in the system specific to instruction. Autonomy and co-adaptation is a system's ability to evolve and adapt to changes while still maintaining its independence. This attribute was evident when Diodora opted to demonstrate activities that she deemed not rigorous enough for undergraduate students, which in turn allowed more time for discussions and group activities. Interconnectivity highlighted interactions between components that show the nature of the connections between professed epistemological beliefs and science instructional practices.

Cross Case Analysis of Commonalities and Dissonances in Biology GTAs' Professed Features of Epistemological Beliefs and Science Instructional Practices

In this section is a discussion of the cross-case analysis of the biology GTAs. The following outline highlights the structure in which the information is presented. First, the commonalities and dissonances in the professed features of biology GTAs' epistemological beliefs are presented. The areas addressed include epistemological beliefs in general (the nature of knowledge and knowing); epistemological beliefs about NOS; beliefs about learning; and beliefs about teaching. The next section will present the commonalities and dissonances in biology GTAs' science instructional practices. This section will specifically address the science instructional practices most frequently employed and least frequently employed. Finally, commonalities and dissonances will be discussed; first in relation to misalignments and alignments between professed epistemological beliefs and science instructional practices, and second in reference to the components of complexity theory that stimulated changes in biology GTAs laboratory classroom systems.

Commonalities and Dissonances in the Professed Features of Biology GTAs' Epistemological Beliefs

Epistemological beliefs in general (nature of knowledge and knowing). The nature of knowledge and knowing is concerned with the features of epistemological beliefs about the changeability of knowledge, justification of knowledge, the source of knowledge, and the structure of knowledge. Table 26 highlights the results of a summary of a comparison of the four biology GTAs' proclamations regarding the features of epistemological beliefs about knowledge and knowing.

Table 26

A Synthesis of a Compare-and-Contrast Summary of Biology GTAs' Epistemological Beliefs about Knowledge and Knowing

Feature of epistemological belief	Proclamation regarding belief about the nature of knowledge and knowing	Biology GTA who holds the belief
Changeability of Knowledge	Knowledge is fixed and does not change	Aesara and Diodora
	Knowledge changes with time and experiences	Batis and Cleomedes
Justification of Knowledge	Knowledge is justified by self	Aesara
	Knowledge is justified by others	Cleomedes
	Knowledge is justified by both self and others	Batis and Diodora
Source of Knowledge	Both self and others (e.g., authorities and experts) are sources of knowledge	Aesara, Batis, Cleomedes, and Diodora
Structure of Knowledge	Knowledge is complex	Batis
	Knowledge structures move gradually from simple to complex	Aesara and Cleomedes
	Knowledge is both simple and complex	Diodora

Table 26 shows that the biology GTAs held both similar as well as opposed views about the features of epistemological beliefs in general. There were no instances when all of the GTAs held a common epistemic stance. Also, there were cases where GTAs professed to hold more than one view about the same feature of epistemological beliefs. For example, regarding the structure of knowledge, Diodora believed that knowledge structures are both simple and complex, and Aesara and Cleomedes believed that knowledge structures move gradually from simple to complex. These ranges in reasoning seemed to indicate that Aesara, Cleomedes, and Diodora were displaying converging reasoning patterns from the developmental view of ways of knowing, whereas Batis, who professed to have only a single epistemic stance (i.e., knowledge structures are complex) was demonstrating a way of knowing that is unidimensional. The developmental and unidimensional ways of knowing are, at present, the only two main lines of research regarding epistemological beliefs.

Epistemological beliefs about the nature of science (NOS). The discussion of biology GTAs' beliefs about NOS revealed their beliefs about some but not all of the characteristics of NOS. Four tenets that describe NOS were discussed across the board during the GTA Belief interviews. These four tenets or features of NOS were: science as a way of knowing, science is a human endeavor, science uses a variety of methods, and science is based on empirical evidence. A summary of the GTAs' claims regarding four features that describe NOS is provided in Table 27.

Table 27

A Summary of Biology GTAs' Views about Four Features of NOS

Feature of NOS	Proclamation regarding belief about NOS	Biology GTA who holds the belief
Science as a Way of Knowing	Science is a way of knowing and understanding the natural world that is different from other ways of knowing (e.g., religion).	Aesara, Batis, and Cleomedes
	Science is a way of knowing that and is based on the justification of scientific information.	Diodora
Science is a Human Endeavor	Science is a human endeavor that shows the creativity of scientific practices and is fueled by creativity and imagination.	Aesara, Batis, and Cleomedes
	Science is a human endeavor but lacks creativity because the work of a scientist is often suppressed.	Diodora
Science uses a Variety of Methods	There is no one way of doing science, and the methods employed are dependent on the nature of the investigation (i.e., what is being investigated).	Aesara, Batis, and Cleomedes
Science is based on Empirical Evidence	Science is based on empirical evidence.	Aesara, Batis, and Cleomedes
	Science is based on empirical evidence, where the findings of investigations can confirm the validity of scientific information or highlight the need for revision because of errors in the steps or procedures.	Diodora

There was some degree of consistency in the proclamations of four biology GTAs regarding their beliefs about the four features of NOS that were discussed during their GTA Belief interviews. For example, they all believed that science is a way of knowing and understanding the natural world. However, there was one feature of NOS that did not display total commonality in beliefs: the belief about science is a human endeavor.

Diodora's proclamations indicated that she agreed that science was a human endeavor. However, she did not believe that the effort of scientists portrayed their creativity and imagination as declared by the other three GTAs. Diodora stated that she considered herself a scientist and believed that the scientific community is governed by principles that hinder scientists' ability to exercise creativity in their investigations. As a result, Diodora felt that this limits their ability to fully maximize the amount of information that they can add to the body of knowledge in science. None of the other GTAs shared these beliefs. It can be disclosed that Diodora's claims might be based on her current work as a bench scientist who wishes to further her studies in a field that requires mainly laboratory research, unlike the other three GTAs who considered themselves science educators and were pursuing research in the field of science education.

Beliefs about learning. The professed beliefs of GTAs regarding learning were specific to the following features of beliefs about learning: the ability to learn, how to learn, the control of learning, and the role of students. There were many variations in the biology GTAs' proclamations about their conceptions of learning and the process of learning. Table 28 presents a summary of the GTAs' beliefs about learning.

Table 28

A Summary of Biology GTAs' Beliefs about Learning

Feature of beliefs	Proclamation regarding belief about learning	Biology GTA who holds the belief
Ability to Learn	The ability to learn comes from self and is based on effort and motivation, not one's natural ability; the innate ability to learn diminishes with age.	Aesara, Batis, Cleomedes, and Diodora
How to Learn	Students learn best from engaging and interactions with others (e.g., other students, the instructor, or sources of information like textbooks or the internet).	Aesara and Batis
	Students learn best by engaging in hands-on activities that promote the construction of their knowledge.	Cleomedes
	The most effective way to learn is through interactions and engaging in argumentative discourse in a comfortable learning environment.	Diodora
Role of Students	The role of the student is to be curious and to wonder about how things work in the natural world.	Aesara
	The role of the student is to be an active participant in the learning process.	Batis, Cleomedes, and Diodora
Control of Learning	The learner is in charge of their own learning.	Batis, Cleomedes, and Diodora
	Both students and instructors are in control of learning.	Aesara

Analysis of the biology GTAs' proclamations indicated that there were more diverse beliefs about how to learn than the other features of beliefs about learning. However, all of the GTAs seemed to agree that the most effective way to learn is to engage in interactions with others. Interactions, according to the GTAs, involved argumentative discourse and discussions. Cleomedes also highlighted the importance of engaging in hands-on activities. The proclamations of the GTAs regarding how to learn seemed to disclose a teacher-centered mindset.

Beliefs about teaching. The proclamations of the GTAs regarding their beliefs about teaching were specific to how to teach, the role of the instructor, and the goal of teaching. The GTAs' epistemic orientations identified beliefs about teaching that were either similar to or were extensions of their beliefs about learning. Table 29 provides a summary of the Biology GTAs beliefs about teaching.

Table 29

A Summary of Biology GTAs' Beliefs about Teaching

Feature of beliefs	Proclamation regarding belief about teaching	Biology GTA who holds the belief
How to Teach	Provide students opportunities to engage in group work where they can collaborate and interact with each other.	Aesara
	Use methods of inquiry and problem-solving where students can work collaboratively and enjoy the learning experience.	Batis
	Provide students with opportunities where they can engage in hands-on activities and construct their own knowledge.	Cleomedes
	Create a comfortable learning environment and presenting the content to students using simple approaches.	Diodora
Role of Instructor	A facilitator and pacing guide.	Aesara
	A facilitator.	Batis
	A facilitator and lecturer.	Cleomedes
	A facilitator and a spirit-guide (transferrer of knowledge from the instructor or expert to the student).	Diodora
Goal of Teaching	Prepare students to become scientifically literate citizens and extend their natural curiosity into their afterschool years where they can continue to wonder about the natural world and how it works.	Aesara
	Create a learning environment where students can have fun learning science and learn the science and become scientifically literate citizens.	Batis and Diodora
	Increase students' awareness of the natural environment and how things work in the natural world.	Cleomedes

The biology GTAs' professed beliefs about teaching shared commonalities as well as variations. Their proclamations revealed both student-centered (i.e., constructivist) as well as student-centered (i.e., traditional) views of teaching. For example, regarding how to teach, the GTAs' proclamations about teaching disclosed that they believed in approaches that conformed to that of an evaluativist teacher who embraces the worldview that knowledge is tentative and contextual and, as such, promotes learning activities where students can collaborate, and construct knowledge based on shared understanding. However, the GTAs' claims about the role of the instructor highlighted comingled beliefs; that is, they professed both student-centered and teacher-centered views. For example, Diodora claimed that the role of the instructor is to be a facilitator—a student-centered/constructivist approach—as well as a spirit guide, which according to her description of a spirit-guide, represented a teacher-centered/ traditional conception of teaching. According to Diodora, a spirit guide is a transferrer of knowledge from the instructor or expert to the student. This disclosed an absolutist or relativist view of teaching and learning that conformed to the traditional instruction epistemology who perceives the students as naïve, passive learners.

Regarding the goal of teaching, there was a common belief among the GTAs that the goal of teaching is to prepare students to be scientifically literate citizens and to increase students' awareness and understanding of the natural world around them.

Commonalities and Dissonances in GTAs' Science Instructional Practices

There were considerable variations in the biology GTAs' employment of science instructional practices that reflected the recommendations of the AAAS (1993, 2011). According to the AAAS, there are eight science instructional practices that, when employed, accentuate the distinctive characteristics of the material to be learned. These eight practices also stipulate the conditions under which the teaching and learning are to take place in the science classroom and include: (1) start with questions about nature, (2) engage students actively, (3) concentrate on the collection and use of evidence, (4) provide historical perspectives, (5) insist on clear expression, (6) use a team approach, (7) do not separate knowing from finding out, and (8) de-emphasize the memorization of technical vocabulary. Figure 43 summarizes the frequency of the use of the eight science instructional activities for the group of GTAs as a whole.

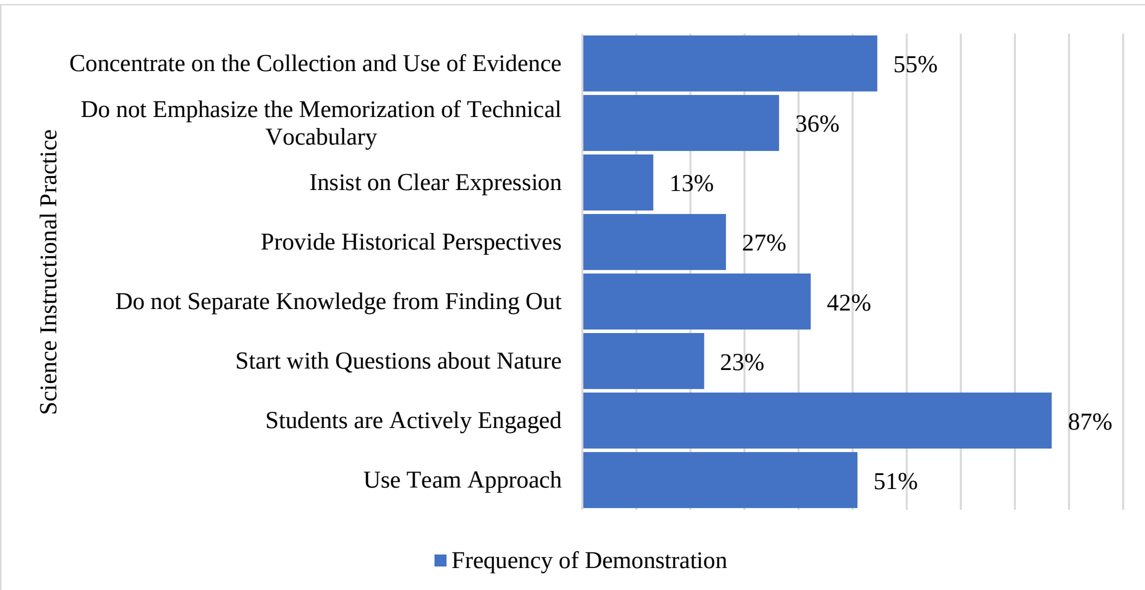


Figure 43. The frequency of demonstration of the eight science instructional practices recommended by the AAAS.

The frequency of demonstration of the science instructional practices was calculated based on the total number of activities taught by the biology GTAs during the four lessons for which they were observed. The science instructional practice demonstrated during the teaching of each activity was noted. Based on the findings, *students are actively engaged* was the most commonly employed science instructional practice (87%), followed by *concentrate on the collection and use of evidence* (55%), and then *use a team approach* (50%). The four biology GTAs demonstrated these three science instructional practices more than 50% of the time that they taught the various activities. The frequency of demonstration of these three science instructional practices aligned with the GTAs' beliefs about teaching and learning, specifically their beliefs about how to teach and how to learn. This disclosed that these beliefs aligned with the views and recommendations of the AAAS and were demonstrated during the teaching episodes of the GTAs in the laboratory represented the core beliefs of the biology GTAs. Additionally, there were five science instructional practices the GTAs employed less than 50% of the time. They were *do not separate knowledge from finding out* (42%), *do not emphasize the memorization of technical vocabulary* (36%), *provide historical perspectives* (27%), *start with questions about nature* (23%), and *insist on clear expression* (13%).

Commonalities and Dissonances in Misalignments and Alignments between Professed Features of Epistemological Beliefs and Science Instructional Practices

Misalignments. A misalignment in this study was described as an instance where the professed epistemological beliefs of the GTAs, although they aligned with the recommendations of the AAAS (1993, 2011), these beliefs were not demonstrated during the GTAs science instructional practice. The misalignments between professed epistemological beliefs and science instructional practices for the GTAs were very different in each case. Although some of the GTAs held some common beliefs about the nature of knowledge and knowing, the nature of science, and about teaching and learning, the data revealed only one commonality in the *misalignment pairs* for all the GTAs. A *misalignment pair*, in this case, was a professed feature of epistemological belief that coincided with the science instructional practices recommended by the AAAS (1993, 2011) but was not demonstrated during the GTA's instructional practice in the laboratory. Aesara and Cleomedes had one common misalignment pair: *the justification of knowledge* and *concentrate on the collection and use of evidence*. Both of these biology GTAs posited that evidence was useful in validating and authenticating scientific information. However, observations of their lessons revealed that they *emphasized the use and collection of evidence* less than 50% of the time (Figure 13 and Figure 30). Overall, each GTA had misalignment pairs that were unique to each of them. Finally, the analysis of the findings revealed that there were no misalignments between Batis' beliefs—akin to the recommendations of the AAAS—and his science instructional practices.

Alignments. Similar to the misalignments between professed epistemological beliefs and science instructional practices, there were few instances where the GTAs had the same *alignment pair*. An *alignment pair* is described as a GTA's professed feature of epistemological belief that coincides with a science instructional practice that is recommended by the AAAS (1993, 2011) and is demonstrated during the GTA's laboratory instruction. Analysis of the alignment pairs for the GTAs revealed two pairs of alignments that were similar between two GTAs.

There were no instances where common alignment pairs were found for three or all four of the GTAs. For example, the alignment pair *how to teach* and *students are actively engaged* were revealed by the cross-case analysis of the data to be common for Aesara and Batis, whom both held the view that instructors need to provide students with opportunities to engage in group work where they can collaborate and interact with each other. These two GTAs typically spent 90% or more of their instruction time doing activities where students were actively engaged. The other alignment pair that was revealed by the cross-case data analysis was the *changeability of knowledge* and *students are actively engaged*, which was typical for Batis and Cleomedes. Both GTAs professed that knowledge changes over time, especially with new experiences. As such, the two GTAs claimed that students should be provided with opportunities where they can engage and interact with each other, which in turn will broaden students' scope of experiences and increase their knowledge. During the observations of Batis' and Cleomedes' laboratory lessons, students were typically actively engaged 90% or more of the time.

Commonalities and Dissonances in the Components of Complexity Theory that Stimulated Changes in Biology GTAs' Laboratory Classroom Systems

Complexity theory in this study was used to shed light on the nature of interactions and interrelatedness of components or individual agents of the GTA's laboratory classroom as a complex system. Many components make up the laboratory system of the GTAs. However, specific to the scope of this study, three components were investigated: the professed features of epistemological beliefs of GTAs, their science instructional practices, and laboratory constraints. Complexity theory provides a framework for investigating how systems develop and change and is transdisciplinary in nature. Specific to research question one, complexity theory, a holistic theory of learning systems, was used to look for connections between biology GTAs' features of professed epistemological beliefs and science instructional practices.

Apart from the components of a system, complexity theory is also explained by focusing on its attributes that allow the understanding of a system and how its components interact to support, compete, condition, or affect each other. These attributes or characteristics include *self-organization, emergence*, *non-linearity*, *connectivity*, and *autonomy and co-adaptation.* A cross-case analysis of the characteristics of complex systems that were used to explain the impact of changes in the GTAs' laboratory systems revealed that there were not many similarities in terms of which characteristics of the complexity theory were used to describe the interactions between components of the various laboratory systems.

Each GTA's classroom system faced distinct effects that stimulated different types of interactions between the components of each system. However, there was one attribute of complexity theory that was common across all four laboratory systems: *interconnectivity*. Interconnectivity revealed interactions between components that showed connections. In all the cases, the data showed interactions between the biology GTAs' features of professed epistemological beliefs and science instructional practices. In some cases, interactions highlighted both misalignments and alignments (e.g., Aesara, Cleomedes, and Diodora) and, in other instances, only alignments (e.g., Batis).

In continuation, there was one incident where another attribute of complexity theory was common for two of the laboratory system. This occurred in Batis' and Diodora's laboratories when faced with the same internal perturbations, missing laboratory materials. However, how the stability of the two systems was maintained after the effect of the agitations was different. The attribute of complexity theory, *self-organization,* revealed how spontaneous reorganization in Diodora's laboratory system influenced slight changes in her beliefs (i.e., the role of active-learning in increasing students' knowledge in science; beliefs about teaching) and instructional practices (i.e., engage students actively) in order to maintain a stable and reorganized system due to a laboratory constraint (i.e., laboratory resources). In Batis' situation, he opted to leave out the activity and chose not to use a YouTube video to replace the dissection activity. Batis posited that he was an avid believer of active learning and acknowledged that "a video would not be able to replace the learning experience of a hands-on activity" (Batis, Plant and Animal VSR Interview, April 14, 2019). Batis used the extra class time as a result of his decision to engage students in further discussions about reproduction in plants and animals. The system remained stable despite the emergence of a sudden change that affected a component in the system.

Aside from these two instances where the same attributes were used to describe interactions and connections between professed epistemological beliefs and science instructional practices for more than one biology GTA, the other attributes of the complexity theory were used to describe the interactions between components for individual GTAs. Table 30 provides a synopsis of the characteristics or attributes of complexity theory that described connections and interactions between the components, professed epistemological beliefs and science instructional practices of the laboratory systems of the four GTAs.

Table 30

Attributes of Complexity Theory that Described Interactions between Professed Epistemological Beliefs and Science Instructional Practices

Biology GTA	Attribute of complexity theory that described connections between components	Type of perturbation or agitation that affected the laboratory system
Aesara	*Self-organization*	Higher than usual number of malfunctioning microscopes
	Non-linearity	
	Interconnectivity	
Batis	*Self-organization*	Missing flowers for dissection activity during Plant and Animal Reproduction laboratory lesson
	Emergence	Difficulties explaining content to students as an ESL instructor of a subject with may technical terminology
	Interconnectivity	
Cleomedes	*Interconnectivity*	None according to the data collected [a]
Diodora	*Self-organization*	Missing flowers for dissection activity during Plant and Animal Reproduction laboratory lesson
	Autonomy and Co-adaptation	Time constraints that did not allow students to learn the content and master the required laboratory skills
	Interconnectivity	

Note. Due to the meticulous and regimented nature of Cleomedes as a laboratory instructor, she planned ahead of time for internal perturbations like time constraints. Therefore, there were no instances during the time for which her lessons were observed that any disturbance or change as a result of internal or external agitation stimulated the need for re-organization or a continually evolving system.

Research Question Two

This section presents the findings of the study that primarily addressed research question two. The first part of this section highlights the laboratory constraints that the GTAs acknowledged were present in their laboratories. Also discussed are the influences of the laboratory constraints on misalignments between the features of GTAs' professed epistemological beliefs and science instructional practices.

Laboratory Constraints

With increased appreciation for the scholarship of teaching and learning in science, more research has been conducted in the study of undergraduate biology laboratory education. There are certain characteristics, such as the instructor's intrinsic factors, laboratory structure, learner differences and expectations, and student assessment, that can provide constraints on the teaching-learning process in the context. The data used for analyses for this aspect of research question two were the GTAs' beliefs interviews as well as the video stimulated recall (VSR) interviews. The GTAs acknowledged that certain factors were present in the laboratory that affected the way that they taught or wanted to teach. These laboratory constraints are presented in Table 31 under four broad categories.

Table 31

GTAs' Laboratory Constraints

Constraints	Description
GTAs' Intrinsic Factors	- Feelings about the biology laboratory curriculum - Preparation for laboratory lessons - Science content knowledge
Laboratory Structure	
a) Physical	- Physical layout - Class size (number of students)

b) Curriculum	- Class time (duration)
	- Design
	    - content material (complexity, rigor, and amount)
	    - teaching resources and laboratory equipment

Learner Constraints	- Individual learner differences - Learner expectations - Learner responses
Student Assessment	- Determining students' understanding

GTAs' Intrinsic Factors

There were person-related factors specific to the GTAs as individuals, which were considered intrinsic factors that posed as laboratory constraints unique to the biology GTA. These person-related factors included the GTAs' sentiments (i.e., how they felt) about the laboratory, individual preparation for laboratory lessons, and their science content knowledge. The narrative for each factor is presented separately.

