ABSTRACT

CHAPMAN, LEEANNA TIFFANY YOUNG. Factors Affecting the Development and Evolution of the Teaching Beliefs of Future Geoscience Professors. (Under the direction of David McConnell).

The pedagogical beliefs of university instructors influence how they design their courses and whether they choose to use research-validated teaching methods that have been shown to improve student learning. The next generation of professors will be drawn from today's graduate students and post-doctoral fellows but we know relatively little about their preparation to use research-validated teaching practices. We followed a broad population of geoscience graduate students and post-docs over a three year period to evaluate changes in teaching beliefs.

This study employed a longitudinal mixed-methods experimental design including surveys, short interviews, and longer case study interviews to: a) collect information on the teaching beliefs of geoscience graduate students and post-doctoral scholars; and b) identify experiences that contributed to the development of reformed teaching beliefs and their interest in an academic career. We collected initial surveys from more than 600 participants and re-surveyed more than 300 of these participants 12-18 months later. We conducted an initial round of interviews with 61 participants and repeat interviews with 31 of these individuals. The survey utilized was the Beliefs about Reformed Teaching and Learning (BARSTL); the interview tool was the Teacher Belief Interview (TBI). Finally, we conducted detailed case study interviews with a sample of ten participants who were either PhD students, post-doctoral scholars, or beginning professors at the time of the interviews.

The data were examined to determine if there was a difference in beliefs about teaching on the basis of factors including number of years in graduate school, teaching assistant (TA) experiences, gender, and participation in professional development. Data from the large initial population were interpreted to show that participation in teaching-related professional development was the experience that was most likely to result in more reformed pedagogical beliefs among graduate students and post-doctoral fellows. Participants who took part in professional development experiences with a duration of a semester or longer exhibited the most reformed beliefs. In addition, females, PhD students and post-doctoral scholars, and participants with teaching assistant experience had statistically more reformed beliefs than their counterparts.

A second round of survey and data collected 12-18 months after the first data collection event revealed that participants who had completed teaching-related professional development in the interim were the only population to experience a statistically significant improvement toward more reformed teaching beliefs. Longer and more rigorous experiences such as pedagogy courses resulted in greater change toward more reformed beliefs

A grounded-theory approach was used to analyze case study interview transcripts and determine relevant themes that influenced teaching beliefs, interest in teaching, or interest in an academic career. The teaching beliefs of our geoscience graduate students and post-doctoral scholars were most strongly influenced by professional development and instructors who they have encountered during their academic experience, with both positive and negative consequences. Participants were most likely to want to teach because of their potential impact on students, their own student experience, and external encouragement. However, they also encountered instances of teaching discouragement. Graduate students and

post-doctoral scholars were interested in an academic career because of the impact they can have on students and because of the perceived flexibility and autonomy associated with such careers. To best prepare graduate students and post-docs for future careers in academia, effective professional development, positive mentoring, and opportunities to teach are crucial.

© Copyright 2017 LeeAnna Tiffany Young Chapman

All Rights Reserved

Factors Affecting the Development and Evolution of the Teaching Beliefs of Future Geoscience Professors

by
LeeAnna Tiffany Young Chapman

A dissertation submitted to the Graduate Faculty of
North Carolina State University
in partial fulfillment of the
requirements for the Degree of
Doctor of Philosophy

Marine, Earth, and Atmospheric Sciences

Raleigh, North Carolina

2017

APPROVED BY:

_____	_____
Dr. David McConnell Committee Chair	Dr. Stith Gower
_____	_____
Dr. Karen McNeal	Dr. John Nietfeld

DEDICATION

This dissertation is dedicated to my family. With your support, anything is possible.

BIOGRAPHY

LeeAnna Tiffany Young Chapman grew up in the small town of Vale, North Carolina. She graduated from West Lincoln High School in 2006. She received the Park Scholarship at NC State University where she graduated with a B.S. in Natural Resources-Ecosystems Assessment in 2010. LeeAnna worked for the Utilities Unit of NC Department of Transportation before returning to NC State for her graduate education. In the fall of 2011, she joined the Air Quality Forecasting Lab. She worked with Dr. Yang Zhang and Dr. Steve McNulty on a study modeling nitrogen mineralization to receive a M.S. in atmospheric science and a graduate minor in Geographic Information Systems. In the summer of 2013, LeeAnna joined Dr. David McConnell's Geoscience Learning Process Research Group.

ACKNOWLEDGMENTS

First, I have to acknowledge and thank my family. Nathan, I couldn't have done this without you. Your support and encouragement (no matter how crazy my idea may be) means the world to me. Mom and Dad, thanks for teaching me to believe that I can do anything. Daphne and Opie, thanks for your endless love and hugs!

A special thanks to my adviser, David McConnell. Thanks for believing in me and helping me grow as a researcher, scientist, instructor, and individual. You showed me that it's possible to love your job and helped me become more confident in all aspects of my life. I am also very appreciative of my other committee members: Karen McNeal, John Nietfeld, and Tom Gower for their guidance and suggestions along the way.

I am extremely thankful for the past and present members of the Geoscience Learning Process Research Group: Michael Pelch, Doug Czajka, Jason Jones, Laura Lukes, Katherine Ryker, April Grissom, Hayley Smith, and honorary member Rachel Atkins. Your support, encouragement, and friendship have made these four awesome years fly by. You made it possible to actually enjoy graduate school! A special shout out to Michael and Jason for being awesome officemates and to Michael and Doug for helping with many TBI co-codes. I would also like to thank the Science Education Research Center (SERC) and the National Science Foundation (NSF) for providing the financial support for my PhD work and for the valuable opportunity of working on InTeGrate.

Lastly, but certainly not least, I have to thank the 600+ participants of my study. This research was only possible because of your input. Thanks for putting up with and responding to what I’m sure felt like endless survey/interview requests.

TABLE OF CONTENTS

LIST OF TABLES x

LIST OF FIGURES xii

CHAPTER 1: Introduction 1

References 3

CHAPTER 2: Promoting the development of reformed pedagogical beliefs among future geoscience faculty: a mixed methods study 4

Abstract 4

Introduction 4

Background 6

Methods 8

Population 8

Instruments 10

Beliefs About Reformed Science Teaching and Learning (BARSTL) 10

Teacher Belief Interview (TBI) 12

Data Analysis 13

Results 14

BARSTL Results 14

TBI Results 21

Discussion 31

Conclusions 35

Limitations 35

Acknowledgements 36

References 37

CHAPTER 3: Tracking the evolution of teaching beliefs among future geoscience faculty 43

Abstract 43

Introduction 43

Background 44

Methods 45

Population 47

Instruments 47

Beliefs About Reformed Science Teaching and Learning (BARSTL) survey 47

Teacher Belief Interview (TBI) 48

Data Analysis 49

Results 50

BARSTL Survey Results 50

TBI Results 54

Discussion 60

Conclusions 62

Limitations 62

Acknowledgements 63

References 64

CHAPTER 4: What? When? How? Case studies exploring experiences motivating the development of reformed teaching beliefs among future geoscience faculty. 67

Abstract.....67

Introduction.....67

Purpose of this study.....69

Methods.....69

Participants.....72

Results: Emergent Themes.....74

Influences on wanting a career involving teaching 74

Influences on wanting to teach 77

Influences on teaching beliefs..... 81

Implications 85

Conclusions.....88

Limitations.....89

Acknowledgements 90

References.....91

APPENDICES..... 94

Appendix 1: Beliefs About Reformed Science Teaching and Learning (BARSTL) Survey.....95

Appendix 2: Additional survey questions included in the BARSTL survey 100

Appendix 3: Teacher Belief Interview (TBI) Questions.....102

Appendix 4: Teacher Belief Interview (TBI) Coding Maps.....103

Appendix 5: Case study interview questions 110

Appendix 6: Case Study Codebook 113

LIST OF TABLES

CHAPTER 1: Introduction

Table 1: Research questions guiding this study. 2

CHAPTER 2: Promoting the development of reformed pedagogical beliefs among future geoscience faculty: a mixed methods study

Table 1: TBI questions. 12

Table 2: BARSTL variables examined (PD = professional development). 16

Table 3: Average BARSTL scores by gender and type of Professional Development (PD) experience. 18

Table 4: Mean scores on the BARSTL sub-categories among low, medium and high scoring participants. 20

Table 5: TBI variables examined 27

Table 6: Average TBI scores by gender and type of Professional Development (PD) experience. 29

Table 7: Average TBI scores by question among low, medium and high scoring participants. 30

CHAPTER 3: Tracking the evolution of teaching beliefs among future geoscience faculty

Table 1: TBI questions 49

Table 2: BARSTL and TBI variables examined (PD = professional development) 52

Table 3: BARSTL score change by professional development (PD) type. 53

Table 4: TBI score change by professional development (PD) category 56

Table 5: Average population difference between TBI phase one and TBI phase two by question. 58

CHAPTER 4: What? When? How? Case studies exploring experiences motivating the development of reformed teaching beliefs among future geoscience faculty

Table 1: Description and scores of case study participants. 74

LIST OF FIGURES

CHAPTER 1: Introduction

Figure 1: Experimental design 1

CHAPTER 2: Promoting the development of reformed pedagogical beliefs among future geoscience faculty: a mixed methods study

Figure 1: Map indicates the geographical distribution of participants. Lighter colors represent a small number of participants from that state; red signifies states with greater than 20 participants. 9

Figure 2: Academic program (a) and institution type (b) of participants. “Research” institutions are doctoral-granting with high or very high research activity. “Doctoral” institutions have at least 20 doctorate degrees and low to moderate research activity. An institution is considered “international” regardless of classification if located outside the US. “Other” includes baccalaureate colleges, special focus institutions, and institutions not classified by the Carnegie Foundation for the Advancement of Teaching. 10

Figure 3: Distribution of BARSTL scores of the 607 participants. BARSTL scores were normally distributed with an average of 85 and standard deviation of 7. 15

Figure 4: BARSTL scores broken down by the duration of teaching-related professional development experiences. Participants who had participated in semester-long PD had an average BARSTL score of 89 followed by an average of 86 for participants with PD less than a semester long. Participants with no PD had an average BARSTL score of 84. 17

Figure 5: Average BARSTL scores broken down by gender. Females had a higher average BARSTL score of 86 versus males with an average of 84 ($p<0.001$; Cohen’s $d=0.29$). 18

Figure 6: Distribution of TBI scores for study participants (n=60). The average TBI score was 20 with a standard deviation of 3. 22

Figure 7: Histograms showing the distribution of interview codes for each TBI question. ... 24

Figure 8: TBI scores of participants categorized by teaching-related professional development. Participants who had participated in semester-long PD had an average TBI score of 22, followed by an average of 20 for participants with PD less than a semester long. Participants with no PD had an average TBI score of 19. 28

Figure 9: Average TBI scores of males versus females. Females had a higher average TBI score of 21 than males with an average of 19 (p=0.026; Cohen's d=0.59). 29

CHAPTER 3: Tracking the evolution of teaching beliefs among future geoscience faculty

Figure 1: Average BARSTL scores among all 607 phase one participants during phase one, 308 phase two participants during phase one, and 308 phase two participants during phase two (a); difference in phase one and phase two (phase two – phase one) BARSTL scores between phase two participants (b). 51

Figure 2: Average gain in BARSTL score from phase one to phase two by duration of professional development experience. Participants who took part in long-term PD experienced much higher BARSTL gains than those with shorter or no PD experiences. 54

Figure 3: Average TBI scores among all 61 phase one participants during phase one, 31 phase two participants during phase one, and 31 phase two participants during phase two (a); difference in phase one and phase two (phase two – phase one) BARSTL scores between phase two participants (b). 55

Figure 4: Difference in TBI score from phase one to phase two by duration of professional development. Participants who have taken part in long-term PD had a statistically significant higher TBI gain than participants with shorter or no PD. 57

CHAPTER 4: What? When? How? Case studies exploring experiences motivating the development of reformed teaching beliefs among future geoscience faculty

Figure 1: A: Phase one BARSTL scores of the entire study population (n=609); B: Phase two BARSTL scores (n=308); C: Phase one TBI scores of the entire study population (n=61); D: Phase two TBI scores (n=31). Arrows indicate score of each case study participant. 73

Figure 2: The differences between influences on the teaching beliefs of Thomas and Danielle model the differences between reformed and traditional participants, respectively. Percentages correspond with number of mentions of each influence during interview. Danielle's teaching beliefs are most influenced by professional development, observation, and discussion with colleagues while Thomas' teaching beliefs are most influenced by positive and negative influences of his instructors. 82

CHAPTER 1: Introduction

This work consists of a longitudinal mixed methods study encompassing three years and three phases (Figure 1). Phase one of the study used surveys and short interviews to characterize the teaching beliefs of more than 600 geoscience graduate students and post-doctoral scholars. Phase two repeated this process to determine change in teaching beliefs for more than 300 of the original participants twelve to eighteen months later. Phase one and phase two utilized the Beliefs About Reformed Science Teaching and Learning survey (BARSTL; Sampson, Enderle, & Grooms, 2013) and the Teacher Belief Interview (TBI; Luft & Roehrig, 2007). In phase three, ten participants were selected who participated in both prior phases. Phase three involved detailed case study interviews to determine what experiences lead participants to become interested in an academic career and contributed to the development of their teaching beliefs. Each chapter represents one phase of the study.