Feelings about the biology laboratory curriculum. Some of the GTAs had firm opinions regarding some of the laboratory activities and believed that the way they felt directed some of the decisions that they made. For example, Diodora shared her frustration about having to do the strawberry DNA extraction activity with her students and noted that,

> This lab isn't one of my favorites. I think the strawberry extraction is trying to make it fun, but it's the stuff that you do with, you know fourth, fifth graders, and I think having undergraduates do something simple like that is a waste of their time and I think so personally. I prefer to have my students watch me do it because I think having them do it wastes their time. And I don't feel like they want to. I almost feel like its busy work for them, and so I don't like that aspect of it. (Diodora, DNA Extraction and Mitosis VSR Interview, March 12, 2019)

Like Diodora, Batis was also critical of the strawberry DNA extraction activity. According to Batis,

> I shadowed a senior GTA, and he had his students do the strawberry activity. But I remember sitting there and watching the students' reactions, and they were like, "You've got to be kidding me." This is a waste of our time. And you can just feel that in the room. So, when I had my own lab, I had to look for ways to make that activity more enjoyable for students. (Batis, DNA Extraction and Mitosis VSR Interview, March 17, 2019)

Batis added that he tried to play videos from YouTube and talk about real-life stories to make the strawberry DNA extraction activity more interesting for his students.

Cleomedes shared her views about the Plant and Animal Reproduction laboratory and expressed her feeling about students having to learn about the male and female reproductive parts at this stage in their education. However, Cleomedes admitted that she allocated more time on aspects of the lab that she thought were more practical for students to be learning at the undergraduate level. According to Cleomedes,

> I feel like the male and female reproductive Anatomy. For me, that's just busy work for [students]. At this level, I feel like that's pointless. Now the spread of

> STI's I really enjoy this one, and I think it opens their eyes. I think this is one of the most practical labs that we do because I don't think that as 18- to 24-year olds, they really realize what risk they are at. So that was something that I really, really wanted them to take home, and I make time for students to get this. (Cleomedes, Plant and Animal Reproduction VSR Interview, April 16, 2019)

Aside from being critical about some of the labs, some of the GTAs also expressed discomfort about certain aspects of the Plant and Animal Reproduction laboratory. Diodora explicated that any display of discomfort in class impacted the teaching-learning process. She explained that,

> I didn't feel as comfortable as I normally do, teaching this lab, and so I know just with this type of student, meaning a typical 1031 student if you don't come in confident and feeling like you really know it most of the time they've lost. So, I know if I did – I felt a little shaky, then I knew they probably did too. So, when I am not up to my A-game, my students feel it, and they too are not up to their best. (Diodora, Plant and Animal Reproduction VSR Interview, April 16, 2019)

Preparation for the laboratory. The GTAs admitted that some of the laboratories required more preparation than others, and even after teaching them multiple times over the years or even during the same week, they felt that they were still never fully prepared. Batis explained that there were some aspects of some laboratories that were always unclear for him, and at times, that made his preparation more time consuming so that he could get it right and make it a more enjoyable experience for students. For instance, Batis described his experience doing the strawberry DNA and extraction activity, and indicated that,

> The first lab was fine. It just, it is what it is, like, but there was one part of the procedure, the ethanol, and the liquid, the buffer – I wasn't sure which one is supposed to be on top of which. I just forgot, and it was not clear on the lab manual too. It seems like it didn't matter. Because the students figured it out and they enjoyed that. Yeah, it worked out anyway. Also, I showed them the video, but the video doesn't really like to cover the different stages like the telophase. So, I feel like it's a mess there. Yeah, so, the video and the lab manual and the experiment were just not consistent. I tried to make it work for the students so

> they can learn something and still enjoy it. (Batis, DNA Extraction and Mitosis VSR Interview, March 17, 2019)

Another aspect of preparation that represented a major constraint for Batis was inadequate preparation for explaining the biology content to students. Batis highlighted that his preparation in that regard could have been better if the science department provided professional development for international GTAs like him. Batis noted that as a result of this limitation, he resorted to using a lot of YouTube videos to help out with his lessons. According to Batis (Fermentation VSR Interview, March 4, 2019), “I have a hard time explaining in English. So, I use a lot of videos from YouTube to help me with the vocabulary and to use it in class for the students.”

Science content knowledge. Batis was the only GTA who thought that science content knowledge was a constraint that could negatively affect the learning experience of his students. Batis acknowledged that he was not able to explicitly explain a lot of the material, especially when there was much technical vocabulary. Batis acknowledged that he had never had the opportunity to sit in a biology lecture and experience first-hand the science content material presented in English. Batis explained that he was not happy with his lesson on DNA Extraction and Mitosis. According to Batis,

> I have never even had the chance to listen to a lecture in person. Like, hear a professor talking about the structure of DNA in English. This is something I would like. So, I have to watch a video about that before class. During the lesson, I don’t think I addressed it explicitly about like the information contained in DNA. It was just very implicit. I should think of that before when I’m preparing for that I have to think about the ideas, what the major core concepts would be. I’m trying to explain. I think this is because of my limited understanding. Even if I read the information, but since I never explained it before in English to my students, it is challenging. So, I want to be able to explain that better. (Batis, DNA Extraction and Mitosis VSR Interview, March 17, 2019)

Batis further stated that he hoped that he could get some professional development that involved doing the laboratory activities. Batis claimed,

> If we have better professional development, weekly meetings. If I have a chance to do the experiment myself with other GTAs, as a PD [professional development]. That'd be better. I could develop my own limited content knowledge and scientific literacy and language skills. (Batis, DNA Extraction and Mitosis VSR Interview, March 4, 2019)

Laboratory Structure

The laboratory setting provides a unique medium for teaching and learning in science education, where one of the affordances of the laboratory is to provide students with the first-hand experience in observation and manipulation of the materials of science. However, the physical layout of the laboratory, as well as the curriculum structure, may present certain constraints to laboratory instructors. The data was divided to consider the physical structure of the laboratory as well as the course structure in order to present the findings for laboratory constraints. The course structure focused explicitly on the curriculum and highlighted the findings that looked at curriculum design, class size, the content material, and teaching resources.

Physical layout. The GTAs believed that the physical layout of the laboratory was not the best, specifically regarding the position of the PowerPoint projector and screen. For example, Batis and Diodora explained that the screen was not centrally located and that it was disadvantageous for students who were sitting on the far front left of the room. Per Batis (GTA beliefs interview, January 8, 2019), "Sometimes the PowerPoint, the slides and the projector, only half of the room can see clearly. The other half of the students have difficulty seeing the screen." Diodora stated that,

> The students who sat on the opposite end of the room from where the PowerPoints were projected, especially those who sat up front, did not have the best view of the slides. Also, it is uncomfortable for the ones sitting with their backs facing the front of the room because they have to turn and take notes on their laps. It is not the best set up because there are so many other things going on in the front of the room. (Diodora, GTA beliefs interview, January 29, 2019)

Another constraint regarding the physical set up was that the layout of the room was not conducive for certain types of group activities. Aesara noted that,

> I feel like the room is not the best for all group work. It's sometimes harder to have large poster paper on the tables. Like, everybody would have to come to one side because the tables aren't flat. But sometimes I would have to hang [the posters] on the wall or something like that. Then again, there's not as much wall space so I hang them on the whiteboards. But then I need the whiteboards to write and illustrate. So, as far as group work outside of doing the actual experiment there may be constraints on that just because [students] would have to, like I said, group on one side or talk over the little hood thing. (Aesara, GTA beliefs interview, January 8, 2019)

Class size. The GTAs believed that a laboratory size of 24 students was too large. Diodora (GTA beliefs interview, January 29, 2019) posited that she felt that the class is large. "Twenty-four is a lot of students. You don't get that one-on-one time." Aesara also believed that 24 students were a lot to have, especially when students have questions and "you are trying to get to everybody and attend to their questions"(GTA beliefs interview, January 8, 2019).

Class time. All of the GTAs agreed about class time as a constraint, mainly because of the amount of work that needed to be covered for two hours. The GTAs explained that sometimes they had to make on the spot decisions about which laboratory activities they should omit because of time. Diodora explained that,

> There is so much in this plant and animal reproduction lab, and I just feel like I would not want to be a student in this lab because it's – I feel like yeah – It's all centered around the idea of reproduction we have what 1, 2, 3, 4, 5, 6, 7, 8, 9 activities to complete in two hours. Nine and I omitted two, so 9 to 11 activities

> to do in two hours. I feel like it's way too much. You have to know what to omit and what you can do and sometimes it not easy to choose. (Diodora, Plant and Animal Reproduction VSR Interview, April 11, 2019)

Omitting activities was not the only time-based decision that the GTAs regarded as a laboratory constraint. Other decisions included cutting back on discussion time, and some of the GTAs felt that the students were "shortchanged on rich, explicit discussions that would further their understanding of the content" (Cleomedes, GTA beliefs interview, January 10, 2019). Cleomedes also added that,

> I think just a time constraint because it is such a short lab it's like you have to do everything kind of at a certain pace or a certain flow and then making sure the students get to do the hands-on component in a timely manner. There are certain things that they require us to talk about, and students learn the basics of it but not in-depth. (Cleomedes, Fermentations VSR Interview, March 8, 2019)

Similarly, Aesara admitted that,

> When I know that we have to get something before a certain time. When I know, I have to get these three labs in before they leave. We may not have enough time to explain something or have a rich discussion about things. So, when I know I have to get 1-2-3 done before they leave then, we cut out on discussion time. Time is a constraint in the sense that I feel like some stuff has to be rushed to get through all that we're scheduled to get through. (Aesara, DNA Extraction and Mitosis VSR Interview, March 15, 2019)

Curriculum design. The biology GTAs pointed out that the pre-determined curriculum design was a major laboratory constraint for them. Included in their discussion of the laboratory design were the amount of content material (e.g., activities and experiments), the rigor and complexity of the content material, the teaching resources (e.g., PowerPoints and notes), and the laboratory equipment (e.g., microscopes, slides). According to the GTAs, although they had some degree of autonomy in their teaching, the factors as previously mentioned restricted some of the things that they would have wanted to include in their instruction.

The order of how the lesson should progress was one of the constraints that the GTAs identified as a major constraint. The structure of the laboratory involved a 10-minute quiz at the start of class, followed by a short lecture of not more than 10 minutes, experiments and activities, and then completion and submission of their in-lab assignments at the end of class. The GTAs acknowledged that there was sometimes a disconnect between the various subjects covered in one laboratory, making it challenging to present a short and smooth 10-minute lecture after the quiz. The GTAs felt that the variety in the content sometimes required more than one short lecture, and sometimes there was not enough time to be explicit enough. Batis noted,

> There is definitely an order issue, and also another restriction is the procedure. Like, there should be a quiz at the beginning of the lab. And why? Just to make sure people get in time! That's not a good justification. There should be a very short lecture overall. But it is not possible because there are so many different topics. Technically, you cannot talk about all these different things in about 10-minutes. (Batis, GTA beliefs interview, January 8, 2019)

The biology GTAs thought that the amount of content material was too heavy for a laboratory where they believed that lecturing should be minimalized and more directed to hands-on activities and active learning. During her plant and animal reproduction VSR interview, Aesara explained that,

> I feel like the nature of the lab itself could be considered as a constraint because there were so many activities within there that we were required to do, and there is always some little lecture before each one. The students need to do some more hands-on and inquiry. So, there's this whole thing about cookbook labs, right? There's this whole thing about step 1, step 2, step 3. I think that in itself is a constraint, the structure of the lab. Like put this ingredient in here, do this and do that. I would prefer they would be more inquiry-based. Like, let's have a question, and you design an experiment to try to figure out that question. However, there is just so much to do. I think there's a grey line between the number of activities we can skip and then the amount that we need to focus on and do. I don't think that has been established like you have to do this or you can't do this because we skipped, I skipped part of the karyotyping and the cross,

> monohybrid crosses, the dihybrid crosses. I skipped all that, but I felt like I couldn't have skipped like everything like the blood typing and the pipe cleaners and stuff, the little activities. I feel like there were certain activities I had to do so that within itself could be, I guess, seen as a constraint. (Aesara, Plant and Animal Reproduction VSR Interview, April 14, 2019)

Similarly, Batis admitted that some of the laboratories had so much content during the plant and animal activities to complete he was not sure which ones he should do, and which ones would be best to leave out. According to Batis,

> Like with the plant and animal reproduction experiment, the lab is really long and has too much content in it. I can just choose some of them to do, but sometimes I am not sure. And even for the questions like the lab assignment, I can just choose some questions, not all of them. The students cannot do all of that. It's too much. (Batis, Plant, and Animal Reproduction VSR Interview, April 14, 2019)

All of the GTAs agreed that some of the laboratory activities were not rigorous enough for undergraduate students and identified this issue as a constraint because they felt that they were losing students' interest during these activities. The GTAs also indicated that some of the students felt that some of the students had already done some of the activities in middle and high school science and felt that some of the experiments were not complex enough for undergraduate students. In order to keep students focused and interested, Cleomedes explained that she had a specific type of "time distribution and elimination strategy" for the activities. For example, she affirmed that,

> I would touch on that more, and as far as the DNA extraction, I would probably not do the strawberry. I would do something else that was more challenging and spend more time doing it only because I know they did the strawberry lab in high school. One of the things last year that a student said on the evaluation was that the labs were very elementary to him and so just stepping it up with what we could extract, and if we have the resources to choose something different. (Cleomedes, DNA Extraction and Mitosis VSR Interview, April 14, 2019)

Diodora also stated that a few of her students complained about the complexity of the laboratory and also highlighted that her students, at times, felt offended because they felt that they were still in high school. According to Diodora,

> So, it needs to be a more rigorous type of lab, so that [students] feel like they get the lab experience and that they need and that they're not just repeating what they've already done in their own high school lab. So, [students] feel like this is a college-level lab. Currently, some of the activities are more high school level. So, the labs have to be more rigorous because of that. (Diodora, GTA beliefs interview, January 29, 2019)

Another constraint related to curriculum design that the GTAs recognized as a constraint was the teaching resources and laboratory equipment. The teaching resources included the pre-determined PowerPoints and notes that were given to them beforehand that were required to support their laboratory lessons. The GTAs all felt that these resources were beneficial, especially the PowerPoints; however, they restricted instruction to some degree.

For instance, Batis (DNA Extraction and Mitosis VSR Interview, March 17, 2019) explained that the objectives listed on the notes, the PowerPoints, and students' laboratory manuals were not in sync with each other and as a result of the mismatch he felt confused at times as to what the main objective of the lesson should be. During their plant and animal reproduction VSR interviews, the GTAs noted that the microscope and slide activities were always stressful because some of the microscopes did not function properly. For example, some of the images on the slides were not visible at all. Aesara, Cleomedes, and Diodora expressed that the quality of the slides, specifically those for the genetics and plant and reproduction laboratories, were inferior and created some setbacks during their lessons. For example, Aesara acknowledged that,

> I think there were a lot of difficulties in this plant and animal reproduction lab. With this class, in particular, it was a lot more difficult than my other classes because there were a lot of microscopes that were hard to focus. I had to either spend a lot of time trying to focus whereas in times past I could help them really quick and then go to another student and help them and so forth. Whereas [in] this one, I had to spend a significant amount of time trying to help them focus and still some of them like two or three of them I didn't get focused. And so, I felt that this one was a little more difficult to navigate because of the quality of the lens. (Aesara, Plant and Animal Reproduction VSR Interview, April 14, 2019)

In addition, Cleomedes expressed that,

> I think the quality of the root tips wasn't that good. I think we should have just used the white fish slides because they were of better quality. And then also, it was very difficult for the students to find the different phases of mitosis even though I tried to go back to the PowerPoint and kind of show them what they would look like under the microscope and then talk about that before they looked at the microscope. Just looking at those different phases, and they were so small. And it was just a hard thing. I think the root tip was left to right, so that was a challenge for them. (Cleomedes, Genetics VSR Interview, April 2, 2019)

Learner Constraints

The biology graduate teaching assistants identified certain aspects of their students as constraints. These aspects included learners' differences, expectations, and responses. Aesara and Batis explained that student differences were a major constraint. The GTAs defined learner differences in terms of the background information that the students were bringing with them into the laboratory. According to Batis (GTA beliefs interview, January 8, 2019), "As the instructor for my lab, I have no idea where [students] are in the lecture and the students come from different lectures. They have different paces, so the students have different prior knowledge." The GTAs posited that since students were not all part of the same lecture, there were cases where they were doing the laboratory activity before being exposed to the content material in the course lecture. As a result, it was difficult to know how explicit and how in-depth to go with lectures and discussions.

Another learner difference that presented as a constraint was students' laboratory skills. The GTAs explained that some of the students had difficulty manipulating and correctly using some of the laboratory equipment, and this constraint made it challenging to complete all required laboratory activities, especially with the limited time available. There was hardly enough time to spare to teach students how to use the microscope, measure, or record results appropriately. For instance, Diodora pointed out that,

> It's something that if you're experienced with a microscope, you can work around and figure out what to look for but for these students, this is their third time ever on a microscope, and if anybody missed a day it's their second or even the first time on a microscope. They don't even know how to put a slide on a microscope properly. They don't know how to move the stage properly. They don't know how to move the objectives or the stage to actually get the organism and focus. I spent so much time ensuring that students can see at least one of the specimens and learn something, and sometimes we do not have enough time for me to work one-on-one with all of those who are having trouble. (Diodora, DNA Extraction and Mitosis VSR Interview, March 12, 2019)

Students' expectations and responses were another learner constraint that the GTAs acknowledged that they faced within the laboratory. Some of the GTAs acknowledged that some of the students felt that they were not doing undergraduate level work and mentioned that they were either bored with the material or offended by it. According to Cleomedes (GTA beliefs interview, January 10, 2019), some of these expectations led to "disinterest and distractions." Cleomedes also added that "a lot of students did reach out and say that some of the labs were very elementary and they were offended by the – some of the labs that we did sort of thing" (Cleomedes, GTA beliefs interview, January 10, 2019).

Similarly, Diodora stated that,

> I remember sitting and watching them and watching the students' reactions to some of the activities in this lab, and they were like you got to be kidding me. This is a waste of our time. And you can just feel that in the room. They were like bored out of their minds because they felt like I was high school all over again. (Diodora, DNA Extraction and Mitosis VSR Interview, March 12, 2019)

Diodora further noted that when students had these expectations about the laboratory, it created a negative atmosphere in the learning environment, which made it "difficult to try to get everyone on board and enthusiastic about learning science" (GTA beliefs interview, January 29, 2019).

Student Assessment

The final laboratory constraint identified by the biology GTAs was student assessment. The GTAs believed that even with the amount of autonomy that they were given with the laboratory, they were not able to assess students' understanding of the laboratory content fully. One of the reasons provided for this belief among the GTAs was that the 10-minute quiz at the start of the lesson did not allow much room for explicit evaluation of students' understanding.

For instance, Cleomedes believed that this aspect of the laboratory needed restructuring. Cleomedes stated that,

> I would restructure the lab in a way that it's not necessarily a quiz. It may be some type of activity or participation or something that still you have to be here at 8:00 or whatever time class starts. Then in the first 10 minutes, you've missed it – some ways that could better assess students' understanding. (Cleomedes, GTA beliefs interview, January 10, 2019)

Furthermore, the GTAs explained that since the laboratory lesson runs so quickly during the two hours, using questioning as a type of formative assessment was not very useful. According to Aesara,

> I don’t know if they’re really learning other than talking to them. It’s always – it’s always unsure because, like I said, the only type of formal assessment I have is are the quizzes, and then I have asked them questions, but not everybody answers the questions, so I don’t really know if they’ve gotten those concepts or not. So, the ones that I individually went around to talk to, some got it, and some didn’t. So, I don’t know necessarily if they understood these concepts. The people that speak out in class when I ask questions are the same people that always speak out in class, so you know I can understand that they kind of got it, but the other ones that are quiet I have to kind of go around and check on, right? But I still don’t get to really know. I just cannot assess in the way that I would like to. (Aesara, Fermentation VSR Interview, March 1, 2019)

Batis was very concerned about assessing students’ understanding and mentioned that this constraint was always on his mind. He was the only GTA who administered his own student evaluation to gather feedback not only on how to make him a better laboratory instructor but also to determine students’ understanding of various topics. Batis affirmed that “the way you assess whether students are learning can improve your teaching and make it more effective, as it provides immediate feedback on what works and what doesn’t and so I always give my own class evaluation” (Batis, GTA beliefs interview, January 8, 2019).

Summary of Laboratory Constraints

The biology GTAs identified certain aspects of teaching and learning in the laboratory that presented constraints. These laboratory constraints included GTAs' intrinsic factors, laboratory structure, learner constraints, and student assessment. According to the GTAs, these laboratory constraints influenced their instruction. The following section highlights the influence of the laboratory constraints on the misalignments between GTAs' professed epistemological beliefs and their science instructional practice.

Influence of Laboratory Constraints on Misalignments between Professed Epistemological Beliefs and GTAs' Science Instructional Practices

The data sources, GTA beliefs and VSR interviews were examined to determine how the laboratory constraints identified by the GTAs impacted the misalignments between their epistemological beliefs and science instructional practice. The cases where laboratory constraints influenced misalignments between GTAs' professed features of epistemological beliefs and science instructional practices were described as circumstances where GTAs were aware of inconsistencies between their epistemological beliefs and science instructional practices and attributed the mismatch to laboratory constraints. The next section presents the findings of the influence of laboratory constraints on the misalignment between professed features of epistemological beliefs and science instructional practices for each case.

Case One: Aesara

Influence of time allocated for laboratory instruction. Aesara identified the time allocated for the laboratory as a constraint and stated that she did not have enough time to complete all that she wished to do during her laboratory instruction. Findings indicated that the duration of class time influenced the misalignment that was found between Aesara's claims about the *structure of knowledge* and the science instructional practice *de-emphasize the memorization of technical vocabulary* (Figure 44).

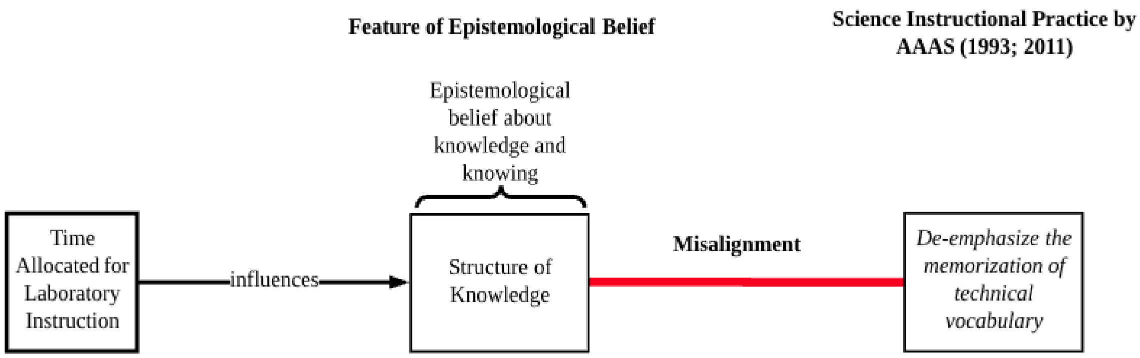


Figure 94. The influence of the duration of class time on the misalignment between Aesara's epistemological beliefs about the *structure of knowledge* and the enactment of the science instructional practice *de-emphasize the memorization of technical vocabulary*.

Aesara posited that "knowledge structures move gradually from simple to complex" (Aesara, GTA beliefs interview, January 8, 2019). She also claimed that "students should be able to understand the concepts being taught in the laboratory" (Aesara, GTA beliefs interview, January 8, 2019). Aesara described her lesson on Human Genetics as one that was complicated and entailed a lot of technical terms that students were required to know and understand in order to be able to engage in the laboratory activities. She declared that,

> I think, as a GTA, I can have that liberty to bring them back to that big point. And sometimes that we get caught up with all that we have to do, and it's easier for them if they don't know the stages of mitosis – you know, just memorize that.