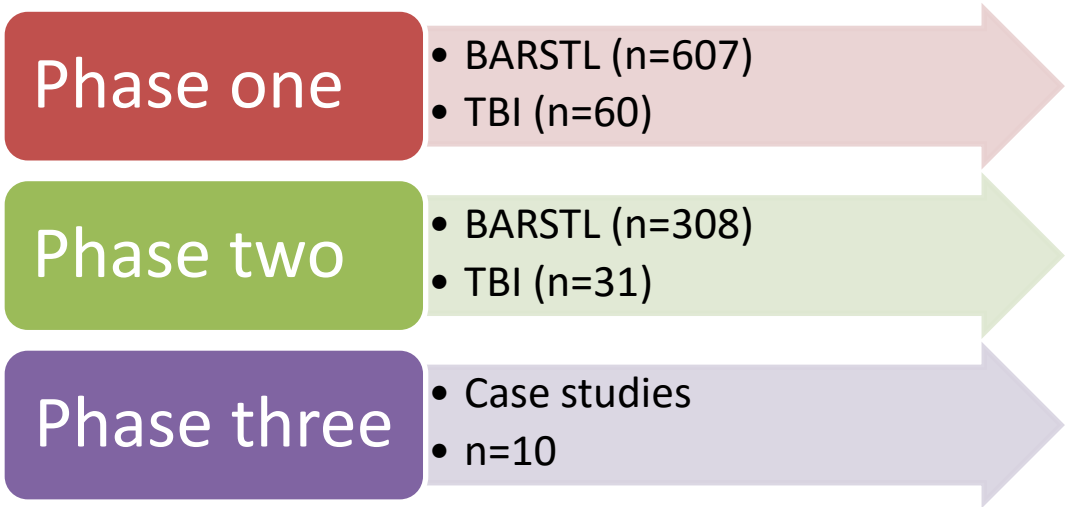


Figure 1: Experimental design

Table 1: Research questions guiding this study.

Phase	Research question 1	Research question 2	Research question 3
Phase 1	How do teaching beliefs vary among geoscience graduate students and post-docs?	What factors are most influential in promoting the development of student-centered teaching beliefs among graduate students and post-docs?	
Phase 2	To what degree did our populations' teaching beliefs shift toward a more reformed perspective during this time?	What experiences may have contributed to these changes?	
Phase 3	What led to participants' interest in an academic career?	How do participants with reformed and traditional teaching beliefs differ?	What experiences contributed to the development of reformed teaching beliefs?

References

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.

Sampson, V., Enderle, P., & Grooms, J. (2013). Development and Initial Validation of the Beliefs About Reformed Science Teaching and Learning (BARSTL) Questionnaire. *School Science and Mathematics*, *113*(1), 3–15.

CHAPTER 2: Promoting the development of reformed pedagogical beliefs among future geoscience faculty: a mixed methods study

Abstract

The next generation of professors will be drawn from today's graduate students and post-doctoral fellows but we know relatively little about their preparation to use research-validated teaching practices. This study characterizes the teaching beliefs of graduate students and post-doctoral fellows, the future geoscience instructors. We analyzed results from more than 600 participants who completed the Beliefs about Reformed Teaching and Learning (BARSTL) survey and a subpopulation of sixty participants who responded to the Teacher Belief Interview (TBI). We compared teaching beliefs on the basis of a range of factors including gender, teaching assistant experiences, and participation in professional development. Our results indicate the factor most likely to result in reformed pedagogical beliefs is participation in teaching-related professional development, especially longer more rigorous experiences.

Introduction

The next generation of professors will be drawn from the current population of graduate students and post-doctoral fellows (post-docs). A majority (57%) of PhD students stay in academia after graduation (Zolas et al., 2015) and approximately one out of every three STEM field PhDs will become a faculty member or instructor within six years of their degree (Pfund et al., 2012). Nearly two-thirds of doctoral students in arts and sciences are

primarily interested in a faculty career, but feel that they are not adequately prepared for some of the responsibilities a faculty job entails (Golde & Dore, 2001, 2004). Many current graduate students and post-docs may soon be teaching college courses, but most have minimal training in effective teaching practices as doctoral programs focus almost exclusively on research (Austin, 2010). The pedagogical beliefs of instructors impact how they design and structure their courses and whether they choose to use research-validated teaching methods that have been shown to improve student learning (Freeman et al., 2014; Woodbury & Gess-Newsome, 2002). Graduate students have opportunities to gain direct experience teaching as teaching assistants, to observe teaching practices in their own classes, to discuss the teaching experience with peers and mentors, and to participate in a variety of professional development programs. They are frequently confronted with opportunities to observe and participate in teaching. How do these experiences shape the teaching beliefs of potential future professors?

This study adopts a mixed-methods approach in order to characterize the teaching beliefs of geoscience graduate students and post-docs. Surveys (n=607) and interviews (n=60) were used to characterize the range of participants' teaching beliefs. The research questions guiding this study are: (1) How do teaching beliefs vary among geoscience graduate students and post-docs? (2) What factors are most influential in promoting the development of student-centered teaching beliefs among graduate students and post-docs?

Background

An instructor's teaching beliefs are one of the fundamental constructs that control changes in practice (Woodbury & Gess-Newsome, 2002). Teaching beliefs are tacit assumptions about course content and situational factors including student experiences and classroom settings and directly impact how knowledge is presented to students (Kagan, 1992). However, the teaching beliefs of university STEM faculty are often deeply engrained and resistant to change (Henderson & Dancy, 2007). In contrast, the pedagogical beliefs of graduate students and post-doctoral fellows are more malleable and are influenced by both professional and personal experiences (Southerland, Sowell, Blanchard, & Granger, 2010). New instructors rely on their own ideas about how students learn when deciding how to teach (Gess-Newsome et al., 2014). A substantial majority (83%) of respondents to a survey on doctoral education noted that the enjoyment of teaching motivated them to become faculty, and approximately half (51%) reported that they participated in a workshop or seminar on teaching in their discipline (Golde & Dore, 2001).