> But what does that mean if it's out of whack? You know, what does that do to our body when it's out of whack. Like, let's bring it back to the big picture. They may never know because we don't have time to discuss. All they can do in the given time is memorize. (Aesara, Human Genetics VSR Interview, March 28, 2019)

Aesara made this claim during her VSR interview and purported that as a result of the amount of time that is allocated for laboratory, she needed to spend more time lecturing to "clarify thinking and conceptual understanding" (Human Genetics VSR Interview, March 28, 2019). Aesara claimed that she did not have the type of time needed to do so. These claims revealed that Aesara did not have enough time to present the information "from simple to complex" as she believed it should be and instead encouraged students to memorize technical terms. This was an indication of the influence of the time allocated for laboratory on instructional decisions that did not match Aesara's professed epistemological beliefs.

Influence of curriculum design. Another aspect of curriculum design (i.e., teaching resources) was found to have an impact on the misalignment pair, *structure of knowledge* and *de-emphasize memorization of technical vocabulary* (Figure 45).

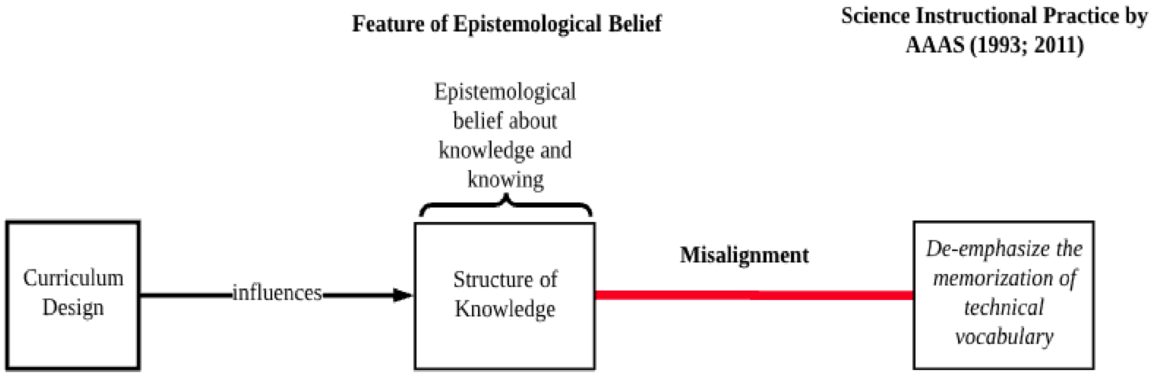


Figure 45. The influence of curriculum design on the misalignment between Aesara's epistemological beliefs about the *source of knowledge* and the enactment of the science instructional practice *de-emphasize the memorization of technical vocabulary*.

Aesara spoke about how the predetermined PowerPoints handed to them by the department posed some challenges for during her laboratory instruction. For instance, Aesara explained that "some of the PowerPoints are heavy on the vocabulary, especially the one for the Genetics lab" (Human Genetics VSR Interview, March 28, 2019). She further posited that as the instructor, she did not have many options to do otherwise because "this is what we were given to teach" (Human Genetics VSR Interview, March 28, 2019). The PowerPoint presentations did not layer the information from simple to complex, as Aesara would have preferred. Instead, the slides only presented the content information to be covered for the laboratory lesson. This situation revealed that Aesara believed that she had no other alternatives but to present the information as it was given even if the information on the PowerPoint slides emphasized technical genetics vocabulary and was not presented from simple to more complex. As such, the curriculum design specific to the instructional delivery of science content based on the biology department's stipulations served as a laboratory constraint that influenced the misalignment between Aesara's beliefs about the *structure of knowledge* and *de-emphasize the memorization of technical vocabulary*.

Summary of influence of laboratory constraints on misalignments between Aesara's professed epistemological beliefs and science instructional practice. The influence of laboratory constraints on the misalignments between professed epistemological beliefs and science instructional practices were determined from data from the VSR interview conducted after each laboratory lesson. The cases where laboratory constraints influenced misalignments between Aesara's professed features of epistemological beliefs and science instructional practices described circumstances where Aesara was aware of inconsistencies between her epistemological beliefs and science instructional practices and attributed the mismatch to laboratory constraints. Aesara identified time allocated for laboratory and the curriculum design as two laboratory constraints that impacted her instructional practice. More specifically, she was confronted with the challenge of presenting the content by layering it from simple to complex or had to encourage students to memorize technical vocabulary, two practices that did not reflect her epistemological beliefs. The next section highlights the third case (i.e., Cleomedes) since the data did not reveal any misalignments between Batis' professed epistemological beliefs and science instructional practices.

Case Three: Cleomedes

Influence of time allocated for laboratory instruction. Findings indicated that there was a misalignment between Cleomedes' professed beliefs about the role of evidence in science (i.e., science is based on empirical evidence) and her emphasis on the collection and use of evidence during her instructional practice. Cleomedes acknowledged that evidence plays a very significant role in science and is essential to science as a body of knowledge because it validates scientific knowledge. She claimed that “scientific evidence makes people more accepting of scientific knowledge and its development” (GTA beliefs interview, January 10, 2019). Although she professed this belief about the role of evidence in science, her instruction did not place great emphasis on the collection and use of evidence. During the majority of the time for which she was observed, it was noted that during the activities where students collected evidence, Cleomedes would call upon a student to summarize the findings. According to Cleomedes, “There was not much time for lengthy discussions since there were so many things to cover in just two hours” (GTA beliefs interview, January 10, 2019). Also, in an attempt to ensure that there was some form of discussion about the results in the time she was given, Cleomedes reviewed some of the expected results before students engaged in the experiments. During VSR interview she was asked specifically about that instructional decision. Cleomedes explained that she provided students with information about the activity in advance so that there would be available time to complete the other laboratory activities. She explained to the students,

> So, with this lab, we’re going to see if, in fact, you are breathing out carbon dioxide, and we’re gonna use bromothymol blue as our indicator. So, does anybody know what an indicator is like what does an indicator tells us? So, if you indicate something, what does that mean? Pointing it out, making it known, or making it visible. So, of course, you can’t really see your carbon dioxide when you exhale. Only if you live like in a cold climate, you can kind of see the carbon dioxide. But we can’t really visibly see the carbon dioxide. But with this activity, we’re gonna actually see the color change of the bromothymol blue when you’re blowing into the test-tube. (Cleomedes, Fermentation Lesson, February 28, 2019)

This excerpt revealed that for the sake of time, Cleomedes guaranteed that students were briefed about the data that they would be collecting. In so doing, Cleomedes believed that students were aware of the role of evidence during their investigation and supposedly made some connection between the evidence and content information. This teacher-centered approach did not reflect Cleomedes' beliefs about the important role of evidence in science since she mostly glossed over the collection and use of evidence in a review that typically engaged one student or herself telling students what the results should be before they began experimenting. Cleomedes believed that this strategy was practical since time was an issue. As such, the time allocated for laboratory instruction served as a constraint that influenced the misalignment between Cleomedes' beliefs about the *science is based on empirical evidence* and *concentrate on the use and collection of evidence* (Figure 46).

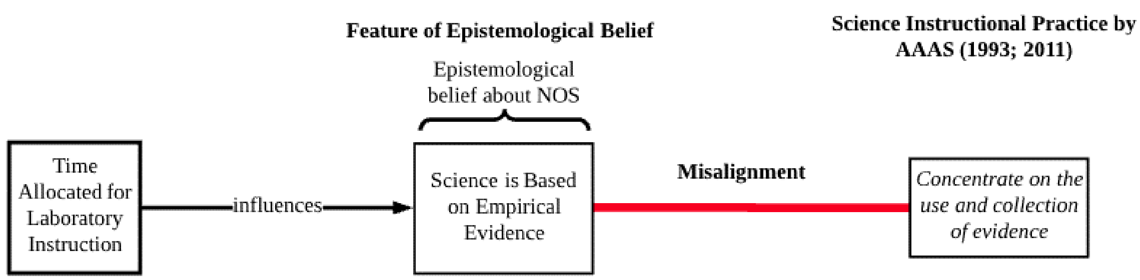


Figure 46. The influence of the duration of laboratory class time on the misalignment between Cleomedes's epistemological beliefs about *science is based on empirical evidence* and the enactment of the science instructional practice *concentrate on the use and collection of evidence*.

Summary of the influence of laboratory constraints on misalignments between Cleomedes' professed epistemological beliefs and science instructional practice. The amount of time allocated for the laboratory was a constraint that influenced the misalignment between Cleomedes' beliefs about *science is based on empirical evidence* and the science instructional practice *concentrate on the collection and use of evidence*. Cleomedes was aware that time presented a constraint on her instructional practice. Therefore, she employed an instructional strategy where she briefed students about expected results and what to look for during their investigations as a way to focus students' attention on the evidence.

Case Four: Diodora

Influence of time allocated for laboratory instruction. Diodora believed that "knowledge does not change, but rather it is an individual's understanding of a piece of knowledge that changes" (GTA beliefs interview, January 29, 2019). Consequently, she declared that students should be provided with ample opportunities in the laboratory to understand the biology content material. However, her instructional practice indicated a misalignment between the *changeability of knowledge* and *do not separate knowledge from finding out* (Figure 47).

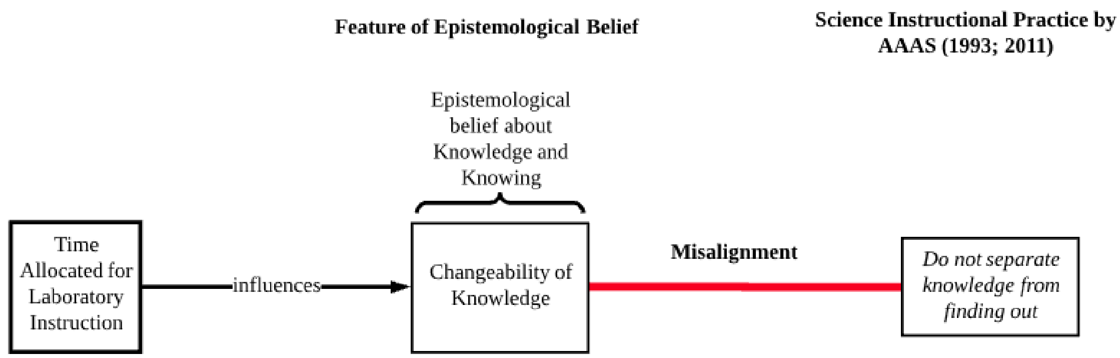


Figure 47. The influence of the duration of laboratory class time on the misalignment between Diodora's epistemological beliefs about *the changeability of knowledge* and the enactment of the science instructional practice *do not separate knowledge from finding out*.

Diodora stated that,

> I mean, I feel like doing the best that you can in a limited amount of time, right? Because we're asked to do so much with these students in a short amount of time. I don't have students typically focus on the procedures for the experiment. I know that this is important. But I have to jump right to the results and drawing conclusions from the results. There's just not a lot of time to talk about the procedures. I would like [students] to make connections between what they did and their results, but there is not enough time. So, what can they take away from this lab? Measuring skills, how to observe. (Diodora, GTA beliefs interview, January 29, 2019)

In this instance, it was recognized that class time or duration was responsible for the misalignment between the *changeability of knowledge* and *do not separate knowledge from finding out*, where Diodora's claims revealed that she believed there was not enough time during the lesson to help students develop scientific habits of the mind. Therefore, she focused on the steps of the scientific method (e.g., observing) and laboratory skills, where an understanding of how the methodology and findings of the fermentation experiment connected to the concept of fermentation would have led to a change in students' understanding of fermentation. However, Diodora's claims revealed that because of time as a constraint, changeability of knowledge as she described it led to an instructional practice that separated knowledge from finding out.

Summary of the influence of laboratory constraints on misalignments between Cleomedes' professed epistemological beliefs and science instructional practice. Diodora professed that the understanding of a piece of information changes and that students should be provided with opportunities to be able to gain that type of understanding. She also claimed that it was important to help students make connections between how the methods and results connected to the content. However, Diodora emphasized laboratory skills and the scientific methods as a way of ensuring that students grasped some sort of knowing because time constraints would not allow for the type of discussions that were required for the students to see that theory and practice were not separate. Diodora identified time allocated for laboratory as a laboratory constraint that impacted her instructional practice. More specifically, she was confronted with the difficulty of helping students acquire both scientific knowledge of the world and scientific habits of mind at the same time. The following sections provide a discussion of how the complexity theory and its attributes can explain the interrelatedness between the three main constructs of the study: features of GTAs' professed epistemological beliefs, science instructional practices, and laboratory constraints.

Relationship between Epistemological Beliefs, Science Instructional Practice, and Laboratory Constraints

Findings from this study indicated that there was a connection between the biology GTAs' professed features of epistemological beliefs and their science instructional practice and that laboratory constraints influenced misalignments between the two constructs. Misalignments arose when biology GTAs' professed epistemological beliefs, although they aligned with the views of the AAAS (1993, 2011), these epistemic orientations were not demonstrated during their laboratory instruction. Furthermore, there was evidence that some of the misalignments were a result of the influence of laboratory constraints. Although the findings identified four main laboratory constraints (i.e., GTAs' intrinsic factors, laboratory structure, learner constraints, and student assessment), the analysis of the findings revealed that only constraints due to laboratory structure influenced the misalignments discovered. The aspects of laboratory structure that posed as constraints were time allocated for laboratory instruction and curriculum design. The constraint, time allocated for the laboratory, impacted misalignments specific to Aesara, Cleomedes, and Diodora; while the constraint, curriculum design, influenced a misalignment specific to only Aesara. The interactions between laboratory constraints and the misalignments between professed features of epistemological beliefs and their science instructional practice are highlighted in Figure 48.

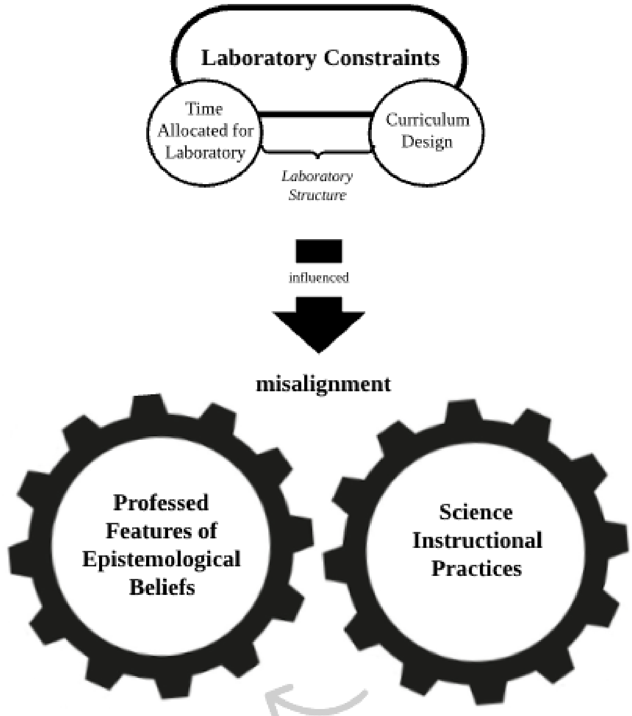


Figure 48. The influence of laboratory constraints on misalignments between the professed features of GTAs' epistemological beliefs and science instructional practice.

The Nature of the Complexity of the Interrelatedness among the Features of GTAs' Professed Epistemological Beliefs, Science Instructional Practice, and Laboratory Constraints

Complexity theory is concerned with learning systems and provides a framework for those interested in examining how these learning systems develop and change. In education, the complexity theory provides a complex rather than simplistic view of teaching and learning. It offers an alternative to linear and reductionist conceptualizations. It emphasizes relationships among the subparts of a system and the emergence of something new. One of the key ideas of complexity theory and education, which was particularly relevant to this research, is that many aspects of education, including classrooms, can be understood as a complex system. Complex systems have several attributes that typify complex systems, including *self-organization, emergence*, *non-linearity*, *connectivity*, and *autonomy and co-adaptation*. Findings revealed interactions and connections between the three components: features of GTAs' professed epistemological beliefs, science instructional practice, and laboratory constraints. The laboratory classroom is an example of an open system fed by energies coming into the system. Laboratory constraints may be seen as an example of a form of energy that feeds the laboratory classroom system and enables it to maintain itself. Through confronting these constraints, the biology GTAs were able to maintain the dynamic stability of the laboratory systems.

Self-Organization

Using complexity language, self-organization in the laboratory system revealed the interactions among features of GTAs' professed epistemological beliefs, science instructional practice, and laboratory constraints and relied on local interactions among the three components. For example, there were adaptations in some of the GTA's own systems as a result of a struggle between their core and peripheral beliefs. This was evident in Cleomedes' case where the findings revealed a conflict between her core and peripheral beliefs about how to teach and how to learn, where her beliefs led to instructional practices that highlighted a teacher-centered teaching approach (e.g., lecturing) and a student-centered approach (e.g., students engaged in hands-on and inquiry).

According to the theory, as a component adapts, its adaptations influence how the other agents within the system adapt and change, which, in turn, influences how the first adaptations continue to change. For instance, both Cleomedes' core and peripheral beliefs about how to teach and how to learn influenced her instructional decisions in the laboratory, and based on how things worked out after adaptations, there were further changes in Cleomedes belief system. These changes enabled Cleomedes to maintain a stable laboratory system that did not encounter the typical perturbations or agitations that affected the other GTAs' laboratory systems.

Another example of the self-organization of the GTAs' laboratory system as evidenced by the findings of this study, was the effect of missing laboratory materials in Diodora's laboratory. The flowers for the dissection activity for the Plant and Animal laboratory lesson were not on time. Diodora admitted that the absence of the flowers had "put me off, and I had to think of something at the last minute that would replace the dissection activity but would still meet the learning outcomes of that activity (Plant and Animal VSR Interview, April 16, 2019). Diodora believed that students needed the hands-on experience of the exercise, but a YouTube video of a flower dissection was just as useful in helping students learn the parts of a dicotyledon flower. Here, there was a spontaneous reorganization in the laboratory system where there were slight changes in Diodora's beliefs (i.e., the role of active-learning in increasing students' knowledge in science; beliefs about teaching) and instructional practices (i.e., engage students actively) in order to maintain a stable and reorganized system due to a laboratory constraint (i.e., laboratory resources).

Emergence

Another interaction that stimulated evolution and change within the biology GTAs' laboratory system was the impact of laboratory constraints on the misalignments. The presence of laboratory constraints stimulated emergence with then GTAs' laboratory systems. Emergence is defined as the appearance of new and coherent structures, patterns, and properties during the process of self-organization in complex systems. Emergent features are not previously observed in the complex system under observation and are not anticipated before they show themselves and arise as complex systems evolve. Regarding the laboratory system, there was the emergence of a laboratory that was stable and comfortable for the GTAs as well as the students. For example, Batis (Genetics VSR Interview, March 28, 2019) admitted that he had difficulty explaining to his students some of the key aspects of the content, and that made him feel uncomfortable at times. However, Batis explained that over time, after he admitted his shortcomings to the students, his laboratory lessons began to run smoother because the students started taking more responsibility for their learning and began to work more cooperatively with each other. According to Batis, he urged students to work cooperatively, mainly since scientists always worked in teams. For example, there were instances when Batis stated that he allowed the students who had a good understanding of the content to "take charge and teach the others" (Batis, Genetics VSR Interview, March 28, 2019).

Batis identified his ability to deliver the content as effectively as he would like to as a laboratory constraint (GTA beliefs interview, January 8, 2019). In this case, the interactions among laboratory constraint (i.e., science content knowledge), science instructional practice (i.e., use team approach), and features of GTAs' epistemological beliefs (i.e., knowledge and knowing about the nature of science) produced a system that evolved and highlighted the emergence of a system that was stable.

Non-Linearity

The GTAs' laboratory systems were complex, dynamic, non-linear, and capable of altering strategies of adapting to internal and external changes. Due to the multiple interactions of components within complex systems, proportionality does not hold for non-linear systems. This means that small changes may have remarkable and unanticipated effects, while stimuli may not consistently lead to drastic changes in the behavior of the system. This signifies that the output does not commensurate the input and that the existence of simple causality is absent.

An example of non-linearity was the effect of malfunctioning microscopes, which presented a laboratory constraint specific to laboratory teaching resources. Aesara had an issue with non-functional microscopes and slides with disintegrating specimens. According to Aesara,

> There were a few non-functional microscopes. I think that there was at least one student who did not get the opportunity to see and identify any of the structures. He may have left without learning anything from that activity. (Aesara Human Genetics VSR Interview, March 28, 2019)

The professed epistemological beliefs of Aesara highlighted her views about student understanding in that she claimed that understanding of complex information is by learning from simple to complex information. During her Genetics VSR Interview (March 28), Aesara posited that there were so many non-functioning microscopes that she spent more than the usual amount of time assisting students and because of time, was unable to work one-on-one with all of the students who were having microscope trouble and that everything had to be rushed after that.

Here, Aesara was faced with two laboratory constraints at the same time: time allocated for laboratory and laboratory equipment. Aesara stated that she believed that visualizing the various specimen and being able to identify the different stages of mitosis was valuable in developing students' understanding of a complex process like mitosis. Aesara's laboratory circumstance showed the presence of positive feedback where a small cause (i.e., non-functional microscopes) led to the amplified effect that affected teaching and learning as well as highlighting the presence of another laboratory constraint (i.e., time allocated for laboratory). Aesara noted during her Genetics VSR Interview (March 28, 2019) that after reflecting on her Genetics laboratory lesson, she wished that she had had students work in teams to view and discuss the process of mitosis because she believed that at least all students would have had a chance to learn something during that activity if they worked collaboratively. She also acknowledged that she embedded the team approach in her laboratory lesson with her second group of students.

The interactions among professed features of epistemological beliefs (i.e., how students learn and the structure of knowledge), science instructional practice (i.e., use team approach), and laboratory constraints (i.e., non-functional microscopes) showed fluctuations in terms of stability of the system where the last portion of lesson seemed rushed. The display of non-linearity, in this case, amplified the effect of the interactions of the three components on teaching and learning in the laboratory.

Interconnectivity

There was interconnectivity between the components. The findings of this study have already indicated that there was a connection among the professed features of biology GTAs' epistemological beliefs, science instructional practices, and laboratory constraints. Specifically related to this study, the biology GTAs professed to have certain features of epistemological beliefs regarding knowledge in general, the nature of science, teaching, and learning. Findings indicated that there were misalignments between the GTAs professed epistemological beliefs and their science instructional practices, which asserted that the instructional practices did not reflect the professed beliefs of the GTAs. Also revealed was that laboratory constraints contributed to some of the misalignments. This indicated that the three components of the laboratory system (i.e., features of epistemological beliefs, science instructional practices, and laboratory constraints) were distinct but connected, autonomous, yet mutually dependent. All were interacting with each other in a stable yet unpredictable, complex system. Figure 49 provides a synopsis of the interconnectivity of the GTAs' laboratory system.