The adoption of research-validated, reformed instructional practices can contribute to improvements in student learning (e.g., Derting & Ebert-May, 2010; Freeman et al., 2011, 2014; Pollock & Finkelstein, 2008), increased retention rates (Russell et al., 2007), and a reduction in the achievement gap among different student populations (Eddy & Hogan, 2014; Haak et al., 2011). However, translating these practices to the classroom represents a high hurdle in higher education (Singer, et al., 2012). Despite a trend to a greater diversity of teaching approaches, approximately half of undergraduate teaching faculty continue to rely heavily on lecture in their courses (Eagan, et al., 2014) and the proportion of faculty using

extensive lecture is greater in STEM fields than in other disciplines (Hurtado et al., 2012). If future instructors are not trained in the implementation of research-validated teaching strategies, they will likely teach as they were taught (Halpern & Hakel, 2002).

Researchers face many challenges when investigating instructional beliefs. Classroom observations can be misleading and questions (written or oral) may not expose ideas that influence decision making (Yerushalmi, Henderson, Heller, Heller, & Kuo, 2007). Carefully designed interviews featuring open-ended questions permit deeper exploration of teaching practices and beliefs of instructors and allow unexpected issues to emerge (AAAS, 2012). Interviews have many advantages over surveys as they provide flexibility to ask follow-up questions, to identify new topics, to collect both qualitative and quantitative data, and to provide insight into the reasons behind participant's beliefs. Interviewing as a data collection method also has many challenges (AAAS, 2012) as interviews can be time and labor intensive (including design, delivery, and analysis) and may require training or experience to accurately collect and analyze responses. Further, interviews utilize self-report data from the interviewee which feature personal perceptions and may not accurately align with measurements or observations determined from other instruments (Frechtling, 2002). Because of these challenges, interviews are often used in research studies as an accompaniment to another instrument, such as a survey or observations. This study used a mixed-methods approach that combined survey data with results from a suite of interviews.

Methods

The primary goal of this research is to obtain a detailed understanding of the pedagogical beliefs of geoscience graduate students and post-doctoral fellows. An exploratory sequential design was employed, first using a survey to explore quantitative data and then using interviews to collect qualitative data to help explain the quantitative results in more depth. Data collection initially consisted of the Beliefs About Reformed Science Teaching and Learning (BARSTL) survey (Sampson, Enderle, & Grooms, 2013) and some demographic questions. This was followed by an interview protocol that included the Teacher Belief Interview questions (Luft & Roehrig, 2007) and additional questions to designed to collect information on participant experiences. Previous studies have utilized the BARSTL and TBI together to represent participants' pedagogical beliefs (Pelch & McConnell, 2016; Ryker, 2014). All participants completed the BARSTL and demographic survey, while a subset of 10 percent of the population were also interviewed using the TBI. TBI participants were chosen to represent the entire range of BARSTL survey scores. The Institutional Review Board for Research with Human Subjects approved all data collection procedures.

Population

Graduate students and post-docs in more than 150 geoscience departments or programs were emailed and invited to participate. Participants were recruited from the top ten geoscience degree granting institutions for four-year faculty (AGI, 2014) and top earth science schools as ranked by US News. To ensure a wide variety of respondents, graduate

students in at least one geoscience graduate program from each state in the US were invited to participate (Figure 1). Participants were also sought from the 2014 Preparing for an Academic Career in the Geosciences workshop (http://serc.carleton.edu/NAGTWorkshops/careerprep2014/index.html) and the 2014 Geological Society of America annual conference in an effort to obtain a diverse population.

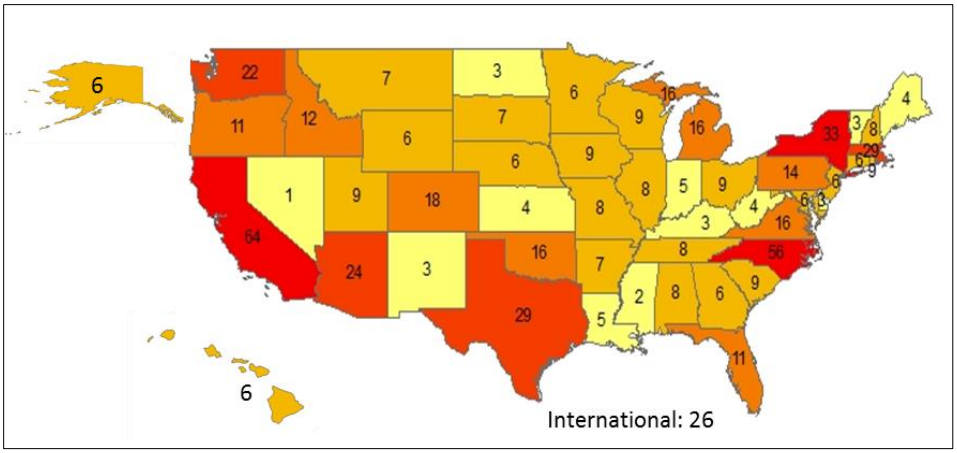


Figure 1: Map indicates the geographical distribution of participants. Lighter colors represent a small number of participants from that state; red signifies states with greater than 20 participants.

Respondents included 607 current masters students (n=211), PhD students (n=362), and post-doctoral fellows (n=34; Figure 2a) in numerous geoscience fields. Most study participants were associated with a research university (Figure 2b). Institutions were classified according to the Carnegie Classifications data file (Carnegie Foundation for the Advancement of Teaching, 2012).

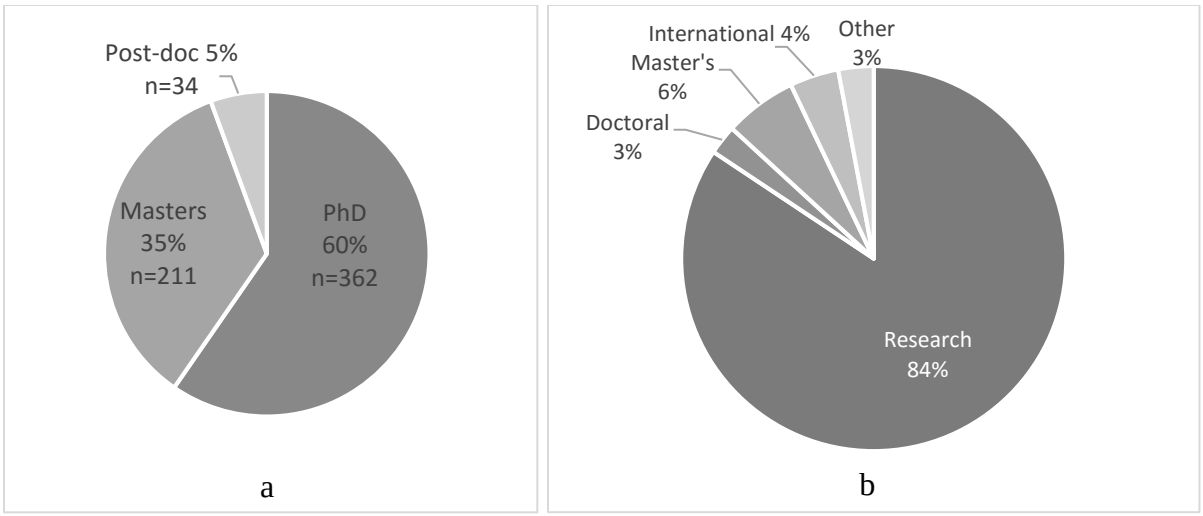


Figure 2: Academic program (a) and institution type (b) of participants. “Research” institutions are doctoral-granting with high or very high research activity. “Doctoral” institutions have at least 20 doctorate degrees and low to moderate research activity. An institution is considered “international” regardless of classification if located outside the US. “Other” includes baccalaureate colleges, special focus institutions, and institutions not classified by the Carnegie Foundation for the Advancement of Teaching.

Instruments

Beliefs About Reformed Science Teaching and Learning (BARSTL)

The BARSTL is a 32-item Likert-type self-report questionnaire designed to quantify an instructor’s pedagogical beliefs are relative to reformed-based teaching of science (Sampson et al., 2013). Participants indicate whether they strongly disagree, disagree, agree, or strongly agree with each item, represented by a statement. Half of the BARSTL statements are phrased from a traditional perspective and are reverse scored. Possible BARSTL scores range from 32 to 128 points, with higher scores reflecting more reformed, student-centered beliefs. The BARSTL has four sub-categories with eight statements each. The four sub-categories are:

1. How people learn about science
2. Lesson Design and Implementation
3. Characteristics of Teachers and the Learning Environment
4. Nature of the Science Curriculum

The BARSTL is a validated, reliable (α=0.77, p=0.001) survey tool (Sampson et al., 2013). We also calculated reliability for our use of the tool using Winsteps software. Winsteps calculates both item and person reliabilities using logit values. Analysis revealed a person reliability of 0.74 with person separation of 1.7 and item reliability of 1.0 with item separation of 21.5. These results indicate the BARSTL displays good internal reliability and construct validity and is an acceptable measurement instrument (Boone, Townsend, & Staver, 2011).

Following the survey, we also asked participants to answer some demographic questions to allow for comparison between groups. Demographic questions addressed the personal characteristics of participants (e.g., gender, race), their academic experience (e.g., prior degrees, current academic status), their participation in professional development, and their experience as a teaching assistant. An additional question asked participants if they were willing to participate in a follow up interview about their teaching beliefs. The subset of participants who were interviewed using the TBI were chosen from those who indicated "yes" on this question.

Teacher Belief Interview (TBI)

The TBI (Luft & Roehrig, 2007) is a semi-structured interview with coding maps designed to capture the epistemological beliefs of participants. The TBI consists of seven focused questions pertaining to teaching and learning (Table 1). The TBI shows a strong significant correlation with classroom observations of teaching practice (Ryker et al., 2013). Only PhD students and post-docs were invited to participate in interviews. All interviews were conducted by the first author, were recorded and transcribed using an online transcription service, and were coded using the protocol outlined by Luft and Roehrig (2007). One quarter of the interviews were co-coded with an independent colleague not involved in the research to assess research reliability. Inter-rater reliability analysis found a Cohen's Kappa value of 0.90 between raters which qualifies as "almost perfect agreement" (Viera & Garrett, 2005). Due to strong agreement, the remaining interviews were coded by the first author alone.

Table 1: TBI questions.

1. How do you describe your role as a teacher?
2. How do you know when your students understand a concept in class?
3. How do you decide when to move on to a new topic in your class?
4. In your class, how do you decide what to teach or what not to teach?
5. How do your students learn science best?
6. How do you know when learning is occurring in your classroom?
7. How do you maximize learning in your classroom?

Each answer to the seven questions was individually coded on a five point scale (1: traditional, 2: instructional, 3: transitional, 4: responsive, 5: reformed). Traditional and instructive responses are considered to represent instructor-centered views, the idea that science is a series of facts and rules. Transitional responses indicate that science is objective, consistent, and connected. Responsive and reformed responses are considered to represent student-centered teaching beliefs, where science is seen to be dynamic and integrated within social and cultural constructs. Possible TBI scores range from 7 to 35, with a maximum score of 35 representing the most reformed pedagogical beliefs.

Data Analysis

BARSTL and TBI scores were analyzed to determine the average and range of participants' teaching beliefs. The quantitative data generated by the BARSTL and TBI were analyzed by Stata. Data satisfied all parametric assumptions including normal distribution and homogeneity of variance. Independent t-tests were used to determine whether there was a statistically significant difference in BARSTL and TBI scores between participants on the basis of factors such as number of years in graduate school, academic status (master's, PhD, post-doc), gender, ethnicity, race, and citizenship. Scores were also compared between participants who noted they have been a teaching assistant or had participated in professional development opportunities related to teaching. One-way ANOVAs were performed to check for type I error. ANOVA results agree with t-test results, therefore we present t-test results.

Results

BARSTL Results

Based on visual inspection of the BARSTL quantile-quantile (Q-Q) plot, data are normally distributed. A kurtosis value of 3.33 with a skewness value of 0.36 also support the assumption of a normal distribution. The average BARSTL score of the 607 participants was 85.33, with a minimum of 61 and maximum of 115 and standard deviation of 7.38 (Figure 3). Using the outlier labeling rule and g-factor described in Hoaglin and Iglewicz (1987), one outlier value was detected. First level winsorization (0.16% winsorized) was used for this outlier (Dixon & Massey Jr., 1969) because the parameters for trimming were not met according to Hawkins (1980). Winsorization had minimal impact on data. BARSTL mean and standard deviation decreased slightly to 85.32 and 7.33 respectively. Kurtosis and skewness values also slightly decreased to 3.11 and 0.31 respectively, indicating a more normal distribution. The winsorized BARSTL scores were used for analysis.