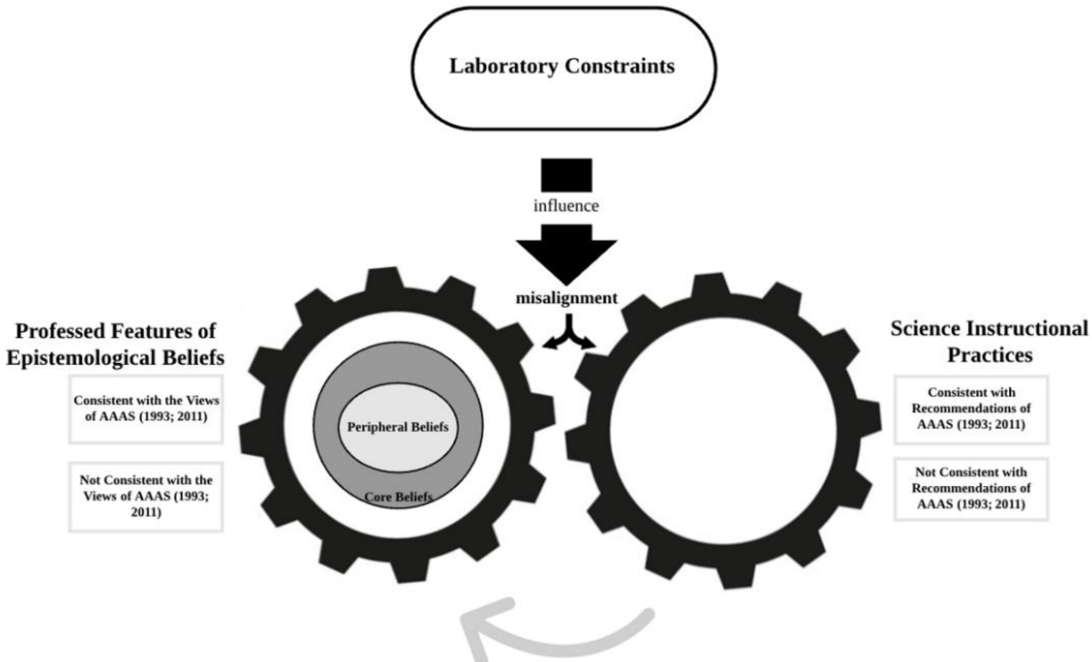


Figure 49. Interactions between the components of the GTAs' laboratory system.

As evidenced by the findings, there was interconnectivity between GTAs epistemological beliefs and science instructional practices. Although for the scope of this study, the focus was mainly on the GTAs' epistemological beliefs that reflected the views of the AAAS (1993, 2011), the data revealed that the GTAs held epistemological beliefs that were not aligned with the views of the AAAS. The same was revealed for their science instructional practices. Figure 47 highlighted those laboratory constraints, which influenced misalignments between epistemological beliefs and science instructional practices. Also emphasized in Figure 46 was the relationship between the professed features of epistemological beliefs and science instructional practices.

Autonomy and Adaptation

Within complex systems, components have varying degrees of autonomy through their capacity to adapt to their local environment. In this study, the GTAs had various features of epistemological beliefs and demonstrated various science instructional practices while faced with different laboratory constraints. As a result, the laboratory system was found to be continually adapting to contextual changes in the laboratory and showed internal changes via the process of adaptation. For example, changes such as laboratory constraints led to some misalignment between epistemological beliefs and instructional practice. Diodora held the belief that knowledge can increase by accessing information, and increasing knowledge was more productive when students were engaged and learning the required laboratory and science process skills. However, due to time constraints, Diodora claimed that she demonstrated many of the activities (GTA beliefs interview, January 29, 2019). Diodora also posited that by doing that, she had more time to focus on the other activities. Diodora supposed that her actions "kind of eliminated the time constraint because students now had more time for the different activities" (GTA beliefs interview, January 29, 2019). Here, it was noted that Diodora adapted her science instructional practice to try to eliminate the laboratory constraint component, which in turn led to a misalignment between her professed epistemological beliefs and science instructional practices. This highlighted the coadaptation of the components of the laboratory system to make it more stable.

Summary of The Nature of the Complexity of the Interrelatedness among the Features of GTAs' Professed Epistemological Beliefs, Science Instructional Practice, and Laboratory Constraints

Typically, the individual components of the laboratory system are stable but not static and favor settling down in their preferred situations. However, what is best for one component may not be best for the other components of a system. For example, the GTAs established that they held specific beliefs regarding knowledge and knowing in general, knowledge and the nature of science, teaching, and learning, and that their beliefs were enacted during their teaching in the laboratory. These beliefs were either aligned with or countered the views of the AAAS (1993, 2011). However, this study reported that some of the misalignments between professed epistemological beliefs and science instructional practices were a result of laboratory constraints. Characteristic features of complexity theory were used to show how three components of the laboratory system (i.e., features of biology GTAs' professed epistemological beliefs, science instructional practices, and laboratory constraints) interact to produce a complex but stable system. The laboratory system showed self-organization, emergence, non-linearity, interconnectivity, and autonomy and adaptation.

Chapter Summary

This chapter presented the results of an exploration of the research questions of how the features of biology GTAs' professed epistemological beliefs were related to their instructional practice in the laboratory and how laboratory constraints influenced misalignments between the GTAs' professed features of epistemological beliefs and science instructional practice. These results were presented in two main sections with subparts that reflected an arrangement that provided the findings specific to each research question. Chapter V will contain a summary of these results, an interpretative analysis of the findings, and a discussion of their importance.

CHAPTER V: SUMMARY AND DISCUSSION

Introduction

This study explored the relationship among GTAs' professed epistemological beliefs, science instructional practices, and laboratory constraints while teaching an introductory biology laboratory course. One goal of the study was to investigate the features of GTAs' epistemological beliefs and examine how these features related to their instructional practice. Another goal of this study was to determine the laboratory constraints that persisted according to the GTAs and explore how these constraints contributed to misalignments between GTAs' professed features of epistemological beliefs and science instructional practices. A brief restatement of the research problem, a review of the methodology utilized in this study, and a summary of the results are presented first in order to frame the discussion. The chapter ends with a discussion of the results, which includes a connection to prior research, theoretical and practical implications, and recommendations for future science education research and practice.

The Research Problem

This study was conducted to address the call for science reform in undergraduate science education. For example, *Vision and Change in Undergraduate Biology Education* (AAAS, 1993, 2011) has become a pivotal reform initiative towards the improvement of teaching and learning of biology at the undergraduate level. Biology GTAs are vital instructors in undergraduate biology education (Sundberg et al., 2005) and represent the primary teaching workforce for undergraduate students in discussion and laboratory sections at many universities (Lee, 2019). However, it is difficult to ensure that undergraduates are receiving quality instruction since GTAs are inexperienced teachers who receive little training and may hold beliefs that can impede effective instructional practice (Nasser-Abu & Fresko, 2018).

Contemporary science education established that instructors play a critical role in the teaching and learning process where science instructional practices are emphasized (Harris & Rooks, 2010) and that the relationship between epistemological beliefs and science instructional practice is complex in nature. The complexity comes from the fact that researchers and educators need to think in terms of connections among beliefs, instructional practice, and teaching context not only as independent subsystems (Pajares, 1992; Lee, 2019). Therefore, it was essential to investigate the contextual influences of laboratory constraints on GTAs' science instructional practices, explore how the GTAs' experiences in the laboratory context related to their beliefs and/or instructional practices, and attempt to identify the resulting relationship among the three constructs: epistemological beliefs, science instructional practice, and laboratory constraints.

Shifts in the views about science education do not necessarily induce changes in teachers' epistemological beliefs and instructional practice. They do not explain the misalignments that exist between these two concepts. The culture of GTAs as laboratory instructors has not changed in a fashion that is analogous with the goals of science reform (AAAS, 2011; NRC, 1996, 2012). Laboratory instruction is mostly teacher-centered and follows the traditional design (Gardner & Parrish, 2019; Handelsman et al., 2004; Lee, 2019), although science reform advocates for inquiry-based instruction.

The epistemological beliefs of instructors have been accredited as a factor that has restricted instructional change and reform in science education (Mansour, 2013; Mofreh & Ghafar, 2019). Mansour (2013) highlighted that the epistemological beliefs of instructors (GTAs included) are not consistent with their instructional practice. That is, there is a misalignment between professed epistemological beliefs and science instructional practices. This misalignment may be an overriding factor that has served as a hindrance to the necessary changes in biology laboratory teaching and learning practices at the undergraduate level. The inconsistencies between epistemological beliefs and science instructional practices may be explained by exploring contextual factors such as contextual constraints (Mansour, 2013; Zheng, 2015). According to Darling-Hammond et al. (2019), understanding the attitudes of educators appears to be a critical component of the educational change process. In order to bridge the gap between calls for reform in higher education science and actual changes in undergraduate teaching and learning, there is a need for a bottom-up focus which commences with the laboratory instructors, including GTAs, who may be possible barriers to educational change (Brownell & Tanner, 2012; NRC, 2000; Van Driel et al., 1997).

Review of Methodology

As an interpretative, holistic multi-case study design (Yin, 2014), this research used a qualitative approach to capture the features of epistemological beliefs of biology GTAs and to determine how laboratory constraints influenced misalignments between practice and beliefs. This multi-case included four GTAs, each of whom was an instructor of an undergraduate biology laboratory. Multiple sources of data were utilized to achieve triangulation, including semi-structured interviews, laboratory lesson observations and field notes, video recordings, and a researcher’s reflective journal. All data sources were coded in three phases. The first phase involved the professed features of biology GTAs’ professed epistemological beliefs based on the work of Suh (2016) as well as an examination of the GTAs' science instructional practices. This examination allowed the researcher to write a summary profile for each participant as well as a cross-case to determine similarities, differences, and additional themes that emerged across the four participants. The second phase presented the results of misalignments between GTAs' professed epistemological beliefs and science instructional practices based on the recommendation of the AAAS (1993, 2011). The third phase presented findings regarding the laboratory constraints that the GTAs claimed to have an impact on teaching and learning in the laboratory and how these constraints influenced misalignments between GTAs' professed epistemological beliefs and science instructional practices. Finally, the complexity theory was used to interpret the findings and to describe the relationship among the features of GTAs' professed epistemological beliefs, science instructional practices, and laboratory constraints. The data generated a narrative description of the themes generated through the analysis. A description of the summarized results is presented in the following section.

Discussion of the Results

The results of Chapter IV of this dissertation identified the features of GTAs' professed epistemological beliefs and science instructional practices and the relationship (i.e., positive associations and misalignments) between the two concepts. Also, presented in Chapter IV were the laboratory constraints with which GTAs were confronted and the influence of these laboratory constraints on misalignments between professed epistemological beliefs and science instructional practices. Finally, the results discussed how characteristic features of the complexity theory were used to explain the relationship among the features of GTAs' professed epistemological beliefs, science instructional practices, and laboratory constraints as a complex system. A discussion of these results constitutes the remainder of this section.

Features of Biology GTAs' Professed Epistemological Beliefs

Schommer-Aikins (2004) defined epistemological beliefs as beliefs regarding the source and certainty of knowledge, knowing, and learning. Individuals who have naive epistemological beliefs believe that the ability to learn is genetically predetermined, knowledge is certain and handed down by authority or experts, and the process of learning is not gradual. Contrarily, individuals with sophisticated beliefs believe that the ability to learn is acquired through experience, knowledge is not absolute or certain, and learning is a gradual process (Brownlee, Purdie, & Boulton-Lewis, 2001; Schommer, 1990). The biology GTAs, in this case, all professed to have more or less sophisticated epistemological beliefs in that they believed that knowledge and understanding were changeable and attained through various experiences (i.e., achieved as a result of self-motivation and effort, especially as it pertains to learning; Schommer, 1990) and that knowledge is a continuous process of inquiry (King & Kitchener, 1981).

Epistemological beliefs in general (knowledge and knowing). The professions of the biology GTAs revealed their epistemic orientations. The work of Suh (2016) was used to explain the epistemic of the biology GTAs:

- changeability of knowledge (e.g., scientific knowledge is open to revision in light of new evidence);
- justification of knowledge (e.g., scientific is a way of knowing that is based on empirical evidence);
- structure of knowledge (e.g., knowledge is complex); and

- source of knowledge (e.g., self as a source of knowledge rather than experts).

Although the GTAs professed to hold mostly sophisticated epistemological beliefs, there were instances where some of the perspectives of the GTAs were not consistent with Schommer's (1993a) description of sophisticated beliefs. Two of the GTAs claimed that knowledge in itself does not change, but instead, it was an individual's perception and understanding of things that change, although their beliefs in the other categories of beliefs harmonized with more sophisticated beliefs. This circumstance where the GTAs' conceptions of the certainty of knowledge were described as absolute was explained by Schommer's (1990) *more or less independent* belief system. This was demonstrated by the GTAs who were sophisticated in some beliefs about knowledge and knowing (e.g., the justification of knowledge) but not necessarily sophisticated in others (e.g., changeability of knowledge). For example, Batis and Diodora held the sophisticated belief that knowledge is justified by both self and others, whereas Cleomedes held the naïve belief that others justify knowledge. Schommer (1990; 1993a) posited that these belief systems are positions on a continuum that are not permanent but continue to change with experiences and time. Also, Jehng et al. (1993) provided evidence linking graduate school experiences to the development of epistemological beliefs. This proposition by Jehng and his colleagues was supported by the work of Schommer (1994), whose research noted that age and level of education affected epistemological beliefs. One may concur that graduate programs elicit different reasoning skills and methods of thinking.

Batis and Cleomedes described experiences as being important in the attaining of knowledge. This perspective highlighted the propositions of Baxter-Magolda's (1992) model of epistemological reflection, and GTAs were seen to display Baxter-Magolda's fourth way of knowing (i.e., contextual knowing), which emphasizes knowledge as based on personal perspectives. Baxter-Magolda (1992) also purported that the various ways of knowing lead to various expectations and provide an understanding of how teaching and learning should be evaluated as well as what instructional decisions should be made.

All four biology GTAs identified with Perry's (1970) fourth stage of development: *commitment with relativism*. This stage describes the highest and most complex level of beliefs and confirms an individual's personal identity among multiple responsibilities, in this case, the GTAs as both instructors and students. According to Perry (1970), in this final stage, individuals show more commitment to their jobs, values, and relationships. These attributes were evident in the GTAs' beliefs about teaching, specifically concerning the feature of epistemological beliefs: *goals for teaching*. For example, Aesara and Batis wanted students to become scientifically literate students. Cleomedes wanted students to become more conscious of the natural environment with the hope that this, in turn, would make them more appreciative of the world around them. The GTAs were perhaps emphasizing the need to be responsible and accountable, which required some degree of commitment on the part of the individual. Perry acknowledged that undergraduate students do not typically reach this point and that the description of individuals within this stage of development was more expressive of graduate students. Furthermore, Perry (1970) proposed that continuing to graduate school may provide the experiences that will push students' epistemological beliefs into the fourth stage. The GTAs' teaching experiences as biology laboratory instructors may be one such experience that enabled them to be considered as displaying the characteristic features of stage four of Perry's Epistemological Developmental model (1970).

Additionally, King and Kitchener's (1981) work with graduate students facilitated a seven-stage Reflective Judgment model to build on the work of Perry and further explain the epistemological beliefs of graduate students. All the biology GTAs held the assumption that knowledge claims cannot be made with certainty and that they make decisions based on judgments that are being considered as most reasonable and certain based on their evaluation of available data or evidence. This type of reasoning, according to King and Kitchener (1981; 2002), revealed that the GTAs' reasoning falls within stages six and seven of the Reflective Judgment Model: *reflective level of thinking.* Aesara, Batis, and Diodora readily admitted their willingness to reevaluate the adequacy of their judgments per the availability of new information and/or methodologies, a factor that further supports the reflective thinking of stages six and seven of King and Kitchener's (1981; 2002) Reflective Judgement model.

Furthermore, the GTAs' epistemic stance corresponded with Kuhn's (1991) *evaluativist epistemological view*. The evaluativist' s epistemic assumptions are that certainty of knowledge is skeptical, but viewpoints can be compared and evaluated. The conceptions of the biology GTAs like Batis and Diodora became evaluative as they identified the need for more reflective practices. For example, Batis acknowledged that he faced instructional limitations as a GTA, and evaluating his instruction after each lesson had helped him grow professionally. However, other GTAs like Cleomedes demonstrated little evidence of critical reflection, focusing on concerns that are more technical or practical in nature. Perhaps Cleomedes' lack of evaluative reflection was a result of the influence of contextual factors (Bonfield & Hogan, 2016; Zheng, 2015) such as laboratory constraints, more specifically time allocated for instruction in the case of Cleomedes.

Epistemological beliefs about NOS and teaching and learning science

Epistemological beliefs about NOS. Teacher and student understanding of NOS is currently an important educational objective worldwide. The achievement of this objective presupposes having teaching personnel that can provide adequate NOS instruction (Ackerson et al. 2006; Lederman, 2002). For this reason, a rather extensive body of literature has explored what teachers believe about NOS and often involves several general aspects of NOS (Abd-El-Khalick, 1998; Ackerson et al., 2006; Lederman et al., 2002; Lederman & Lederman, 2014; Suh, 2016). The list comprising of these aspects is by no means perfect and would not be accepted in toto by most philosophers. Still, at the same time, it is widely adopted by science educators as appropriate for kindergarten to university science instruction. These aspects include the empirical basis, the subjectivity, and tentativeness of scientific knowledge (open to change in light of new evidence), the role of human endeavor, imagination and creativity, the absence of a universal step-by-step scientific method, the function of and relationship between scientific theories and law (to explain natural phenomena), science as a way of knowing, the scientific interpretation of order and consistency of natural systems, and scientific explanations of questions about the natural world.

A few of the biology GTAs possessed mixed understandings of the various aspects of NOS based on the features of their professed epistemological beliefs. Lederman (1992) used the terms fluid, mixed, and naïve to describe teachers' understanding of NOS. Lederman described fluid understandings of NOS as teachers' conceptions of NOS that lacked coherence and indicated teachers' inability to commit to a consistent philosophical position or stance. Mixed understandings about NOS described teachers whose beliefs of NOS indicated that while they expressed some views that were consistent with the more recent conceptions of NOS, they held many naïve views (Lederman, 1992). Naïve understandings of NOS indicated that teachers held uninformed views about NOS and did not demonstrate adequate knowledge and understanding of the structure, function, and development of their disciplines (Lederman, 1992).

The findings in this study indicated that Diodora overlooked the role of creativity and imagination in scientific practices. This naïve conception suggested that Diodora regarded science as static and aimed primarily at accumulating scientific information. Further, she saw the scientific method as a lock-step and universal stepwise procedure. Her emphasis on the scientific method and laboratory techniques and procedures also indicated her position regarding the static nature of the scientific enterprise. Perhaps Diodora's perception in this regard may be explained by the work of Schwartz (2004) and Abd-El-Khalick and BouJaoude (1997), who explained that science teachers' beliefs about NOS and their science knowledge base were unrelated to their years of teaching experience, class level(s) that they teach, and their level of education. In this case, the variations in the biology GTAs' years of teaching, teacher preparation, and professional development in science teaching and learning influenced their understanding and beliefs about NOS, which was contrary to the work of Abd-El-Khalick and BouJaoude (1997). For example, Diodora was the least experienced science instructor with only 1.5 years of teaching experience and had no previous participation in professional development programs related to the teaching and learning of science, unlike the other three biology GTAs. Diodora was the only biology GTA who displayed some naïve views of NOS. For instance, she believed that science is a human endeavor, but science lacks creativity because the work of a scientist is often suppressed. These findings were perhaps a result of the influence of the other three GTAs' graduate program, where these GTAs were usually engaged in scholarly activities and kept informed about current research in science education by reading the relevant literature. For instance, Cleomedes acknowledged that reading current literature and engaging in scholarly conversations about teaching and learning, especially in science, led to her rethinking of some of her ideas about science education. These results indicated that perhaps experiences gained from being in graduate programs that facilitate graduate students' engagement in scholarly activities related to teaching and learning in science might influence their understanding of NOS and lead to more sophisticated beliefs about the structure, function, and development of the scientific enterprise.

The GTAs' professed epistemological beliefs highlighted three aspects of NOS: science is a way of knowing, science is a human endeavor, and scientific knowledge is founded on empirical evidence. First, the GTAs' conceptions that science is a body of knowledge and a way of knowing that explains the natural world is perhaps a plausible view of NOS as this understanding expresses the content-oriented nature of science (Abd-El- Khalick et al., 1998; Lederman & Lederman, 2014). Also, the GTAs' belief supports Lederman's (1999) claim that science as a body of knowledge is at the depth where it is appropriate to be presented to students in a manner that will prepare them to participate knowledgeably in discussions and ways of understanding science topics as citizens.

Second, the biology GTAs professed that they considered science as a human endeavor. If individuals are to understand what science is, they must accept that it is something that people do and create (Lederman et al., 2013; NGSS Lead States, 2013). This perspective supports that science involves creativity, and that teams from many nations and cultures have made vital contributions. Through science, humans seek to improve the understanding of and explanations of natural phenomena (Lederman et al., 2013). Diodora was the only GTA who believed that although science was a human endeavor, it lacked creativity, which depicted her naïve views of this attribute of NOS. The GTAs' professed beliefs about NOS might be linked to and embedded in their classroom thinking and practices where they encouraged students to work in groups and share ideas during discourse and learning.

The fundamental idea that science is a human endeavor is associated with the notion that science involves the construction of explanations that are based on empirical evidence (NGSS Lead States, 2013), which leads to the discussion of the biology GTAs' third professed epistemological belief about NOS and teaching and learning. Scientific knowledge is founded on empirical evidence or results that can be observed by our senses (AAAS, 2011). Perhaps this feature of epistemological belief persisted because of the GTAs' explanations about how the advancement in science consists of the development of better explanations for the occurrences of natural phenomena. For example, Aesara posited that scientists never could be sure that a given explanation is complete and final and that some of the hypotheses advanced by scientists are rejected when tested by further observations or experiments. However, many support that scientific explanations have been so thoroughly tested and confirmed that they are held with high confidence, hence lending support to the aspect of nature of science that highlights that science is tentative yet durable (e.g., Lederman, 1999; Lederman & Lederman, 2013; NGSS Lead States 2013).

Epistemological beliefs about teaching and learning. The biology GTAs held several beliefs about how teaching and learning should be in the science classroom, specifically the laboratory. Their epistemological stance maintained that a laboratory instructor should be a facilitator and, as such, should be focused on promoting learner interactions (e.g., group activities) and engagement, helping students access information, and organizing laboratory lessons according to student learning. For instance, Diodora explained that the laboratory instructor should provide teaching and learning opportunities that include creating a comfortable and relaxed learning environment. Batis posited that laboratory instructions should be designing lessons to include inquiry-based and problem-solving strategies. Aesara claimed that science instructors should provide students opportunities to engage in group work where they can collaborate and interact with each other. Finally, Cleomedes purported that a laboratory instructor should design laboratory lessons where students can engage in hands-on activities and construct their own knowledge. The collective epistemic position of the GTAs classified them as constructivists, according to Koballa et al.'s (2000) categories of science teacher beliefs. The constructivist category perceives science teaching as helping students construct knowledge and learning of science as a way of knowing. Luft and Roehrig (2007) also described this conception of teaching as reform-based teaching, which emphasizes students' construction of their individual learning. Although the teachers in Luft and Roehrig's study held teacher-centered beliefs about teaching and learning in science, these professed beliefs were not always reflected in their science instructional practices. This aspect is discussed in the section that follows.