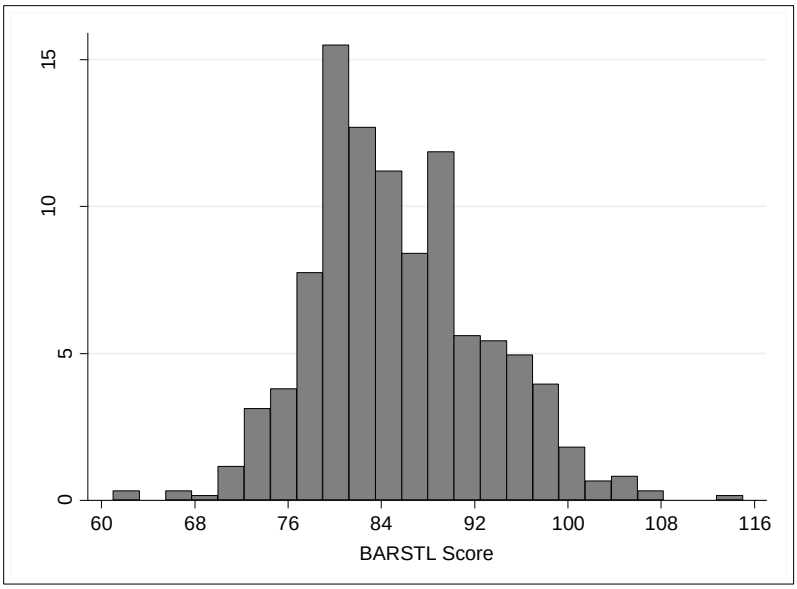


Figure 3: Distribution of BARSTL scores of the 607 participants. BARSTL scores were normally distributed with an average of 85 and standard deviation of 7.

We examined the relationship between BARSTL scores and several demographic variables (Table 2). Most demographic variables did not significantly influence BARSTL scores. The type of institution participants attended as classified by the Carnegie Foundation was not statistically significant, nor was there a statistically significant difference in scores due to race, ethnicity, citizenship, US versus international institution, PhD versus post-doc, undergraduate degree of Bachelors of Science versus Bachelors of Arts, or number of years in graduate school (Table 2). However, we did see contrasts in BARSTL scores on the basis of professional development, gender, teaching assistant experience, and graduate student rank (Table 2).

Table 2: BARSTL variables examined (PD = professional development).

Variable	***p*-value**	**Cohen's *d***
Semester long PD vs no PD	<0.001	0.61
Semester long PD vs any PD	0.006	0.36
Any PD vs no PD	<0.001	0.47
Gender	<0.001	0.29
TA experience	0.009	0.29
PhD vs master's students	0.004	0.24
PhD vs post-docs	0.13	0.27
Race	0.50	0.08
Ethnicity	0.39	0.17
Citizenship	0.98	0.002
Institution type	0.34	0.11
Years in graduate school	0.053	0.16
BS vs BA	0.54	0.19
US vs international institution	0.19	0.27

Participation in any professional development related to teaching beyond a required teaching assistant orientation session was statistically significant ($p<0.001$) with a medium effect size (Cohen's $d=0.47$). Participation in teaching-related professional development had the greatest effect of any researched variable on BARSTL score. Participants who had not engaged in teaching-related professional development (PD) had a BARSTL average of 84 (Figure 4) in comparison to an average of 87 for participants with any PD experience. The duration of the professional development experience was also statistically significant with a moderate effect size. Participants claiming semester-long PD had a higher BARSTL average

of 89 compared with an average of 86 of those with PD less than a semester long (Figure 4; p=0.006; Cohen's d=0.36).

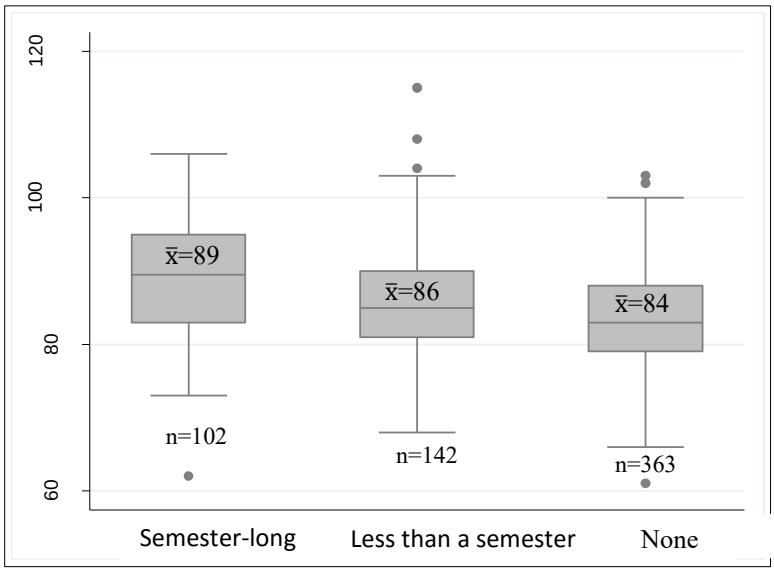


Figure 4: BARSTL scores broken down by the duration of teaching-related professional development experiences. Participants who had participated in semester-long PD had an average BARSTL score of 89 followed by an average of 86 for participants with PD less than a semester long. Participants with no PD had an average BARSTL score of 84.

After participation in professional development, the next most significant variable on BARSTL score was gender, which had a small effect size (Table 2; p<0.001; Cohen's d=0.29). Female participants averaged statistically higher BARSTL scores (86) than males (84; Figure 5). A larger proportion of female participants (19.8%) had completed semester-long PD experiences than male participants (13.4%). However, females scored higher than males on every PD category (Table 3). In addition, we conducted a two-way ANOVA to

check for interaction effects between professional development type and gender. There were no statistically significant interaction effects between gender and PD type (p=0.1052)

Table 3: Average BARSTL scores by gender and type of Professional Development (PD) experience.