This study empirically supports the importance of biology GTAs' beliefs about learning. The GTAs' views about learning included the ability to learn comes from self, students learn by doing, and students are in control of their learning. These beliefs were transferred into their practice, and the GTAs taught science in the ways that they believed that it should be, which were mostly drawn from their science learning experiences as students (Luft & Roehrig, 2007). For example, Aesara professed to learn science through mainly engaging in hands-on activities and acknowledged that this was her preferred way of teaching. Contrarily, Batis expressed that his early experience with learning science was only through lectures and memorization of text from books. Based on his experience, Batis claimed that students learned best from engaging and interacting with others and designed his laboratory lessons where students were usually involved in teamwork. Although these beliefs had been developed throughout their lives, these beliefs were further developed as the biology GTAs gained new experiences as graduate students and as GTAs. They began to make connections between their personal experiences, professional experiences, and their increased understanding of teaching and learning. This aligns with Schraw et al. (2017), who stated that teachers' experiences help them improve and justify their practices.

Science Instructional Practices of Biology GTAs

Research on the relationship of an understanding of NOS to science instruction has focused on teachers' understanding and how this is influential in the teachers' instructional practices. Gallagher's (1991) study highlighted that secondary science teachers held reform-based views of their purpose for teaching science, yet their instructional practices reflected the traditional teaching approaches. In this study, the biology GTAs reported that they acknowledged the importance of reform-based science instruction and open inquiry where students are expected to construct their own knowledge. These beliefs emphasized the claims of Deniz (2011) and the AAAS (2011), who posited that the use of open inquiry to facilitate students' conception of their knowledge is one of three strategies that may be used to increase awareness and sophistication of epistemological beliefs regarding NOS. However, although these beliefs were professed, the biology GTAs did not demonstrate these proclamations in their science instructional practices in the laboratory. Instead, their science instructional practices highlighted some of the traditional, teaching-oriented, and teacher-centered instruction. For example, Cleomedes' teaching, in most instances, was usually content-focused, and she and Aesara began their laboratory lessons with content-based questions instead of using questions about nature. According to the AAAS (1993, 2011), starting science lessons with questions about nature invokes students' natural curiosity. Content-based questions may not stimulate critical thinking in all students because some students may not have the necessary background knowledge to do so.

Another example where traditional approaches were demonstrated during laboratory instruction was in instances where GTAs like Diodora emphasized the mastery of knowledge and procedures, hence, separating knowledge from finding out. The recommendations of the AAAS (1993, 2011) asserted that such science instructional practices did not provide students with opportunities to make connections between the tightly coupled methodology, results, and conclusions. According to science education researchers like Koballa et al. (2000) and Luft & Roehrig (2007), teacher-directed science instruction aims to provide well-structured, clear, and informative lessons on a topic and includes teachers' explanations, classroom discourse, and students' questions. Perhaps the GTAs' focus on content, although categorized as a traditional teaching approach, facilitated opportunities for the explanation of scientific ideas, whole-class discussion with students that incorporated students' questions and/or alternate conceptions. These teaching strategies may be considered as adaptive instruction based on content and context, and the GTAs can be categorized somewhere towards the middle of Tsai's (2002) traditional-constructivist continuum. It may be possible that GTAs like Cleomedes, who struggled with her preference for traditionalist teaching approaches versus constructivist teaching, falls in the middle of Tsai's (2002) traditional-constructivist continuum.

Fluctuations in epistemological beliefs are considered to take place when individuals are challenged to rethink or reconstruct their beliefs into more mature ways of knowing (Hofer & Pintrich, 1997). Perry (1999), King and Kitchener (1994), and Schommer (1998b) acknowledged that there is evidence that tertiary studies are likely to provide exposure to a variety of educational perspectives that may stimulate changes in students' epistemological beliefs, as was evidenced in this study in the case of Cleomedes. The GTAs' exposure to further education may have led to a cognitive conflict that resulted in their reconstruction of simplistic epistemological beliefs into more relativistic and sophisticated ways of knowing.

In some instances, the GTAs' science instructional practices revealed a learning-centered orientation where there were active learning environments (*engage students actively*) that emphasized the value of group work (*use a team approach*). This highlighted the constructivist conception, which emphasizes the need to develop students' critical thinking and collaboration skills in an environment where they can participate actively (Chan & Elliot, 2002; Cheng et al., 2009). Hence, these findings provided a conceptualization of the biology GTAs' science instructional practice that highlights the teaching and learning orientation that coincides with the student-centered/learning orientation. According to Suh (2016), a learning-centered orientation underlines various modes of group work for both private and public negotiations and discourse.

The findings indicated that in some circumstances, based on the science instructional practices during particular laboratory lessons, the biology GTAs could be categorized as either absolutist or relativist (Diodora and sometimes Cleomedes), multiplist (Aesara, Batis, and sometimes Cleomedes) instructors. Absolutist or relativist, multiplist, and evaluativist are terms that researchers who are concerned about teacher beliefs about knowledge have used to describe teacher- and student-centered teaching approaches (e.g., Brownlee et al., 2011; Kuhn; 1991; Olafson & Schraw, 2010, Schraw et al., 2017; Tsai, 2007). Absolutist teachers conform to the traditional instruction epistemology. They believe that teaching encompasses the transfer of knowledge from the teacher or expert to the student who is, in contrast, the naïve, passive learner. For this reason, absolutist teachers adopt a *conduit metaphor* of instruction (Mascolo, 2009). Multiplist teachers adhere to a constructivist epistemology and create a learning environment that allows students to actively construct their own knowledge and meaning (Olafson & Schraw, 2010). Finally, the evaluativist teacher embraces the worldview that knowledge is tentative and contextual and, as such, promotes learning activities where students collaborate and construct knowledge based on shared understanding (Tsai, 2002). However, although the GTAs made claims about evaluativist teaching, there were rarely any instances where this type of teaching was demonstrated during their instructional practice in the laboratory.

In some instances, the biology GTAs instructional approaches could be categorized, for example, as absolutists, relativists, or traditionalists, which explained their teacher-centered teaching and learning approach (e.g., Kuhn, 1991; Schraw et al., 2017). However, in other instances, they could not. For example, during her laboratory instruction, Cleomedes displayed both types of teaching approaches (i.e., absolutist and multiplist). As a result, this indicated that the GTAs could not be placed into a discrete category or even on any one point on a continuum based on their science instructional practices, as was done by Tsai (2007) and others (e.g., Mascolo, 2009; Olafson & Schraw, 2010). Instead, the science instructional practices of the biology GTAs can be considered as fluid and highly influenced by contextual factors. By and large, the fluidity in the teaching and learning orientation of the GTAs can perhaps be credited to contextual factors that can have a more or less role in fostering a situation where GTAs were unable to enact their professed beliefs. The influence of contextual factors such as laboratory constraints is discussed in the following section.

The Influence of Constraints on Misalignments between Features of Biology GTAs' Professed Epistemological Beliefs and Science Instructional Practices

Findings from this study reported non-linear relations between the features of the GTAs' professed epistemological beliefs and their science instructional practices. For this study, these relationships were classified as misalignments. One thought-provoking question that has persisted in education research is why there are discrepancies between what teachers deem as appropriate and what they actually do in their classrooms. Tamimy (2015) posited that although teaching is an intentional activity, not all instructional activities are based on a teacher's beliefs since the environment that surrounds teachers have a stronghold on instructional practices. Fishbein and Ajzen (1977) also accredited the role of contextual factors in classroom behavior prediction. In this study, the contextual factors were laboratory constraints that impacted the instructional practices of the GTAs.

As a result of the laboratory constraints (i.e., time allocated for the laboratory, curriculum design, and laboratory resources), there was dissonance between what the GTAs believed and how they actually taught in the laboratory. For some of the GTAs, the complex dynamic between their core and peripheral beliefs about teaching and learning in the laboratory resulted in the development of dissociations (e.g., Cleomedes). These disassociations challenged the Cleomedes' beliefs and led to a misalignment between her beliefs about *science is based on empirical evidence* and science instructional practice *concentrate on the collection and use of evidence*. The noted misalignments may not have been intentional but instead were a consequence of contextual constraints of the teaching and learning environment, which in Cleomedes case was the amount of time allocated for laboratory instruction. While experiencing dissonance as a result of laboratory constraints, changes that did not reflect professed epistemological beliefs were reflected in the GTAs' science instructional practices. This coincides with Suh's (2016) suggestion that challenges to teachers' beliefs and thoughts motivate change in their behavior.

Deniz (2017) argued that the current education system does not typically support the development of epistemic sophistication from instructors, even with empirical findings that reveal the best science instructional approaches and/or strategies that promote conceptual understanding and increase students' scientific literacy. However, there is still a tendency to emphasize isolated facts and methods of science as opposed to presenting scientific knowledge-building activities when there are context-sensitive factors that influence classroom teaching. This was evident in this study as some of the GTAs' science instructional approaches emphasized the memorization of technical vocabulary even when Aesara, Batis, and Cleomedes believed that knowledge is uncertain, tentative, and constructed by learners. Also, GTAs' concentration on the collection and use of evidence did not match their firm stance on the values of evidence and its contribution to the body of knowledge. Perhaps these two misalignments can be explained by the time constraints that GTAs like Aesara and Cleomedes were faced with, where they claimed that they were unable to allow students time to construct their own knowledge or allocate the time required for learners to collect and discuss methods and conclusions based on the evidence collected. Time allocated for a class has been a constant concern for educators; more specifically, how time is allocated during instruction. This agrees with the work of Keiser and Lambdin, who, as early as 1996, documented time as a constraint for educators, specifically how time is allocated during instruction (Keiser & Lambdin, 1996).

In this study, a few of the GTAs (e.g., Cleomedes and Diodora) felt that instruction was inhibited by the procedural focus of the laboratory task. The procedural focus on the laboratory activities was analogous to the traditional teaching approach, which was also identified as the *cookbook* mentality where students are led to focus on task completion instead of thinking about the experimental outcomes (Schamel & Ayres, 1992). This procedural focus was identified as a laboratory constraint that impacted the GTAs' science instructional practices. Perhaps the limitations imposed by this factor can account for the misalignment between Cleomedes' and Diodora's professed epistemological belief about the *structure and changeability of knowledge* and science instructional practices *separating knowledge from knowing* and *emphasizing memorization of technical vocabulary*. These two biology GTAs professed that although they would instead do more hands-on activities that incited critical thinking and students constructing their own knowledge, they admitted that they were stuck with traditional teaching approaches like lecturing and leading students through step-by-step laboratory activities. According to Hofstein and Lunetta (2004), during their laboratory experience, students tend to focus on manipulating equipment instead of manipulating or generating ideas, as was evident in the observations of the two GTAs' laboratory lessons.

The misalignment between professed features of epistemological beliefs and science instructional practices that were instigated by the laboratory constraints can also be associated with what Lampert (1985) identified as *dilemma managing*. In such instances, instructors like Cleomedes encountered tensions in their teaching or have to deal with conflicts between what they believe and what they actually do. Tensions and the dilemma caused by the tensions have been a central focus of reform on education (Zheng, 2015). According to Zheng, there is a disconnect between the high demands of educational reform and what teachers really do in the classroom.

Furthermore, different features of GTAs' epistemological beliefs and their science instructional practices were either compatible or contradictory in the laboratory teaching and learning context. That is, some of the professed features of epistemological beliefs were either realized and demonstrated during laboratory lessons or differed from what was professed. Although the contradictions were as a result of the influence of laboratory constraints, the resulting enactment that occurred may be credited to the interaction of the GTAs' peripheral beliefs and rather than core epistemological beliefs. In other words, when misalignments occurred, certain beliefs were in accordance with GTAs' peripheral beliefs. For example, Cleomedes claimed that teaching and learning are most effective when students engage in collaborative, hands-on experiences where this conception resonated as her core beliefs about teaching and learning. However, Cleomedes also claimed that most of her past teaching and learning experience in science, especially as an undergraduate student, was through teacher-centered learning experiences like lecturing and memorization. She explained that as a K-12 science teacher preparing students for state exams, she had grown comfortable using the instructional practices that her teacher used when she was a K-16 student. Cleomedes believed that lecturing, as a science teaching strategy, was acceptable because it worked for her as a student. This proclamation represented Cleomedes' peripheral beliefs about teaching and learning.

According to Schraw et al. (2017), the more a belief is connected with other beliefs within the belief system, the more central or core the belief.

On the contrary, peripheral beliefs are more vulnerable beliefs that are easily changed, and this was evident in the case of Cleomedes, who asserted that she had started to rethink some of her thoughts and views about teaching and learning in science. Therefore, beliefs about teaching and strategies, influences on teaching and learning, and conceptions of teaching and learning are more likely to change depending on the particular learning environment (Hofer & Pintrich, 1997). This means that perhaps peripheral beliefs are more likely to be changeable and context-specific. Therefore, the prevailing epistemological beliefs that were demonstrated (belief in practice) and seemed to contradict the GTAs' professed features of epistemological beliefs might be classified as the biology GTAs' peripheral beliefs, like in the case of Cleomedes.

This discussion illustrates the organic nature of the overall process of interactions between the professed beliefs of biology GTAs, science instructional practices, and contextual factors like laboratory constraints when dissonance between the GTAs' epistemological beliefs and instructional practices occur. That is, the mismatch between professed epistemological beliefs and science instructional practices and classroom events (e.g., unexpected circumstances like a high number of malfunctioning microscopes and missing flowers for laboratory activities) triggered misalignments between what the biology GTAs said they believed and what they did during instruction. The following provides a discussion of the complexity theory and how it was used to describe the relationship among epistemological beliefs, science instructional practice, and contextual factors such as laboratory constraints.

Complexity Theory and the Interrelatedness between the Professed Features of GTAs' Epistemological Beliefs, Science Instructional Practice, and Laboratory Constraints

The interaction among the features of epistemological beliefs, science instructional practices, and laboratory constraints is an essential indication of the complexity of the laboratory as a teaching and learning system. The interactions included *self-organization*, *emergence*, *non-linearity*, *interconnectivity*, and *autonomy and co-adaptation*, which have been identified as critical attributes of any complex system (Davis & Sumara, 2006). The connection among the three components indicated that each area was by no means independent and was related to each other so closely that researchers cannot study one area without considering the other. This study revealed that factors which the biology GTAs believed to be important in the teaching and learning of science were, at times, evident in their science instructional practices and other times absent, perhaps due to the influence of laboratory constraints. As a result, the view of teaching and learning was complex rather than simplistic (Martin, McQuitty, & Morgan, 2019) in the laboratory.

As agents within a system adapt, their adaptations influence other agents within the system and influence how the first set of adaptations continue to change. For example, as laboratory constraints influenced misalignments between some of the GTAs' professed epistemological beliefs and science instructional practices, they were unable to display their epistemological orientations. As GTAs' epistemological orientations were inhibited, there were modifications in their science instructional practices (e.g., in the cases of Aesara, Cleomedes, and Diodora), which led to the emergence of novel and coherent structures and patterns in their laboratory systems. This was consistent with propositions made by Goldstein (1999) regarding emergence as an attribute of complex systems. As a result of these changes, the emergence of new phenomena was supported. This idea was specific to Aesara and Diodora, who believed that their teaching should be different but adhered to instructional practices that were contrary to their professed epistemological beliefs. Feasibly, the GTAs became comfortable enough with the changes and evolution in their laboratory systems because the effect of the changes presented a high degree of stability to the laboratory teaching and learning system (Larson-Freeman, 1997; Gleick, 1987).

As revealed in the above discussions, there were moments when there were tensions and dissociations between the biology GTAs' professed epistemological beliefs and their science instructional practices, which were a result of contextual constraints of the laboratory. For example, Aesara believed that an understanding of a piece of knowledge changes with time and experience and that students should be provided with multiple hands-on experiences to facilitate that change and understanding. However, Aesara placed much emphasis on the memorization of technical vocabulary and explained that this was a "go-to" strategy because of insufficient class time. How Aesara handled her situation suggested that her pedagogical choice may not have necessarily been made linearly. That is, she demonstrated a change in her way of teaching, and there was not necessarily a change in her epistemological beliefs when she encountered a critical incident like insufficient class time. According to Darling-Hammond et al. (2019), the epistemological orientations of teachers are resistant to change. Pedagogical approaches were not selected just based on inner logic regarding methodology but also on that of meaning. In the case of GTAs like Aesara, meaning was dependent on her particular teaching situations (specifically, the laboratory constraints). According to complexity theory, the processes that enable complex systems to maintain an ordered state when faced with pressures in teaching situations are referred to as the self-reorganization process (Larsen-Freeman & Cameron, 1997).

Implications for Science Education Practice

Theoretical Implications

This study on biology GTAs is situated in the context of the laboratory. Research on science education reform has pushed for laboratory instructors to adopt a more student-centered approach to teaching and learning of science. To this point, the laboratory is an open system where there are interacting elements whose characteristics as complex systems seem evident. Such processes involve changes that may be difficult not only for instructors such as GTAs but also for biology department heads who are responsible for the structure and design of undergraduate laboratory courses for non-science majors. Therefore, the focus of this study on biology GTAs' instruction was not merely based on the description of the complexity of the laboratory teaching and learning system, but more importantly on how the biology GTAs reconciled their epistemological beliefs when faced with dissonance and tension.

Zheng (2015) described the dissonance between professed beliefs and practice as *token adoption*. Concerning the complexity theory, the practice of token adoption illustrates the non-linear feature of interactions between the various components that influence changes in components of the system, which in turn incites re-organization and eventual stability of the system. Token adoption can be used to describe how the GTAs managed the emergent patterns of the interactive relationships between their epistemological orientations and the contextual constraints of teaching in the laboratory and how order and stability arose from interactions between the different components of the system.

In order to address these issues, this study adopted complexity theory to represent the teaching and learning in the laboratory as a complex system that consisted of the features of epistemological beliefs of the biology GTAs, their science instructional practices, and contextual factors such as laboratory constraints. These factors were interconnected and coordinated. Based on the research findings, the five theoretical contributions were extrapolated to further the understanding and research of teaching and learning of science in the laboratory.

First, the study revealed that it is important to take a holistic perspective in order to understand and explain the phenomena of teaching and learning in the laboratory system. The foundation of this holistic research framework is the presentation of the features of the epistemological beliefs of the biology GTAs and the in-depth exploration of the interaction between these epistemological beliefs and their science instructional practices as it relates to the contextual constraints of teaching and learning in the laboratory. Findings from previous studies claimed that teachers' beliefs exert a powerful influence on their classroom practice (e.g., Luft & Roehrig; 2007, Zheng 2015; Suh, 2016). Moreover, this study extended such findings by highlighting the interactions between features of epistemological beliefs and science instructional practice. In this case, it was the interaction between the GTAs' epistemological beliefs and how their peripheral beliefs replaced core beliefs when GTAs were faced with laboratory constraints and, as a result, defined how the biology GTAs conducted their teaching in the laboratory. For example, one of Cleomedes' core beliefs was the important role of evidence in science. She posited that students should engage in hands-on activities where they can discuss their results as a group. However, observations of her instructional practices showed that she provided students with information on the expected results before the students started the experiment. Cleomedes' actions did not reflect a concentration on the use and collection of evidence, which was a mismatch to her beliefs about the role of evidence in the scientific enterprise. To explain her instructional approach in this regard, Cleomedes acknowledged that since time was an issue, she employed an instructional strategy where she briefed students about expected results and what to look for during their investigations as a way to focus students' attention on the evidence. This belief represents a peripheral belief and perhaps highlights the relationship among the main elements of the system (i.e., epistemological beliefs, science instructional practices, and laboratory constraints), revealing the interactions among these elements and their influence on the nature of interactions within the elements themselves (Figure 50).

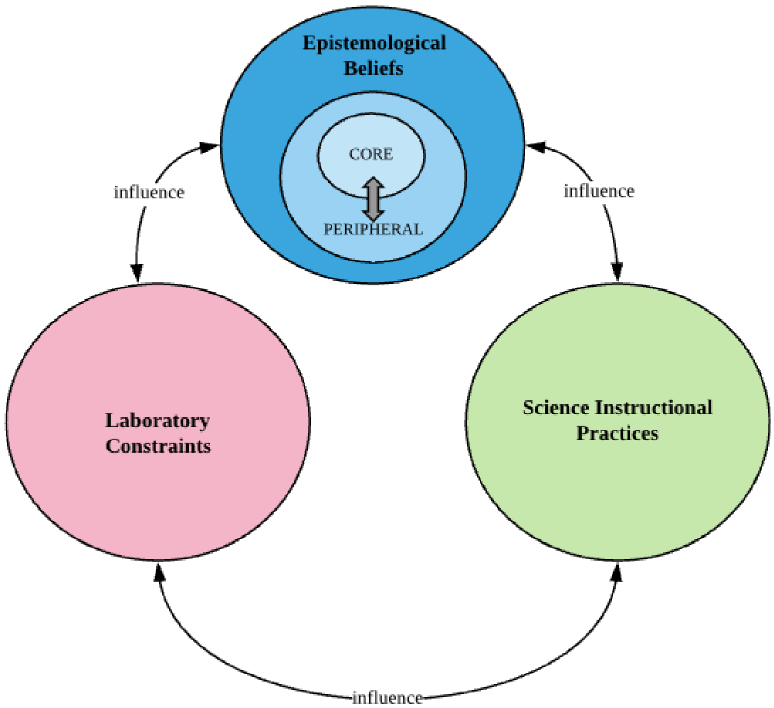


Figure 50. The relationship between elements of the laboratory teaching and learning system.

Second, the interaction between the biology GTAs' core and peripheral epistemological beliefs may have contributed to their science instructional practices. Although the GTAs held firm core beliefs regarding some issues (e.g., the role of evidence in science), their beliefs were not emphasized during teaching due to laboratory constraints (e.g., insufficient class time). The GTAs instead highlighted the results of experiments without making connections to methods and conclusions. Here, the peripheral beliefs about the need to focus on results, are characteristic of the GTAs' core beliefs, which are demonstrated in their teaching practice.

In most cases, the core beliefs corresponded to the GTAs' epistemological orientations or stance about the nature of knowledge and knowing, NOS, and beliefs about teaching and learning. As tensions between core and peripheral beliefs arose due to contextual constraints of the laboratory, there presented a challenge for the GTAs, requiring them to abandon their core beliefs and enact peripheral beliefs in their science instructional practices in order to meet the various teaching and learning objectives. If the peripheral and core epistemological beliefs were not consistent with each other, the core beliefs were, in some cases, rejected. As a result, the GTAs developed an eclectic approach to their science instructional practices. Therefore, future research on the relationship between epistemological beliefs and instructional practice should abandon the search for dualistic evidence of alignments or misalignments between beliefs and practice. Instead, research investigations should explore the interactive features of both core and peripheral epistemological beliefs and contextual factors (e.g., classroom constraints) and how such interactions impact science instructional practices.

Third, the examination of the interactions between the components of the laboratory teaching and learning system provided a perspective from which it can be viewed dynamically. Such a dynamic perspective helped capture the mechanism of the system in terms of its variability and stability. The laboratory system was dynamic because of the changes that occurred and the contextualized interactions between the various components in different teaching situations. For example, what would appear to be misalignments between epistemological beliefs as a consequence of the influence of laboratory constraints may be seen as the co-adaptation and self-organization characteristic to any complex system. During such processes, the biology GTAs tended to settle down into habitual patterns of behavior and thinking (e.g., Cleomedes, whose instruction followed a regimented structure). According to Zheng (2015), these patterns of behavior and thinking can be relatively fixed and unlikely to change unless there are strong forces that can move the system into another way of thinking or behavior. Hence, the investigation of the mechanism of how GTAs maintained stability further indicated the variability of the laboratory teaching and learning system.