	No PD	**Single-day PD**	**Multi-day PD**	**Semester PD**
Female	84 (n=199)	88 (n=36)	87 (n=37)	90 (n=67)
Male	83 (n=164)	86 (n=39)	83 (n=29)	87 (n=36)

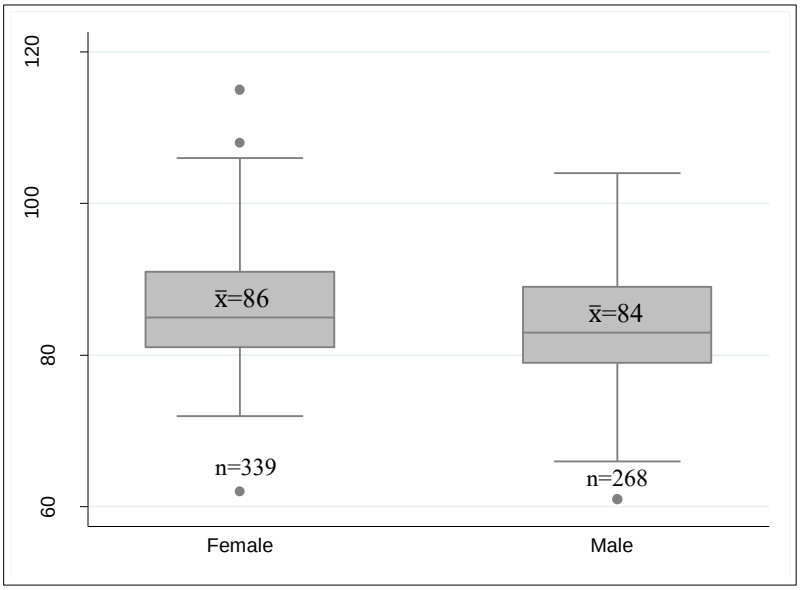


Figure 5: Average BARSTL scores broken down by gender. Females had a higher average BARSTL score of 86 versus males with an average of 84 (p<0.001; Cohen's d=0.29).

Experience as a teaching assistant also has a statistically significant effect on BARSTL score (p=0.009), with a small effect size (Cohen's d=0.29). Participants who have been a teaching assistant or instructor at least once had a higher average BARSTL score of 86 versus the non-teaching assistant average of 84. PhD students had a statistically significant (p=0.004) higher BARSTL average of 86 than master's students' average of 84, with a small effect size (Cohen's d=0.24; Table 2). BARSTL scores of PhD students and post-docs showed no statistical difference (Table 2) and will be considered together as a single population hereafter as PhD students.

Participants scored similarly on the four BARSTL sub-categories (Table 4). There is a statistically significant difference (p<0.0001, Cohen's d=0.35) between the lowest scoring section (Part 1: How people learn about science, $\bar{x}$=21.05) and the highest scoring section (Part 3: Characteristics of teachers and the learning environment, $\bar{x}$=21.92). In an effort to further examine the differences between the lowest-scoring and highest-scoring participants, we grouped participants into lowest 20% (most instructor-centered), middle 20%, and highest 20% (most student-centered) for both the BARSTL and TBI. We then looked at the averages and most common response for these groups for each statement (Table 4).

Table 4: Mean scores on the BARSTL sub-categories among low, medium and high scoring participants.

BARSTL Sub-category	Population Mean	Standard deviation	Mean of lowest 20%	Mean of middle 20%	Mean of highest 20%
Part 1: How people learn about science	21.05	2.44	18.86	21.22	23.58
Part 2: Lesson design and implementation	21.11	2.91	18.19	21.20	24.48
Part 3: Characteristics of teachers and the learning environment	21.92	2.61	19.33	21.86	24.88
Part 4: Nature of the science curriculum	21.25	2.25	19.58	21.06	23.38

BARSTL statements 13, 16, and 31 differed the most between the most instructor-centered group and the most student-centered group. The largest discrepancy between the groups occurred in item 31: "Students should learn that all science is based on a single scientific method—a step-by-step procedure that begins with 'define the problem' and ends with 'reporting the results.'" This is a reverse-scored item in which disagree corresponds with a reformed view. During data analysis, reverse-scored statements are transformed so that a reformed answer corresponds to a high score on the item (i.e., "1: strongly disagree" on this item is converted to "4"). The most reformed individuals choose "disagree" or "strongly disagree" " (reversed $\bar{x}$=3.23) while the most traditional group choose "agree" or "strongly agree" (reversed $\bar{x}$=2.02). The difference in responses between reformed and traditional groups was most obvious in BARSTL section 2: Lesson design and implementation (Table 4). Two statements in this section had large discrepancies between groups. On item 13, "Lessons should be designed in a way that allows students to learn new concepts through

inquiry instead of through a lecture, a reading, or a demonstration," the most reformed 20% responded with mostly "strongly agree," ($\bar{x}$=3.50) while the most traditional 20% responded with "disagree" or "agree" ($\bar{x}$=2.48). Item 16: "Assessments in science classes should only be given after instruction is completed; that way, the teacher can determine if the students have learned the material covered in class" also showed significant variation between groups. This statement is reverse-scored, in which "strongly agree" would score a "1." The reformed group responded with "disagree" and "strongly disagree" (reversed $\bar{x}$=3.21) while the traditional group responded with mainly "agree" (reversed $\bar{x}$=2.18).

TBI Results

Based on visual inspection of the TBI quantile-quantile (Q-Q) plot, data are normally distributed. A kurtosis value of 2.3 with a skewness value of -0.29 also support the assumption of a normal distribution. Using the outlier labeling rule and g-factor described in Hoaglin and Iglewicz (1987), there are no outliers. TBI scores of this population (n=60) range from 12 to 25 with an average of 19.9 and standard deviation of 3.3 (Figure 6). Results show TBI scores cluster around 16 and 22.

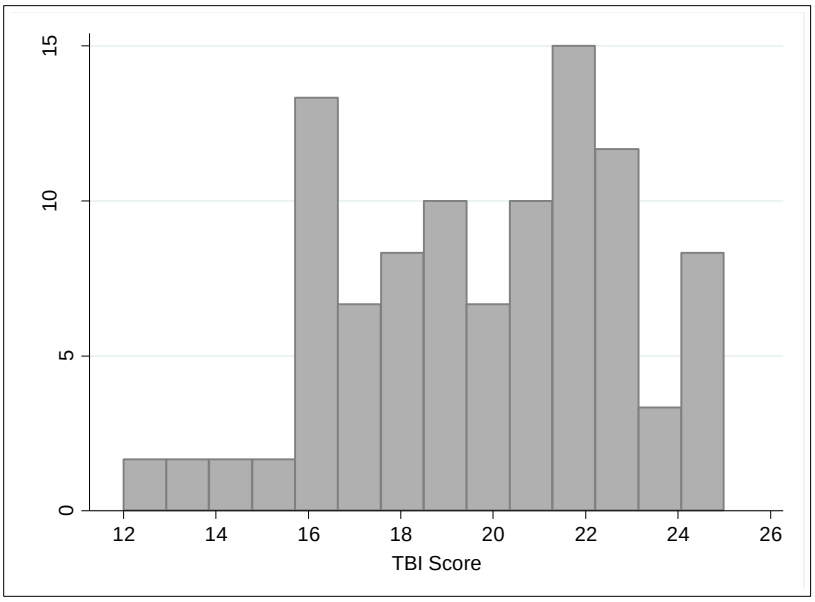


Figure 6: Distribution of TBI scores for study participants (n=60). The average TBI score was 20 with a standard deviation of 3.