Fourth, in this study, the laboratory context was regarded as a key component of the GTAs' laboratory system. The context was examined in terms of the micro-system of the classroom, taking into account factors that hindered the implementation of the GTAs' epistemological beliefs into their science instructional practice and presented misalignments between the two constructs. It was some GTAs' engagement with and interpretation of the laboratory context and its constraints that perhaps shaped their beliefs and allowed them to respond to what they believed to be hindrances to different tasks and purposes. As contextual factors (i.e., laboratory constraints) functioned in the GTAs' beliefs through their engagement in the laboratory context, their epistemological beliefs, in turn, played a role in changing what a laboratory constraint would be. For example, this was evident in the case of Diodora, who believed that students should acquire the knowledge of how to use and manipulate a microscope, would view non-functioning microscopes as a laboratory constraint. In contrast, GTAs like Batis and Aesara, who viewed collaboration and team-work is crucial, utilized the opportunity to use as few microscopes as possible so that students could work together to co-construct knowledge. Therefore, it is crucial to view the relationship among epistemological beliefs, instructional practice, and contexts in an adaptable way to address both the influence of contexts and the autonomy of individuals.

Finally, taking a holistic, dynamic approach to examine the features of the biology GTAs' epistemological beliefs, science instructional practices, and contextual constraints of the laboratory as a complex system, extrapolated interactive patterns revealed the influence of the three components on each other. By avoiding a reductionist interpretation that isolates each component and reduces behavior measurements at a single point in time and remains static, this outlook may shed light on the nature of the relationship among epistemological beliefs, science instructional practices, and contexts from a complex, dynamic perspective. Also, this view may provide significant implications for educational reforms in science where new concepts are being promoted while epistemological beliefs that are old and resistant to change are still operating.

Methodological Implications

As an emerging theoretical paradigm, complexity theory provides a significant challenge to existing research methods in education (Morrison, 2002; Zheng, 2015). Complexity theory does not introduce a new way of doing research that is separate from the existing research paradigms, but rather it reconceptualizes the research on teacher beliefs by integrating various forms of existing research methods to achieve the aim of capturing the complex features of the classroom as a system. Three implications for research in education emerged.

This study highlights the importance of adopting different data collection methods and drawing on multiple sources to capture the complex phenomenon of the laboratory as a complex system. The use of different data sources, including laboratory lesson observations and participant interviews, helped overcome the limitations of each method. Also, the combination of observations and interviews revealed the dissonance and tensions between the different data requiring exploration in more detail (e.g., the different types of epistemological beliefs, core and peripheral, and how they influenced science instructional practices). This provided a more precise understanding as to how laboratory constraints elicited misalignments between professed epistemological beliefs and science instructional practices, which would not have been possible if only one instrument had been used.

Furthermore, it proved to be important in this study that the biology GTAs were encouraged to self-reflect on their laboratory teaching. For example, Aesara and Batis always evaluated their instruction. During his VSR interviews, Batis most times highlighted instructional decisions that he should work on for the next lesson. Batis acknowledged that the Human Genetics laboratory had a great abundance of technical vocabulary and that he needed to make an effort to be more proficient in his instructional delivery of the content and further indicated that he was open to professional development to help him advance his science content knowledge in the English language. Batis' critical self-reflection not only offered rich data about how his mental activities underpinned his practice but also advocated an awareness of the features of his epistemological beliefs that, in turn, incited changes in his science instructional practice. This study revealed how repeated stimulated recall interviews resulted in Batis making conscious efforts to make changes to his science instructional practices.

Finally, this research revealed the value of keeping an open mind regarding the use of both the inductive and deductive approaches in data analysis. The process of analysis can be both open and inductive, as well as guided and deductive. In so doing, the researcher was able to avoid premature categorization and idealization in addition to more precisely determining whether a causal relationship or link seemed to be implied by a particular theory.

Pedagogical Implications

This study focused on GTAs, their perspectives, and what they did in an undergraduate biology laboratory. Therefore, it provides pedagogical implications mainly for the training and preparation of GTAs. Based on the findings of this study, the researcher suggests several implications for the development of GTAs as a way of improving teaching and learning in the laboratory system and making the GTAs' science instructional practices more aligned with the recommendations for reformed science teaching.

This study suggests that an awareness of the laboratory teaching and learning system is essential. An understanding of this system should be made available to biology GTAs as well as the administrators and department heads who make important decisions about undergraduate laboratory courses. Decisions include the structure and design of the undergraduate biology laboratory curriculum. Current biology laboratory curriculum design and structure are still barriers to reformation since they present certain constraints that influence the nature and quality of teaching and learning of science in the laboratory. In order to determine what factors presented themselves as laboratory constraints, GTAs should have some input in discussions that lead to redesigning the undergraduate laboratory curriculum as biology departments work to change the outdated systems that do not reflect the current fundamental goals of reform in science education.

GTAs need to be part of professional development programs or professional learning communities. They can incorporate discussions that will provide ample opportunities where they can learn and experience science instructional practices as a learner. The idea of gaining experience by doing laboratory activities before teaching them was one of the concerns of the GTAs. By engaging in the practice of learning and experiencing as a learner before teaching, the biology GTAs can see the alignment among epistemological bases of general knowledge, scientific knowledge, and teaching and learning. This will also help the biology GTAs understand how they incorporate different science instructional practices in the laboratory. In designing these opportunities for biology GTAs, it is necessary to take an approach that will address both the epistemic nature of science and how individuals can develop a conceptual understanding of science.

The findings from this study revealed the science instructional practices *insist on a clear expression*, *start with questions about nature*, and *provide historical perspectives* as the least frequently demonstrated during the biology GTAs' teaching episodes in the laboratory. This suggests a need for professional development programs for biology GTAs that will facilitate their awareness and increase their understanding of science reform practices such as that of the recommendations of the AAAS (1993, 2011). Science-reform advocates posit that in order for students to understand science as ways of thinking and doing as well as a body of knowledge, science instructors need to create opportunities where students will gain experience with the kinds of thought and actions that are typical of the scientific enterprise. This type of teaching will not be translated into the teaching practices of the biology GTAs if they are not first, aware of these sound teaching practices, and second, trained on how to effectively embed all of recommended reformed practices into their laboratory instruction. As such, the design of professional development programs for biology GTAs' need to focus on highlighting laboratory teaching that is consistent with the nature of scientific inquiry and consider a specific focus on the least frequently employed science instructional practices and how these practices can be embedded in laboratory instruction.

Another implication is related to laboratory resources and equipment. Since these were identified as laboratory constraints for the GTAs, it can be suggested that professional development programs address the use of resources and equipment in ways that engage students in the learning process. If GTAs share their ideas and experience during the sessions, this may foster ways in which the resources and equipment may no longer present as laboratory constraints. Given that GTAs have full autonomy in the laboratory and that student-centered lessons cannot be prescribed to them, the professional development should focus on changing the GTAs' orientation about the use of resources and laboratory equipment rather than on designing or providing well-structured curricular materials.

GTAs need to be aware of their epistemic orientations and core and peripheral beliefs about knowledge and knowing in science, the nature of science, and teaching and learning. All teachers come into the classroom with their own beliefs about teaching and learning that influence how they teach (Luft & Roehrig, 2007). Hence, it is essential for all biology GTAs to discover the features of their epistemological beliefs and question them. Furthermore, instead of introducing new methods or skills for teaching and learning science, professional development programs should target the development of epistemic orientation. In order to help the biology GTAs develop their epistemic orientations, instruction should be designed with a student-centered approach keeping in mind that teachers like to teach in the way they were taught (Reeves et al., 2016). By engaging in student-centered practices as a learner, the biology GTAs can increase their understanding of how students learn and take control of their own learning. Biology GTAs can benefit more from learning science and science instructional practices together, rather than learning them separately, while at the same time developing more sophisticated features of epistemological beliefs.

Finally, it is important to create supporting and non-threatening learning environments, for example, creating learning environments where the GTAs can feel comfortable to share their ideas freely and know that their ideas are valued. Professional development instructors must carefully consider whether an alternate perspective to their own is represented in the literature on science education and not only supported but protected in class discussions (Bondy et al., 2007).

Limitations and Future Areas of Research

What needs to be acknowledged is that this study was restricted by an exclusive reliance on the biology GTAs' professions of their epistemological beliefs, their perceptions of contextual factors that presented as constraints and hindrances to teaching and learning in the laboratory, as well as the researcher's perspectives of the GTAs' epistemological beliefs at the micro-context. This study was context-bound, and findings showed how the laboratory teaching and learning system exerted powerful influences on the GTAs' epistemological beliefs and science instructional practices. However, other contextual factors may influence the system and were not explored in this study. These may include, for example, taking into account the influence of other related aspects such as exo-school context (school policies and requirements or expectations, GTAs' program of graduate studies, that is, masters or doctorate) and macro-society context (educational policies and social environments) that may act as affordances or constraints/hindrances to the science instructional practices.

The perspective of the study focused only on three main aspects as part of the complex system: features of epistemological beliefs, science instructional practices, and contextual constraints of the laboratory. However, the study could be expanded to give a more thorough exploration of the cultural and social aspects of the complex laboratory system. In this case, the researcher suggests an ethnographic study that will provide a complete description of the culture and social structure of the social group that is an essential aspect of the system.

Furthermore, in order to depict the change and development of the laboratory teaching and learning system, a more longitudinal study would be necessary to capture the dynamic interplay between the components within this complex system. However, it is not sufficient to simply suggest lengthening the time frame of the research. It is also essential to identify critical incidents in such a longitudinal study that will draw patterns of how the GTAs develop in handling similar issues and will note their behavior in various situations. In this case, a longitudinal study could capture the trajectory of the development of the biology GTAs especially in instances where science reform practices are more grounded and encouraged.

The complexity theory approach to exploring the classroom as complex systems is new in the field of science education. As complexity theory generated initially from the natural sciences, its application in the field of education integrates some features of social science research. Several concepts, such as *non-linearity* and *self-organization* are used metaphorically, and researchers from different research backgrounds may have different interpretations of the definition of such concepts. Future research can work on determining other theoretical frameworks that can be adapted to work out various metaphorical understandings that will meet the needs of education research, hence making complexity theory a legitimate research theory in research in education.

Chapter Summary

Biology GTAs' epistemological beliefs about teaching and learning in the laboratory share a complex relationship with the quality of their science instructional practices where contextual factors (more specifically, laboratory constraints) imposed by the laboratory, in turn, influence both constructs. The dynamic relationship among the features of epistemological beliefs, science instructional practices, and laboratory constraints contributed to the emergence—through the process of self-organization and adaptation—of the laboratory teaching and learning system as an ecological circle that is continually changing and developing yet maintains stability. This study examined the relationship between the features of biology GTAs' professed epistemological beliefs and the relationship to their instructional practice. Also investigated was the influence of laboratory constraints on misalignments between professed epistemological beliefs and science instructional practice.

This chapter discussed these complexities by examining connections between the findings and prior research while addressing the research questions, explained how the study's theoretical framework interpreted the findings, provided recommendations for specific practices for designers of GTA professional development, and suggested avenues of research related to the study. Overall, the study was found to support the cannon of its theoretical framework and provided insights into how laboratory constraints influenced misalignments between epistemological beliefs and science instructional practices. The results suggested that epistemological beliefs include both core and peripheral beliefs and that peripheral beliefs supplanted GTAs' core beliefs when confronted with laboratory constraints. Biology GTAs should be made aware of the features of their epistemological beliefs and the influence of laboratory constraints on their science instructional practices. Also, heads of science departments and persons in charge of designing undergraduate biology laboratories should be aware of these results as this can inform changes to the undergraduate laboratory that will eventually meet the requirements of reformed teaching and learning in science. Similarly, designers of professional development for biology GTAs need to understand the role of contextual constraints on core and peripheral epistemological beliefs of laboratory instructors. In this regard, the biology GTAs can discover the features of their epistemological beliefs, question them, and work on the development of epistemic orientation that incorporates constructivist science teaching and learning approaches. Recommendations for future research include testing the robustness of and expanding the use of complexity theory in science education research.

REFERENCES

Abd-el-Khalick, F., Bell, R. L., & Lederman, N. G. (1998). The nature of science and instructional practice: Making the unnatural natural. *Science Education, 82*, 417-436.

Addy, T. M., & Blanchard, M. R. (2010). The problem with reform from the bottom-up: Instructional practices and teacher beliefs of graduate teaching assistants following a reform-minded university teacher certificate program. *International Journal of Science Education, 32*, 1045-1071.

Aguirre, J. M., Haggerty, S. M., & Linder, C. J. (1990). Student-teachers' conceptions of science, teaching and learning: A case study in preservice science education. *International Journal of Science Education, 12*, 381-390.

Akerson, V. L., Abd-El-Khalick, F., & Lederman, N. G. (2000). Influence of a reflective explicit activity-based approach on elementary teachers' conceptions of nature of science. *Journal of Research in Science Teaching, 37*, 295-317.

Allen, D., & Tanner, K. (2006). Rubrics: Tools for making learning goals and evaluation criteria explicit for both teachers and learners. *CBE – Life Sciences Education*, *5*, 197-203.

American Association for the Advancement of Science. (1993). *Benchmarks for science literacy*. New York, NY: Oxford University Press.

American Association for the Advancement of Science. (2011). *Benchmarks for science literacy*. New York, NY: Oxford University Press.

Andrews, P., & Hatch, G. (2000). A comparison of Hungarian and English teachers' conceptions of mathematics and its teaching. *Educational Studies in Mathematics, 43*, 31-64.

Artzt, A. F., & Armour-Thomas, E. (1999). A cognitive model for examining teachers' instructional practice in mathematics: A guide for facilitating teacher reflection. *Educational Studies in Mathematics, 40*, 211-235.

Arvold, B. (2002). Transforming mathematics education through dialogue and themes of caring: A tribute to Nel Noddings. *Curriculum and Teaching Dialogue, 4*(2), 101-111.

Aslan, A., & Zhu, C. (2017). Investigating variables predicting Turkish pre-service teachers' integration of ICT into teaching practices. *British Journal of Educational Technology, 48*, 552-570.

Atkins-Randle, B. (2012). *Graduate teaching assistants' perceptions of their preparation for teaching in departments of communication studies at selected universities* (Order No. 3547279). Available from ProQuest Dissertations & Theses Global. (1267776180). Retrieved from https://ezproxy.mtsu.edu/login?url=https://search.proquest.com/docview/1267776180?accountid=4886.

Baç, M. (2007). Epistemological naturalism, skeptical threat and the question of normativity in Post-apocalyptic times. *Filozofia, 62*, 590-600.

Baicchi, A. (2015). Complex adaptive systems: The case of language. In *Construction learning as a complex adaptive system* (pp. 9-31). New York, NY: Springer, Cham.

Ball, D. L., & Cohen, D. K. (1996). Reform by the book: What is—or might be—the role of curriculum materials in teacher learning and instructional reform? *Educational Researcher*, *25*(9), 6-14.

Basturkmen, H. (2012). Review of research into the correspondence between language teachers' stated beliefs and practices. *System, 40*, 282-295.

Basturkmen, H., Loewen, S., & Ellis, R. (2004). Teachers' stated beliefs about incidental focus on form and their classroom practices. *Applied Linguistics*, *25*, 243–272.

Baxter, J. A., & Lederman, N. G. (1999). Assessment and measurement of pedagogical content knowledge. In J. Gess-Newsome & N. G. Lederman (Eds.), *Examining pedagogical content knowledge* (pp. 147–161). Dordrecht, Netherlands: Kluwer.

Baxter Magolda, M. B. (1987). *Gender differences in cognitive development.* Paper presented at the Annual Meeting of the American Educational Research Association, Washington, D.C. (ERIC No. ED 284 908).

Baxter-Magolda, M. B. (1992). *Knowing and reasoning in college: Gender-related patterns in student's intellectual development* (No. 370.1523 B355k). San Francisco, US: Jossey-Bass.

Beck, J., Czerniak, C. M., & Lumpe, A. T. (2000). An exploratory study of teachers' beliefs regarding the implementation of constructivism in their classrooms. *Journal of Science Teacher Education*, *11*, 323-343.

Belbase, S. (2012). Teacher belief, knowledge, and practice: A trichotomy of mathematics teacher education. Retrieved from http://files.eric.ed.gov/fulltext/ED530017.pdf

Belenky, M. F., Clinchy, B. M., Goldberger, N. R., & Tarule, J. M. (1986). *Women's ways of knowing: The development of self, voice, and mind* (Vol. 15). New York, NY: Basic Books.

Bendixen, L. D., & Corkill, A. (2011). Personal epistemology change due to experience? In J. Brownlee, G. Schraw, & D. Berthelsen (Eds.), *Personal epistemology and teacher education* (pp. 100-113). New York, NY: Routledge.

Bendixen, L. D., Dunkle, M. E., & Schraw, G. (1994). Epistemological beliefs and reflective judgement. *Psychological Reports, 75*(3_suppl), 1595-1600.

Biggs, J. (1999). What the student does: Teaching for enhanced learning. *Higher Education Research & Development*, *18*(1), 57-75.

Bogdan, R.C., & Biklen, S. K. (2006*). Qualitative research for education: An introductory to theory and methods* (5th ed.). Needham Heights, MA: Allyn and Bacon.

Boyatzis, R. (1998). *Transforming qualitative information: Thematic analysis and code development.* Thousand Oaks, CA: Sage.

Brickhouse, N. W., Bonder, G. M., & Neie, V. E. (1987). Teacher beliefs about science and their influence on classroom practice. In J. Novak (Ed.), *Proceedings of the second international seminar on misconceptions and educational strategies in science and mathematics* Vol. 2 (p. 3448). Ithaca, NY: Cornell University

Bronfenbrenner, U. (2005b). Ecological systems theory. In U. Bronfenbrenner (Ed.), *Making human beings human: Bioecological perspectives on human development* (pp. 106-173). Thousand Oaks, CA: Sage.

Brown, R., & Redmond, T. (2008). Reconceptualizing agency through teachers talking about a sociocultural approach to teaching mathematics in the classroom (pp. 101-108). In M. Goos, R. Brown & K. Makar (Eds), *Navigating currents and charting directions: MERGA 31 conference proceedings* (Vol. 1, pp. 101–108). The University of Queensland, Mathematics Education Research Group of Australasia, Inc.

Brownell, S. E., & Tanner, K. D. (2012). Barriers to faculty pedagogical change: Lack of training, time, incentives, and tensions with professional identity? *CBE – Life Sciences Education*, *11*, 339-346.

Brownlee, J. M. (2001). Knowing and learning in teacher education: A theoretical framework of core and peripheral beliefs in application. *Asia-Pacific Journal of Teacher Education and Development*, *4*(1), 131-155.

Brownlee, J. M. (2003). Paradigm shifts in preservice teacher education students: A case study of changes in epistemological beliefs for two teacher education students. *Australian Journal of Educational and Developmental Psychology, 3*, 1-6.

Brownlee, J. M. (2004). Teacher education students' epistemological beliefs: Developing a relational model of teaching. *Research in Education*, *72*(1), 1-17.

Brownlee, J. M., Boulton-Lewis, G. M., & Purdie, N. (2002). Core beliefs about knowing and peripheral beliefs about learning: Developing a holistic conceptualization of epistemological beliefs. *Australian Journal of Educational and Developmental Psychology, 2*, 1-16.

Brownlee, J. M., Purdie, N., & Boulton-Lewis, G. (2001). Changing epistemological beliefs in pre-service teacher education students. *Teaching in Higher Education, 6*, 247-268.

Brownlee, J. M., Schraw, G., & Berthelsen, D. C. (2011). Personal epistemology and teacher education: An emerging field of research. In J. Brownlee, G. Schraw, & D. Berthelsen (Eds.), *Personal epistemology and teacher education* (pp. 3–22). New York, NY: Routledge.

Brownlee, J. M., Thorpe, K. J., & Stacey, P. S. (2005). *Improving learning and teaching in early childhood teacher education: A focus on personal epistemology*. In Proceedings Higher Education Research and Development Society of Australasia. Sydney, NSW. Retrieved from http://eprints.qut.edu.au

Bryan, L. A., & Atwater, M. M. (2002). Teacher beliefs and cultural models: A challenge for science teacher preparation programs. *Science Education*, *86*, 821-839.

Buehl, M. M. (2003). *At the crossroads of epistemology and motivation: Modeling the relations between students' domain -specific epistemological beliefs, achievement motivation, and task performance* (Order No. 3107202). Available from ProQuest Dissertations & Theses Global. (305319754). Retrieved from https://ezproxy.mtsu.edu/login?url=https://search.proquest.com/docview/305319754?accountid=4886

Buehl, M. M., & Beck, J. S. (2015). The relationship between teachers' beliefs and teachers' practices. In H. Fives & M. G. Gill (Eds.), *International handbook of research on teachers' belief*, (pp. 66-84). New York, NY: Routledge.

Calderhead, J. (1981). Stimulated recall: A method for research on teaching. *British Journal of Educational Psychology*, *51*, 211-217.

Casti, J. (1997) *Would Be World*. New York, NY: Wiley.

Cavallo, A. (2008). Experiencing the nature of science: An interactive, beginning-of-semester activity. *Journal of College Science Teaching*, *37*(5), 12.

Cavaye, A. L. (1996). Case study research: A multi-faceted research approach for IS. *Information Systems Journal*, *6*, 227-242.

Chan, K. W., & Elliott, R. G. (2002). Exploratory study of Hong Kong teacher education students' epistemological beliefs: Cultural perspectives and implications on beliefs research. *Contemporary Educational Psychology*, *27*, 392-414.

Chan, K. W., & Elliott, R. G. (2004). Relational analysis of personal epistemology and conceptions about teaching and learning. *Teaching and Teacher Education*, *20*, 817-831.

Chang, H. P., & Lederman, N. G. (1994). The effect of levels of cooperation within physical science laboratory groups on physical science achievement. *Journal of Research in Science Teaching*, *31*, 167-181.

Chen, C. H. (2008). Why do teachers not practice what they believe regarding technology integration? *The Journal of Educational Research*, *102*(1), 65-75.

Cheng, M. M., Chan, K. W., Tang, S. Y., & Cheng, A. Y. (2009). Pre-service teacher education students' epistemological beliefs and their conceptions of teaching. *Teaching and Teacher Education*, *25*, 319-327.

Chisholm, R. M. (1989). *Theory of knowledge*. Englewood Cliffs, NJ: Prentice-Hall.

Clough, M. P. (2006). Learners' responses to the demands of conceptual change: Considerations for effective nature of science instruction. *Science and Education*, *15*, 463-494.

Cohen, D. K., Raudenbush, S. W., & Ball, D. L. (2003). Resources, instruction, and research. *Educational Evaluation and Policy Analysis*, *25*, 119-142.

Connolly, M. R., Savoy, J. N., Lee, Y. G., & Hill, L. B. (2016). *How teaching development programs can improve undergraduate education*. Madison, WI: Wisconsin Center for Education Research, University of Wisconsin–Madison.

Cooney, T. J. (1985). A beginning teachers' view of problem-solving. *Journal for Research in Mathematics Education, 16*, 324-336.

Crabtree, B. F., & Miller, W. L. (1999). Using codes and code manuals: A template organizing style of interpretation. In B. F. Crabtree & W. L. Miller (Eds.), *Doing qualitative research* (2nd ed., pp. 163-178). Newbury Park, CA: Sage

Creswell, J. W. (2014). *A concise introduction to mixed methods research*. Thousand Oaks, CA: Sage Publications.

Cronin-Jones, L. L. (1991). Science teacher beliefs and their influence on curriculum implementation: Two case studies. *Journal of Research in Science Teaching*, *28*, 235-250.

Cross, R. G. (2004, July 12-13). *Bolitho's 'Eternal Triangle' of communicative language teaching revisited: A place for activity theory in understanding educational practice in foreign language classrooms*. Paper presented at the International Society for Cultural and Activity Research Regional Conference: Application of

Activity Theory to Education, Information Systems and Business, Wollongong, NSW.

Darling-Hammond, L., Flook, L., Cook-Harvey, C., Barron, B., & Osher, D. (2019). Implications for educational practice of the science of learning and development. *Applied Developmental Science, Advance Online Publication,* 1-44. doi:10.1080/10888691.2018.1537791.

Davis, B., & Sumara, D. (2006). *Complexity and education*. Marwah, NJ: Lawrence Erlbaum.

Deniz, H. (2011). Examination of changes in prospective elementary teachers' epistemological beliefs in science and exploration of factors meditating that change. *Journal of Science Education and Technology*, *20,* 750-760.

Denzin, N. K. (1978). *The research act: A theoretical orientation to sociological methods*. New York, NY: McGraw-Hill.

Devlin, M., & Samarawickrema, G. (2010). The criteria of effective teaching in a changing higher education context. *Higher Education Research & Development*, *29*, 111-124.

Duschl, R. A. (1990). *Restructuring science education: The importance of theories and their development*. New York, NY: Teachers College Press.

Dweck, C. S., & Leggett, E. L. (1988). A social-cognitive approach to motivation and personality. *Psychological Review, 95*, 256–273.

Ekinci, N. (2017). Examining the relationships between epistemological beliefs and teaching and learning conceptions of lower-secondary education teachers. *İnönü Üniversitesi Eğitim Fakültesi Dergisi*, *18*, 344-358.

Er, K. O. (2013). A study of the epistemological beliefs of teacher candidates in terms of various variables. *Eurasian Journal of Educational Research, 50*, 207-226.

Ernest, P. (1989). The knowledge, beliefs, and attitudes of the mathematics teacher: A model. *Journal of Education for Teaching*, *15*(1), 13-33.

Fang, Z. (1996). A review of research on teacher beliefs and practices. *Educational Research*, *38*(1), 47-65.

Farrell, T. S., & Bennis, K. (2013). Reflecting on ESL teacher beliefs and classroom practices: A case study. *RELC journal*, *44*, 163-176.

Fenstermacher, G. D. (1994). The knower and the known: The nature of knowledge in research on teaching. *Review of Research in Education*, *20*(1), 3-56.

Fereday, J., & Muir-Cochrane, E. (2006). Demonstrating rigor using thematic analysis: A hybrid approach of inductive and deductive coding and theme development. *International Journal of Qualitative Methods, 5*(1), 80-92.

Feryok, A. (2010). Language teacher cognition: Complex dynamic systems? *System, 38,* 272-279.

Feucht, F. C., & Bendixen, L. D. (2010). Exploring similarities and differences in personal epistemologies of US and German elementary school teachers. *Cognition and Instruction*, *28*(1), 39-69.

Fishbein, M., & Ajzen, I. (1977). *Belief, attitude, intention, and behavior: An introduction to theory and research*. Reading, MA: Addison-Wesley.

Fives, H., & Buehl, M. M. (2012). Spring cleaning for the “messy” construct of teachers’ beliefs: What are they? Which have been examined? What can they tell us? *APA Educational Psychology Handbook*, *2*, 471-499.

Fives, H., & Buehl, M. M. (2017). The functions of beliefs: Teachers' personal epistemology on the pinning block. In G. Schraw, J. Lunn Brownlee, L. Olafson, & M. VanderVeldt (Eds.), *Teachers' personal epistemologies: Evolving models for transforming practice* (pp. 471-499). Charlotte, NC: Information Age Press.

Freeman, D. L., & Cameron, L. (2008). Research methodology on language development from a complex systems perspective. *The Modern Language Journal*, *92*, 200-213.

Freeman, S., Eddy, S. L., McDonough, M., Smith, M. K., Okoroafor, N., Jordt, H., & Wenderoth, M. P. (2014). Active learning increases student performance in science, engineering, and mathematics. *Proceedings of the National Academy of Sciences*, *111*, 8410-8415.

French, D. P., & Russell, C. P. (2002). Do graduate teaching assistants benefit from teaching inquiry-based laboratories? *Bioscience*, *52*, 1036-1041.

Furtak, E. M., & Penuel, W. R. (2019). Coming to terms: Addressing the persistence of "hands-on" and other reform terminology in the era of science as practice. *Science Education*, *103*, 167-186.

Gardner, G. E., & Jones, M. G. (2011). Pedagogical preparation of the science graduate teaching assistant: Challenges and implications. *Science Educator*, *20*(2), 31-41.

Gardner, G. E., & Parrish, J. (2019). Biology graduate teaching assistants as novice educators: Are there similarities in teaching ability and practice beliefs between teaching assistants and K–12 teachers? *Biochemistry and Molecular Biology Education*, *47*(1), 51-57.

Gay, G. (2010). Acting on beliefs in teacher education for cultural diversity. *Journal of Teacher Education, 61*, 143-152.

Gay, L. R., Mills, G. E., & Airasian, P. W. (2011). *Educational research: Competencies for analysis and applications* (10th ed.). Upper Saddle River, NJ: Pearson Education.

Gibbs, G. R. (2002). *Qualitative data analysis: Explorations with NVivo*. London: Open University Press.

Gleick, J. 1987. *Chaos: Making a new science*. New York, NY: Penguin Books.

Goldstein, J. (1999). Emergence as a construct: History and issues. *Emergence*, *1*(1), 49-72.

Hanauer, D. I., & Bauerle, C. (2012). Facilitating innovation in science education through assessment reform. *Liberal Education*, *98*(3), 34-41.

Handelsman, J., Ebert-May, D., Beichner, R., Bruns, P., Chang, A., DeHaan, R., . . . Wood, W. B. (2004). Scientific teaching. *Science, 304*, 521–522.

Harris, C. J., & Rooks, D. L. (2010). Managing inquiry-based science: Challenges in enacting complex science instruction in elementary and middle school classrooms. *Journal of Science Teacher Education*, *21*, 227-240.

Hennessey, M. N., Murphy, P. K., & Kulikowich, J. M. (2013). Investigating teachers' beliefs about the utility of epistemic practices: A pilot study of a new assessment. *Instructional Science*, *41*, 499-519.

Hensiek, S. (2018). *Digital badges and student motivation in the undergraduate general chemistry laboratory* (Order No. 10845161). Available from ProQuest Dissertations & Theses Global. (2112857118). Retrieved from https://ezproxy.mtsu.edu/login?url=https://search.proquest.com/docview/2112857118?accountid=4886.

Herrington, D. G., & Nakhleh, M. B. (2003). What defines effective chemistry laboratory instruction? Teaching assistant and student perspectives. *Journal of Chemical Education*, *80*, 1197.

Hewson, P. W., & Hewson, A. B. (1987). Science teachers' conceptions of teaching: Implications for teacher education. *International Journal of Science Education*, *9*, 425-440.

Hewson, P. W., Hewson, A. B., & Mariana, G. (1988). An appropriate conception of teaching science: A view from studies of science learning. *Science Education*, *72*, 597-614.

Hodson, D. (2014). Learning science, learning about science, doing science: Different goals demand different learning methods. *International Journal of Science Education*, *36*, 2534-2553.

Hoessler, C., & Godden, L. (2015). The visioning of policy and the hope of implementation: Support for graduate students' teaching at a Canadian institution. *Canadian Journal of Higher Education*, *45*(1), 83-101.

Hofer B. K., & Pintrich, P. R. (2002). *Personal epistemology: The psychology of beliefs about knowledge and knowing*. London: Lawrence Erlbaum.

Hofer, B. K., & Pintrich, P. R. (1997). The development of epistemological theories: Beliefs about knowledge and knowing and their relation to learning. *Review of Educational Research, 67*(1), 88-140.

Hofer, B. K. (2000). Dimensionality and disciplinary differences in personal epistemology. *Contemporary Educational Psychology*, *25*, 378-405.

Hofer, B. K. (2001). Personal epistemology research: Implications for learning and teaching. *Educational Psychology Review*, *13*, 353-383.

Hofer, B. K. (2002). Epistemological world views of teachers: From beliefs to practice. *Issues in Education*, *8*(2), 167-173.

Hofstein, A., & Lunetta, V. N. (2004). The laboratory in science education: Foundations for the twenty-first century. *Science Education*, *88*(1), 28-54.

Honderich, T. (Ed.). (2005). *The Oxford companion to philosophy*. Oxford: Oxford University Press.

Huling, M. (2014). *The effect of teachers' epistemological beliefs on practice.* Available from ERIC. (1871568193; ED567558). Retrieved from https://ezproxy.mtsu.edu/login?url=https://search.proquest.com/docview/1871568193?accountid=4886.

Jehng, J. J., Johnson, S. D., & Anderson, R. C. (1993). Schooling and students' epistemological beliefs about learning. *Contemporary Educational Psychology, 18*, 23-35.

Jin, L., & Cortazzi, M. (2002). English language teaching in China: A bridge to the future. In W. K. Ho & R. Y. L. Wong (Eds.), *English language teaching in East Asia today* (pp. 131–145). Singapore: Times Academic Press.

Johnston, P., Woodside-Jiron, H., & Day, J. (2001). Teaching and learning literate epistemologies. *Journal of Educational Psychology*, *93*(1), 223.

Jordan, A., & Stanovich, P. (2003). Teachers' personal epistemological beliefs about students with disabilities as indicators of effective teaching practices. *Journal of Research in Special Educational Needs*, *3*, 535-542.

Jordan, R. C., Ruibal-Villasenor, M., Hmelo-Silver, C. E., & Etkina, E. (2011). Laboratory materials: Affordances or constraints? *Journal of Research in Science Teaching*, *48*, 1010-1025.

Justice, N., Zieffler, A., & Garfield, J. (2017). Statistics graduate teaching assistants' beliefs, practices, and preparation for teaching introductory statistics. *Statistics Education Research Journal*, *16*(1), 294-319.

Kagan, D. M. (1992). Implication of research on teacher belief. *Educational Psychologist, 27*(1), 65-90.

Keen, P. (1991). Relevance and rigor in information systems research: Improving quality, confidence cohesion and impact. In H. Nissen, H. Klein, R. Hirschheim, (Eds.), *Information systems research: Contemporary approaches & emergent traditions*. (pp. 27-49). North-Holland, Amsterdam.

Keiser, J. M., & Lambdin, D. V. (1996). The clock is ticking: Time constraint issues in mathematics teaching reform. *The Journal of Educational Research*, *90*(1), 23-31.

Kendall, K. D., & Schussler, E. E. (2012). Does instructor type matter? Undergraduate student perception of graduate teaching assistants and professors. *CBE – Life Sciences Education*, *11*, 187-199.

King, N. (2004). Using templates in the thematic analysis of text. In C. Cassell & G. Symon (Eds.), *Essential guide to qualitative methods in organizational research* (pp. 257–270). London: Sage.

King, N. (2012). Doing template analysis. Qualitative organizational research: Core methods and current challenges. In G. Symon & C. Cassell (Eds.), *Qualitative organizational research*. (pp. 426–50). London: Sage.

King, P. M., & Kitchener, K. S. (1981). Reflective judgment: Concepts of justification and their relationship to age and education. *Journal of Applied Developmental Psychology*, *2*(2), 89-116.

King, P. M., & Kitchener, K. S. (1994). *Developing reflective judgment: Understanding and promoting intellectual growth and critical thinking in adolescents and adults.* San Francisco, CA: Jossey Bass.

King, P. M., & Kitchener, K. S. (2002). The reflective judgment model: Twenty years of research on epistemic cognition. In B. K. Hofer & P. R. Pintrich (Eds.), *Personal epistemology: The psychology of beliefs about knowledge and knowing* (pp. 37-61). Mahwah, NJ: Lawrence Erlbaum Associates.

Kissau, S. P., Algozzine, B., & Yon, M. (2012). Similar but different: The beliefs of foreign language teachers. *Foreign Language Annals*, *45*, 580-598.

Koballa, Jr, T., Graber, W., Coleman, D. C., & Kemp, A. C. (2000). Prospective gymnasium teachers' conceptions of chemistry learning and teaching. *International Journal of Science Education*, *22*, 209-224.

Kruse, R. A., & Roehrig, G. H. (2005). A comparison study: Assessing teachers' conceptions with the chemistry concepts inventory. *Journal of Chemical Education*, *82*, 1246.

Kuhn, D. (1991). *The skills of argument*. New York, NY: Cambridge University Press.

Kurdziel, J. P., Turner, J. A., Luft, J. A., & Roehrig, G. H. (2003). Graduate teaching assistants and inquiry-based instruction: Implications for graduate teaching assistant training. *Journal of Chemical Education*, *80*, 1206.

Kuther, T. L. (2003). Teaching the teacher: Ethical issues in graduate student teaching. *College Student Journal*, *37*(2), 219.

Kvale, S. (1999). The psychoanalytic interview as qualitative research. *Qualitative Inquiry*, *5*(1), 87-113.

Lantolf, J. P. (2000). Introducing sociocultural theory. *Sociocultural theory and second language learning*, *1*, 1-26.

Larsen-Freeman, D. (1997). Chaos/complexity science and second language acquisition. *Applied linguistics*, *18*, 141-165.

Lederman, N. G. (1992). Students' and teachers' conceptions of the nature of science: A review of the research. *Journal of Research in Science Teaching*, *29*, 331-359.

Lederman, N. G. (1999). Teachers' understanding of the nature of science and classroom practice: Factors that facilitate or impede the relationship. *Journal of Research in Science Teaching*, *36*, 916-929.

Lederman, N. G. (2013). Nature of science: Past, present, and future. In S. K. Abell & N. G. Lederman (Eds.), *Handbook of research on science education* (pp. 831–879). Mahwah, NJ: Lawrence Erlbaum Associates.

Lederman, N. G., & Lederman, J. S. (2004). Revising instruction to teach nature of science. *The Science Teacher*, *71*(9), 36-39.

Lederman, N. G., & Lederman, J. S. (2014). Research on teaching and learning of nature of science. In N. G. Lederman &. K. Abell (Eds.), *Handbook of research on science education volume II* (pp. 600-620). New York, NY: Taylor & Francis.

Lederman, N. G., Abd-El-Khalick, F., Bell, R. L., & Schwartz, R. S. (2002). Views of nature of science questionnaire: Toward valid and meaningful assessment of learners' conceptions of nature of science. *Journal of Research in Science Teaching*, *39*, 497-521.

Lederman, N. G., Lederman, J. S., & Antink, A. (2013). Nature of science and scientific inquiry as contexts for the learning of science and achievement of scientific literacy. *International Journal of Education in Mathematics Science and Technology*, *1*(3), 138-147.

Lee, H. N., & Kim, H. Y. (2014). A study on the complexity theory and its implications on the role of teacher in the knowledge of society. *Theory and Practice of Education*, *19*(3), 147-165.

Lee, J. C. K., Zhang, Z., Song, H., & Huang, X. (2013). Effects of epistemological and pedagogical beliefs on the instructional practices of teachers: A Chinese perspective. *Australian Journal of Teacher Education*, *38*(12), 8.

Lee, S. W. (2019). The impact of a pedagogy course on the teaching beliefs of inexperienced graduate teaching assistants. *CBE – Life Sciences Education*, *18*, 1-12.

Lehman, D. R., Lempert, R. O., & Nisbett, R. E. (1988). The effects of graduate training on reasoning: Formal discipline and thinking about everyday-life events. *American Psychologist*, *43*, 431-442.

Levin, B. (2015). The development of teachers' beliefs. In H. Fives & M. G. Gill (Eds.), *International handbook of research on teachers' beliefs* (pp. 60-77). London: Routledge.

Levitt, E. K. (2001). An analysis of elementary teachers' beliefs regarding the teaching and learning of science. *Science Education, 86*, 1–22.

Li Y., Oliveira H. (2015). Research on classroom practice. In S. Cho (Ed.), *The proceedings of the 12th international congress on mathematical education*. Springer, Cham.

Lin, H. S., & Chiu, H. L. (2004). Student understanding of the nature of science and their problem-solving strategies. *International Journal of Science Education*, *26*(1), 101-112.

Lin, J. W., & Chiu, M. H. (2005, August). *Portraying science in the classroom: A case study about teacher's pedagogical content knowledge influencing in students' understanding of acids and bases.* Paper presented at the Asian Chemical Congress, Seoul, Korea.

Lowyck, J. (2003). Teacher thinking and teacher routines: A bifurcation? In M. Kompf & P. M. Denicolo (Eds.), *Teacher thinking twenty years on: Revisiting persisting problems and advances in education* (pp. 101–110). Lisse, Netherlands: Swets & Zeitlinger.

Luft, J. A., & Roehrig, G. H. (2007). Capturing science teachers' epistemological beliefs: The development of the teacher beliefs interview. *Electronic Journal of Science Education*, *11*(2), 38-63.

Luft, J. A., Kurdziel, J. P., Roehrig, G. H., & Turner, J. (2004). Growing a garden without water: Graduate teaching assistants in introductory science laboratories at a doctoral/research university. *Journal of Research in Science Teaching*, *41*, 211-233.

Mansour, N. (2013). Consistencies and inconsistencies between science teachers' beliefs and practices. *International Journal of Science Education*, *35*, 1230-1275.

Maor, D., & Taylor, P. C. (1995). Teacher epistemology and scientific inquiry in computerized classroom environments. *Journal of Research in Science Teaching*, *32*, 839-854.

Marbach-Ad, G., & Sokolove, P. G. (2000). Good science begins with good questions. *Journal of College Science Teaching*, *30*, 192.

Martin, S. D., McQuitty, V., & Morgan, D. N. (2019). *Complexity theory in education*. New York. NY: Oxford University Press.

Mascolo, M. F. (2009). Beyond student-centered and teacher-centered pedagogy: Teaching and learning as guided participation. *Pedagogy and the Human Sciences*, *1*(1), 3-27.

Mason, M. (2008). Complexity theory and the philosophy of education. *Educational Philosophy and Theory*, *40*(1), 4-18.

Mazur, E. (2009). Farewell, lecture? *Science*, *323*(5910), 50-51.

McComas, W. F., Clough, M. P., & Almazroa, H. (1998). The role and character of the nature of science in science education. *Science and Education*, *7,* 511–532.

Merriam, S. B. (2009). *Qualitative research: A guide to design and interpretation*. San Francisco, CA: Jossey-Bass.

Miller, K., Brickman, P., & Oliver, J. S. (2014). Enhancing teaching assistants' (TAs') inquiry teaching by means of teaching observations and reflective discourse. *School Science and Mathematics*, *114*, 178-190.

Moore, R. (1991). Preparing graduate teaching assistants to teach biology: Ways to improve the teaching readiness of a critical educational influence. *Journal of College Science Teaching*, 20, 358-361.

Morrison, K. (2008). Educational philosophy and the challenge of complexity theory. *Educational Philosophy and Theory*, *40*(1), 19-34.

Morrow, S. L., & Smith, M. L. (2000). Qualitative research for counseling psychology. *Handbook of Counseling Psychology*, *3*, 199-230.

Morse, J. M. (Ed.). (1997). *Completing a qualitative project*. Thousand Oaks, CA: Sage.

Muis, K. R., & Foy, M. J. (2010). The effects of teachers' beliefs on elementary students' beliefs, motivation, and achievement in mathematics. In L. D. Bendixen & F. C. Feucht (Eds.), *Personal epistemology in the classroom: Theory, Research, and implications for practice* (pp. 435-469). Cambridge: Cambridge University Press.

Munby, H., Russell, T., & Martin, A. (2001). Teachers' knowledge and how it develops. In V. Richardson (Ed.), *Handbook of research on teaching* (4th ed.*)* (pp. 877–904). Washington, DC: American Educational Research Association.

Murphy, P. K., Alexander, P., Greene, J., & Hennessey, M. (2012). Examining epistemic frames in conceptual change research: Implications for learning and instruction. *Asia Pacific Education Review, 13,* 475-486.

Muzaka, V. (2009). The niche of graduate teaching assistants (GTAs): Perceptions and reflections. *Teaching in Higher Education*, *14*(1), 1-12.

Nasser-Abu Alhija, F., & Fresko, B. (2018). Graduate teaching assistants: How well do their students think they do? *Assessment & Evaluation in Higher Education*, *43*, 943-954.

National Research Council. (1996). *Science education standards*. Washington, DC: National Academy Press.

National Research Council. (2000). *Inquiry and the national education science standards: A guide for teaching and learning.* Washington, DC: National Academy Press.

National Research Council. (2012). *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas.* Washington, DC: National Academy Press.

Neal, J. W., & Neal, Z. P. (2013). Nested or networked? Future directions for ecological systems theory. *Social Development*, *22*, 722-737.

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

NGSS Lead States. (2013). *Next generation science standards: For states, by state*s. Washington, DC: The National Academies Press.

Nicklow, J. W., Marikunte, S. S., & Chevalier, L. R. (2007). Balancing pedagogical and professional practice skills in the training of graduate teaching assistants. *Journal of Professional Issues in Engineering Education and Practice*, *133*(2), 89-93.

Nowlis, V., Clark, K. E., & Rock, M. (1968). *The graduate student as teacher*. Monograph No. 2. Washington, DC: American Council on Education.

Olafson, L., & Schraw, G. (2010). Beyond epistemology: Assessing teachers' epistemological and ontological worldviews. In L. D. Bendixen & F. C. Feucht

(Eds.), *Personal epistemology in the classroom: Theory, research, and implications for practice* (pp. 516-551). New York, NY: Cambridge University Press.

Pae, J. H. (2015). The implication of the complexity thinking. *Philosophy of Education, 55*(4), 23-51.

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

Park, C. (2004). The graduate teaching assistant (GTA): Lessons from North American experience. *Teaching in Higher Education*, *9*, 349-361.

Park, C., & Ramos, M. (2002). The donkey in the department? Insights into the graduate teaching assistant (GTA) experience in the UK. *Journal of Graduate Education*, *3*(2), 47-53.

Patton, M. Q. (2015). *Qualitative evaluation and research methods*. Newbury Park, CA: Sage.

Perry, Jr., W. G. (1999). *Forms of intellectual and ethical development in the college years: A scheme.* San Francisco, CA: Jossey-Bass Higher and Adult Education Series.

Perry, W. (1970). *Forms of intellectual and academic developments in the college years*. New York, NY: Holt, Rinehart & Winston.

Phan, H. P. (2012, December). *A sociocultural perspective of learning: Developing a new theoretical tenet.* Paper presented at the Australian Association for Research in Education, University of Sydney, Sydney.

Pintrich, P. R. (2002). Future challenges and directions for theory and research on personal epistemology. In B. Hofer & P. Pintrich (Eds.), *Personal epistemology: The psychology of beliefs about knowledge and knowing* (pp. 389–414). Mahwah, NJ: Erlbaum.

Pirie, S. (1996). *Classroom video-recording: When, why and how does it offer a valuable data source for qualitative research?* Eric Document Reproduction Service Number ED401128.

Plsek, P. E., & Greenhalgh, T. (2001). The challenge of complexity in health care. *BMJ*, *323*, 625-628.

Poulson, L., Avramidis, E., Fox, R., Medwell, J., & Wary, D. (2001). The theoretical orientation of primary school literacy teachers: An exploratory study. *Research Papers in Education*, *16*, 271-292.

Quinlan, K. M. (1999). Commonalities and controversy in context: A study of academic historians' educational beliefs. *Teaching and Teacher Education*, *15*, 447-463.

Reed, S. (2003). Beliefs and practices of itinerant teachers of deaf and hard of hearing children concerning literacy development. *American Annals of the Deaf*, *148*, 333-343.

Reeves, T. D., Marbach-Ad, G., Miller, K. R., Ridgway, J., Gardner, G. E., Schussler, E. E., & Wischusen, E. W. (2016). A conceptual framework for graduate teaching assistant professional development evaluation and research. *CBE – Life Sciences Education*, *15*, es2.

Rice, P. L., & Ezzy, D. (1999). *Qualitative research methods: A health focus* (Vol. 720). Victoria, Australia: Oxford.

Richardson, V. (1996). The role of attitudes and beliefs in learning to teach In J. Sikula, T. Buttery, & E. Guyton (Eds.), *Handbook of research on teacher education* (pp. 102–119). New York: Simon & Schuster Macmillan.

Richardson, V. (2003). Preservice teachers' beliefs. In J. Rath & A. C. McAninch (Eds.), *Advances in teacher education* (pp. 1–22). Greenwich, CT: Information Age.

Richardson, V. (Ed.). (1997). *Constructivist teacher education: Building a world of understanding*. London: The Falmer Press.

Rogoff, B., Paradise, R., Arauz, R. M., Correa-Chávez, M., & Angelillo, C. (2003). First-hand learning through intent participation. *Annual Review of Psychology*, *54*(1), 175-203.

Roth, G., & Weinstock, M. (2013). Teachers' epistemological beliefs as an antecedent of autonomy-supportive teaching. *Motivation and Emotion*, *37*, 402-412.

Round, J., & Lom, B. (2015). In situ teaching: Fusing labs & lectures in undergraduate science courses to enhance immersion in scientific research. *Journal of Undergraduate Neuroscience Education*, *13*(3), 206.

Ryan, K. (1986). *The induction of new teachers.* Bloomington, IN: Phi Delta Kappa Educational Foundation.

Savasci-Acikalin, F. (2014). A study of pre-service teachers' science teaching efficacy beliefs during the elementary science laboratory course. *Procedia-Social and Behavioral Sciences, 14,* 221–226.

Schamel, D., & Ayres, P. M. (1992). The minds-on approach: Student creativity and personal involvement in the undergraduate science laboratory. *Journal of College Science Teaching, 21,* 226–229.

Scheffler, I. (1965). *Conditions of knowledge.* New York, NY: Scott, Freeman & Company.

Schoenfeld, A. H. (1985). *Mathematical problem-solving*. San Diego, CA: Academic Press.

Schoenfeld, A. H. (1983). Beyond the purely cognitive: Belief systems, social cognitions, and metacognitions as driving forces in intellectual performance. *Cognitive Science, 7*, 329–363.

Schommer, M. (1989). The effects of beliefs about the nature of knowledge on comprehension. *Dissertation Abstracts International, 50*(8), 2435.

Schommer, M. (1990). Effects of beliefs about nature of knowledge on comprehension. *Journal of Educational Psychology, 82,* 498-504.

Schommer, M. (1993a). Comparisons of beliefs about the nature of knowledge and learning among postsecondary students. *Research in Higher Education*, *34*, 355-370.

Schommer, M. (1994). Synthesizing epistemological belief research: Tentative understandings and provocative confusions. *Educational Psychology Review, 6,* 293-319.

Schommer-Aikins, M. (2004). Explaining the epistemological belief system: Introducing the embedded systemic model and coordinated research approach. *Educational Psychologist*, *39*(1), 19-29.

Schraw, G., Brownlee, J. L., Olafson, L., & Brye, M. V. V. (Eds.). (2017). *Teachers' personal epistemologies: Evolving models for informing practice*. Charlotte, NC: Information Age Publishing.

Schreiber, J. B., & Shinn, D. (2003). Epistemological beliefs of community college students and their learning processes. *Community College Journal of Research & Practice*, *27*, 699-709.

Schwartz, E., & Jordan, A. (2014). Teachers' epistemological beliefs and practices with students with disabilities and at-risk in inclusive classrooms. *Personal Epistemology and Teacher Education*, *61*, 210.

Schwartz, R. S. (2004). *Epistemological views in authentic science practice: A cross - discipline comparison of scientists' views of nature of science and scientific inquiry* (Order No. 3138483). Available from ProQuest Dissertations & Theses Global. (305142179). Retrieved from https://ezproxy.mtsu.edu/login?url=https://search.proquest.com/docview/305142179?accountid=4886.

Seidman, I. (1998). *Interviewing as qualitative research* (2nd ed.). New York, NY: Teachers College, Columbia University.

Sengul, O. (2018). Science teachers' epistemological beliefs, PCK of argumentation, and implementation: An exploratory study. *Science*, *5*, 11-2018.

Seymour, E., & Hewitt, N. M. (1997). *Talking about leaving: Why undergraduates leave the sciences* (Vol. 12). Boulder, CO: Westview Press.

Shenton, A. K. (2004). Strategies for ensuring trustworthiness in qualitative research projects. *Education for Information*, *22*(2), 63-75.

Slotnick, R. C., & Janesick, V. J. (2011). Conversations on method: Deconstructing policy through the researcher reflective journal. *The Qualitative Report*, *16*, 1352-1360.

Speer, N. M. (2005). Issues of methods and theory in the study of mathematics teachers' professed and attributed beliefs. *Educational Studies in Mathematics, 58*, 361–391.

Springer, L., Stanne, M. E., & Donovan, S. S. (1999). Effects of small-group learning on undergraduates in science, mathematics, engineering, and technology: A meta-analysis. *Review of Educational Research*, *69*(1), 21-51.

Staats, C. (2016). Understanding implicit bias: What educators should know. *American Educator, 39*(4), 29.

Stage, F. K., & Kinzie, J. (2009). Reform in undergraduate science, technology, engineering, and mathematics: The classroom context. *The Journal of General Education, 58*(2), 85-105.

Stark, J. S. (2000). Planning introductory college courses: Content, context, and form. *Instructional Science*, *28*, 413-438.

Suh, J. K. (2016). *Examining teacher epistemic orientations toward teaching dcience (EOTS) and its relationship to instructional practices in science* (Order No. 10143056). Available from ProQuest Dissertations & Theses Global. (1811609196). Retrieved from https://ezproxy.mtsu.edu/login?url=https://search.proquest.com/docview/1811609196?accountid=4886.

Sundberg, M. D., Armstrong, J. E., & Wischusen, E. W. (2005). A reappraisal of the status of introductory biology laboratory education in US colleges & universities. *The American Biology Teacher, 67*, 525-529.

Tamimy, M. (2015). Consistencies and inconsistencies between teachers' beliefs and Practices. *The Qualitative Report*, *20*, 1234-1259.

Tanner, K., & Allen, D. (2006). Approaches to biology teaching and learning: On integrating pedagogical training into the graduate experiences of future science faculty. *CBE – Life Sciences Education*, 5, 1-6.

Taylor, J., Gilligan, C., & Sullivan, A. (1995). *Between voice and silence: Women and girls, race and relationship*. Cambridge, MA: Harvard University Press.

Tokuhama-Espinosa, T. (2014). *Making classrooms better: 50 practical applications of mind, brain, and education science*. New York, NY: W.W Norton & Company.

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

Tudor, I. (2001). *The dynamics of the language classroom*. Cambridge, England: Cambridge University Press.

Turner, J. C., & Meyer, D. K. (2000). Studying and understanding the instructional contexts of classrooms: Using our past to forge our future. *Educational Psychologist*, *35*(2), 69-85.

U.S. Department of Education, Office of Innovation and Improvement. (2016). *STEM 2026: A Vision for Innovation in STEM Education.* Washington, DC: Author.

Van Driel, J. H., Verloop, N., Van Werven, H. I., & Dekkers, H. (1997). Teachers' craft knowledge and curriculum innovation in higher engineering education. *Higher Education*, *34*(1), 105-122.

Volkmann, M. J., Abell, S. K., & Zgagacz, M. (2005). The challenges of teaching physics to preservice elementary teachers: Orientations of the professor, teaching assistant, and students. *Science Education*, *89*, 847-869.

Wheeler, L. B., Maeng, J. L., Chiu, J. L., & Bell, R. L. (2017). Do teaching assistants matter? Investigating relationships between teaching assistants and student outcomes in undergraduate science laboratory classes. *Journal of Research in Science Teaching*, *54*, 463-492.

Windschitl, M. (2002). Framing constructivism in practice as the negotiation of dilemmas: An analysis of the conceptual, pedagogical, cultural, and political challenges facing teachers. *Review of Educational Research*, *72*, 131-175.

Windschitl, M., Thompson, J., Braaten, M., & Stroupe, D. (2012). Proposing a core set of instructional practices and tools for teachers of science. *Science Education*, *96*, 878-903.

Wright, E. L., Sunal, D. W., & Day, J. B. (2004). Improving undergraduate science teaching through educational research. In D. W. Sunal, E. L. Wright, & J. B. Day (Eds.), *Reform in undergraduate science teaching for the 21st century* (pp. 1- 11). Greenwich, CT: Information Age Publishing, Inc.

Yang, F. Y., & Tsai, C. C. (2010). An epistemic framework for scientific reasoning in informal contexts. In L. D. Bendixen & F. C. Feucht (Eds.), *Personal epistemology in the classroom: Theory, research, and implications for practice* (pp. 124-162). Cambridge, England: Cambridge University Press.

Yin, R. K. (2003). Designing case studies. In R. K. Yin (Ed.), *Case study research: Design and methods*. Thousand Oaks, CA: Sage Publications.

Yin, R. K. (2014). *Case study research: Design and methods* (5th ed.). Thousand Oaks, CA: Sage Publications.

Zeichner, K.M., Tabachnick, B. R. & Densmore, K. (1987). Individual, institutional, and cultural influences of the development of teachers' craft knowledge. In J. Calderhead (Ed.), *Exploring teachers' thinking* (pp. 21-59) London: Cassell Education.

Zheng, H. (2015). *Teacher beliefs as a complex system: English language teachers in China*. Basel: Springer International Publishing.

APPENDICES

APPENDIX A: EMAIL TO PARTICIPANTS

Hello to you colleagues,

I am emailing you to invite you to participate in my study on ‘An exploration into the Influence of Laboratory Constraints on Biology Graduate Teaching Assistants’ Epistemological Beliefs and Science Instructional Practices as a Complex System. You are a special group of instructors whose contributions are significant in the education of undergraduate university students doing science. My study seeks to provide an understanding of how biology GTAs’ epistemological beliefs (beliefs about the nature of knowledge and knowing) influences practices in the laboratory context. I would like to declare that this study does not focus in any way on your biology content knowledge or your pedagogical knowledge. Also, there will not be any evaluation or the like of you as a teacher.

I intend to collect data via interviews and lesson observations. The interviews and lessons will be audio and video recorded. I will provide you with more specific information and a breakdown of what I will be doing as the semester progresses. The requirements for participation is teaching experience, over one semester in the role of graduate teaching assistant, and willingness to consent and provide information about ideas or assumptions about knowing in science, and science teaching and learning, misalignments between epistemological beliefs and science instructional practices, and the role of laboratory constraints on those misalignments.

I anticipate and appreciate your positive response (being optimistic that all of you will reply within the affirmative) and look forward to working with you. I hope that this experience may serve as a means of helping you with your own ideas for your study. If you agree to participate, please reply in the affirmative.

Thank you.

Napoleon James

....

Ph.D. Candidate | Graduate Teaching Assistant

Mathematics and Science Education: Biology Education

APPENDIX B: BELIEFS INTERVIEW PROTOCOL

Pre- Instruction Interview Questions

Demographic Information

B 1. How old are you? (20-29; 30-39; 40-49; 50+)

B 2. Are you a masters or doctoral student?

B 3. At what stage are you in your program (semesters/years)

B 4. How many years have you been teaching?

B 5. What courses or laboratory sections/grades/level (undergraduate introductory/ advanced) have you taught?

B 6. Have you attended any Professional Developments (PDs) related to teaching science? If so, how many and what were they?

B 7. Can you tell me your memories about K-12 school science experience?

Epistemological Beliefs Interview Questions

Epistemological Beliefs in General: Nature of Knowledge

B 8. Many agree that the purpose of a college education is to prepare individuals for life. Do you believe that knowledge changes with time, or do you think that it is something that does not change? Please explain. Why do you think you have such a belief? (Chan & Elliot, 2002; Cheng, Chan, Tang, & Cheng, 2009)

B 9. You’ve probably heard the adage/saying that says people are ‘searching for truth.’ What is your opinion about this?

B 10. Do you feel comfortable dealing with ambiguous situations? (Suh, 2016)

B 11. Example:

Some people agree with ‘The best ideas are often the simplest.’ On the contrary, others say ‘the best ideas the most complex.’ Which statement do you agree with most and why? (Jacobson, 2012)

Nature of Knowing

B 12. Could you explain where your knowledge came from, that is, the source of your knowledge? Is your knowledge mainly coming from authorities or self-construction? (Chan & Elliot, 2002)

B 13. Do you think what experts say or write is correct? Do you question it? Why or why not? (Cheng et al., 2009)

B 14. Do you agree that the content of textbooks is, in general, correct and highly believable? (Chan & Elliot, 2002) Why or why not?

B 15. In learning about something you really want to know what is the role of an expert regarding the information that you would like to know? (Brownlee, 2003)

B 16. How can you justify your knowledge, that is, what you know and where you got your knowledge from? (Feucht & Bendixen, 2010)

B 17. How do you know when you know and/or understand something? (Brownlee, 2003)

B 18. Which of the following are deciding factors in obtaining knowledge?

a. Innate or inborn ability, effort, understanding, learning method, and strategy

(Cheng et al., 2009)

Beliefs about Learning: Nature of Learning

B 19. In your opinion, can perseverance and hard work overcome difficulties in learning? (Cheng et al., 2009)

B 20. Think about the effort you put into learning new things. On an effort scale of 1 – 10 with one being low and ten being highest, what number would you assign to your innate ability and what number to your learning effort? Can you explain your reasoning?

B 21. In your opinion, how do students learn? (Cronin-Jones, 1991)

B 22. Is learning mainly a result of teaching by an expert, or is it self-constructed? (Cheng et al., 2009). Can you give an example of how this looks in your lab sessions?

B 23. In a science class, what do you think are the students' role in the learning process?

B 24. Explain how you know when your students are learning?

B 25. How do you believe students learn science best? (Luft & Roehrig, 2007)

Beliefs about Teaching: Nature of Teaching

B 26. What type of materials and activities do you use to support learning in your classroom? Can you give specific examples?

B 27. In the laboratory, what is your role as the instructor in the learning process?

B 28. In your opinion, what are the goals of teaching science? Are these your goals as a GTA?

B 29. How do you know what questions to ask students?

B 30. What are the most common strategies that you employ in teaching? What is the reason or principles for choosing these strategies? (Cheng et al., 2009)

B 31. Which do you think are the best teaching approaches or strategies?

B 32. How do you know which aspects of the content are the most important?

Epistemological Beliefs in Science: Nature of Knowledge and Knowing in Science

B 33. What is science? What makes science different from other disciplines of inquiry (e.g., religion, philosophy)?

B 34. Sometimes people argue that 'scientists are searching for truth.' What do you think about this statement?

B 35. Where does scientific knowledge come from?

B 36. Scientists perform experiments/investigations when trying to find answers to the questions they put forth. Do scientists use their creativity and imagination during their investigations?

B 37. What role does evidence play in learning science?

B 38. Who gives the current generation of scientists the 'new' knowledge?

B 39. How would you define an experiment? Does the development of scientific knowledge require experiments? Is there a difference between experiments and research in science?

B 40. After scientists have developed a scientific theory (e.g., atomic theory, evolution theory), does the theory ever change? If you believe that scientific theories do change, why do we bother to learn scientific theories?

B 41. Are the contents of science textbooks believable? How certain are scientists about the knowledge in science textbooks?

B 42. Scientists have formulated several different hypotheses to explain the extinction of dinosaurs. How are different conclusions possible if scientists have access to and use the same set of data to derive their conclusions?

B 43. Are there any constraints in teaching 1031 labs? If so, what are they?

B 44. If you had to restructure your laboratory structure and design, what are some of the things that you may want to change, and why?

APPENDIX C: VIDEO STIMULATED RECALL INTERVIEW PROTOCOL

<u>Nature of Knowledge Questions</u>

C 1. What is your definition of knowledge?

C 2. Do you believe that there are different types of knowledge? If so what are they?

C 3. Do you think that your definition of knowledge fits your teaching style, strategies used, and how you relate to or interact with your students?

C 4. What type of learner are you? Do you promote that type of learning in your laboratory?

<u>Questions about Laboratory Instruction (Pre-VSR)</u>

C 5. Describe what do you think about your laboratory lesson as a whole?

C 6. What kinds of things did you take into consideration when planning this lesson?

C 7. What were the most important ideas or concepts that you wanted students to learn during this lesson?

C 8. What were your goals for this lesson?

C 9. Do you think your students learned the biology concept(s) as you intended? Explain your answer?

C 10. How did you decide what questions to ask your students?

C 11. Can you give me an example of how evidence was emphasized in your lesson?

C 12. What approach or strategy would you say that you used to teach about ______________? Why did you choose this approach or strategy to help students learn about ____________?

C 13. How did you decide how much time to spend on the lecture or discussing/explaining, asking questions, and on activities/exercises?

C 14. Why do you go over the quiz and take questions about the quiz and homework during the beginning of the laboratory?

Questions about Laboratory Instruction (During VSR)

C 15. How did you consider, gauge, or keep track of your students' understanding during that laboratory lesson?

C 16. Why did you choose to do this specific activity (___________) with your students? How did you decide how much time to spend on this activity?

C 17. Why did you decide to allow the students to work alone not share their ideas with the rest of the class? What were the factors influencing your decision in this case?

C 18. Please briefly describe what you and your students are doing in this video.

Questions about Laboratory Instruction (Post-VSR)

C 19. You worked one-on-one a lot during this lesson, why did you choose to do so versus bringing the entire class in on questions posed by students?

C 20. Would you modify your laboratory lesson on ____________ if you were to teach it again? If no, why? If yes, please explain.

APPENDIX D: CLASSROOM OBSERVATION PROTOCOL

Title of Laboratory Lesson

Objective(s) of Laboratory Lesson:

Observation Objectives:

Time	Observation	Significance

Conclusions:

Questions for video stimulated recall interview:

APPENDIX E: INSTITUTIONAL REVIEW BOARD APPROVAL

IRB
INSTITUTIONAL REVIEW BOARD
Office of Research Compliance,
010A Sam Ingram Building,
2269 Middle Tennessee Blvd
Murfreesboro, TN 37129

MIDDLE TENNESSEE STATE UNIVERSITY

IRBN001 - EXPEDITED PROTOCOL APPROVAL NOTICE

Thursday, January 03, 2019

Principal Investigator	**Velta Napoleon Fanis** (Student)
Faculty Advisor	Cindi Smith-Walters
Co-Investigators	Joshua Reid
Investigator Email(s)	vm2f@mtmail.mtsu.edu; cindi.smith-walters@mtsu.edu; jwr4k@mtmail.mtsu.edu
Department	Mathematics and Science Education & Biology
Protocol Title	***Exploring biology graduate teaching assistants' epistemological beliefs and the relationship to instructional practices and context: A complex system***
Protocol ID	**19-2093**

Dear Investigator(s),

The above identified research proposal has been reviewed by the MTSU Institutional Review Board (IRB) through the **EXPEDITED** mechanism under 45 CFR 46.110 and 21 CFR 56.110 within the category *(7) Research on individual or group characteristics or behavior.* A summary of the IRB action and other particulars in regard to this protocol application is tabulated below:

IRB Action	**APPROVED for ONE YEAR**		
Date of Expiration	**12/31/2019**	Date of Approval	1/2/19
Sample Size	10 (TEN)		
Participant Pool	Primary Classification: **Healthy Adults (18 years and older)** Specific Classification: **MTSU Biology Students**		
Exceptions	Video and voice recording of the participants are permitted		
Restrictions	**1. Mandatory signed informed consent; the participants must have access to an official copy of the informed consent document signed by the PI.** **2. Data must be deidentified once processed.** **3. Identifiable data must be destroyed as described in the protocol.** **4. Any identifiable data/artifacts that include photographs, video/audio data and handwriting samples must be used only for research purpose and must be destroyed after data processing.**		
Comments	NONE		

This protocol can be continued for up to THREE years (**12/31/2021**) by obtaining a continuation approval prior to **12/31/2019**. Refer to the following schedule to plan your annual project reports and be aware that you may not receive a separate reminder to complete your continuing reviews. Failure in obtaining an approval for continuation will automatically result in cancellation of this protocol. Moreover, the completion of this study MUST be notified to the Office of Compliance by filing a final report in order to close-out the protocol.

Post-approval Actions

The investigator(s) indicated in this notification should read and abide by all of the post-approval conditions imposed with this approval. Refer to the post- approval guidelines posted in the MTSU IRB's website. Any unanticipated harms to participants or adverse events must be reported to the Office of Compliance at (615) 494-8918 within 48 hours of the incident. Amendments to this protocol must be approved by the IRB. Inclusion of new researchers must also be approved by the Office of Compliance before they begin to work on the project.

Continuing Review (**Follow the Schedule Below:**)

Submit an annual report to request continuing review by the deadline indicated below and please be aware that **REMINDERS WILL NOT BE SENT.**

Reporting Period	Requisition Deadline	IRB Comments
First year report	11/30/2019	PI requested to end the protocol by June, 2019. If not renewed, this protocol will automatically close on the date mentioned in page 1.
Second year report	11/30/2020	NOT COMPLETED
Final report	11/30/2021	NOT COMPLETED

Post-approval Protocol Amendments:

Only two procedural amendment requests will be entertained per year. *In addition, the researchers can request amendments during continuing review. This amendment restriction does not apply to minor changes such as language usage and addition/removal of research personnel. .*

Date	Amendment(s)	IRB Comments
NONE	NONE.	NONE

Other Post-approval Actions:

Date	IRB Action(s)	IRB Comments
NONE	NONE.	NONE

Mandatory Data Storage Requirement: All of the research-related records, which include signed consent forms, investigator information and other documents related to the study, must be retained by the PI or the faculty advisor (if the PI is a student) at the secure location mentioned in the protocol application. The data storage must be maintained for at least three (3) years after study has been closed. Subsequent to closing the protocol, the researcher may destroy the data in a manner that maintains confidentiality and anonymity.

IRB reserves the right to modify, change or cancel the terms of this letter without prior notice. Be advised that IRB also reserves the right to inspect or audit your records if needed.

Sincerely,

Institutional Review Board
Middle Tennessee State University

Quick Links:

Click here for a detailed list of the post-approval responsibilities.
More information on expedited procedures can be found here.