The lowest TBI score was 12, with the individual responding with a either traditional or instructive responses on each question. The highest TBI score was 25, with individual question responses coding as transitional, responsive, or reformed. Responses to the question "How do your students learn science best?" highlight the difference between these extremes. Jacob (all names used are pseudonyms), the individual with the most traditional teaching beliefs responded "From a teacher who is well organized and presents material in a logical organized manner and especially from homework assignments." Emily, a more reformed participant, responded "I think it just depends on the students. I think it's very individual. I think a mixture of all things. Just being told stuff isn't enough. They need to be able to do an activity and get involved and get them thinking about it themselves. Think about it rather

than just telling them. And also working as a group I think is a very big help in terms of learning."

The average TBI score on each of the seven questions varied from 2.1 to 3.4 (Figure 7). Most individuals coded as transitional when responding to "How do you describe your role as a teacher?" (Figure 7a). Kelly felt that her role as a teacher was to "Help guide students through kind of new areas of knowledge and experience" (transitional). "How do you know when your students understand a concept in class" earned a majority of instructive responses (Figure 7b). Many participants' responses were similar to Kate's "When they can explain it back to you or explain it back to somebody else in their own words."

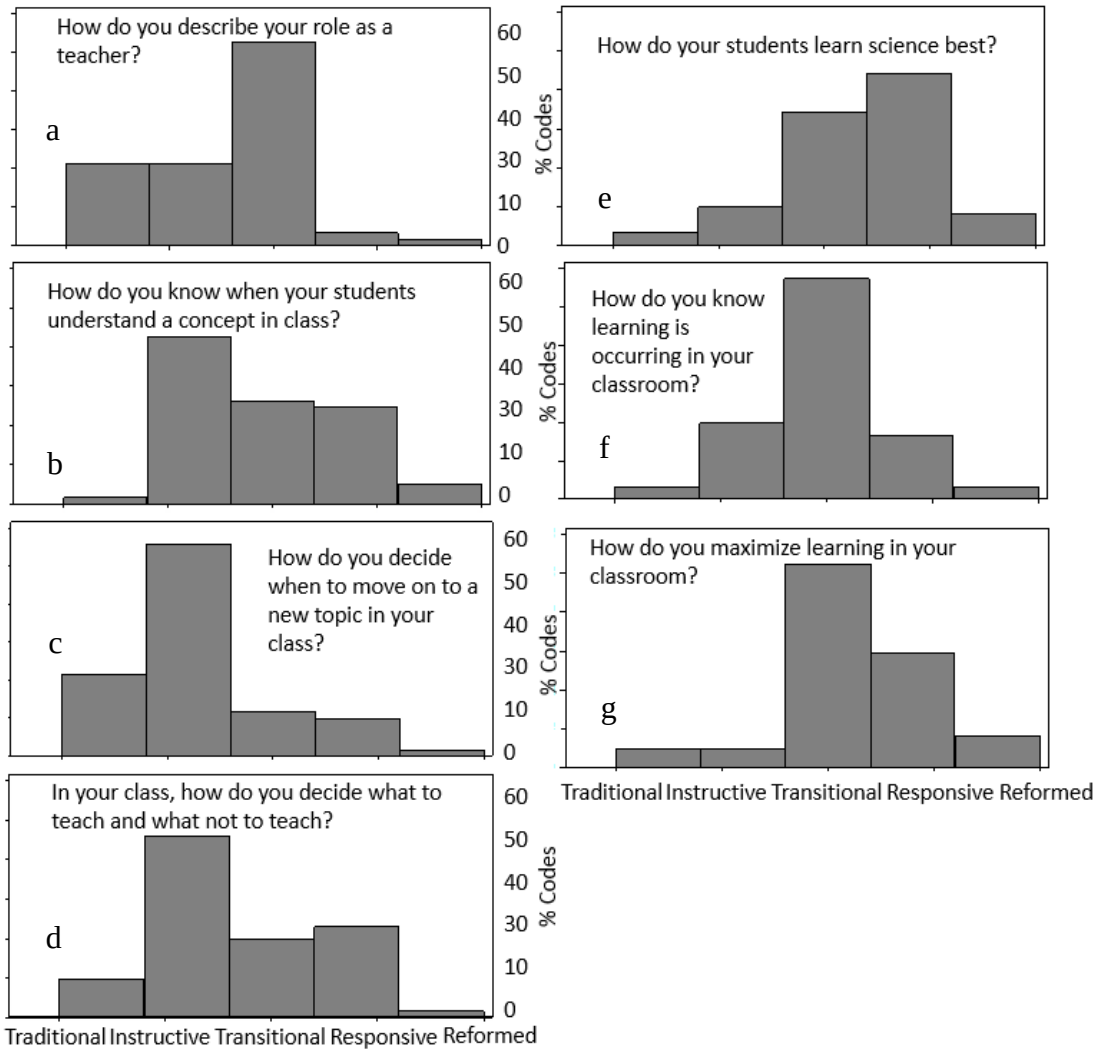


Figure 7: Histograms showing the distribution of interview codes for each TBI question.

The TBI question that participants scored lowest on was "How do you decide when to move on to a new topic in your class?" The low score was primarily due to a lack of control and contemplation of this decision. Many individuals coded as instructive by mentioning assigning quizzes or homework to determine student understanding before moving to a new topic (Figure 7c). Some individuals mentioned being required to follow the syllabus or

follow the direction of their supervisor, resulting in a traditional code. Ethan mentioned "Well, as a teaching associate doing lab work, I don't really have much of a choice for the most part, and that's largely just determined, like, you get this subject this week and another subject next week." Other participants such as Ava mentioned a pre-determined syllabus and time constraints, "Well, I think the biggest constraint is just time. We plan out the syllabus and we had a goal for each day and it was like the decision was made before any student walked into the room."

Lack of classroom control also commonly appeared in the question "How do you decide what to teach or what not to teach?" John mentioned, "As a TA I've only really taught what was assigned to me to teach. It's whatever is required by the instructor" (traditional). The majority of responses coded as instructive to this question (Figure 7d), mentioning that they teach concepts they're interested in or think the students need to know.

Participants scored the highest on the question "How do your students learn science best," with most participants coding either transitional (3) or responsive (4). Many participants mentioned that students learn science best by "doing it," earning a transitional code. For example, Todd noted "So I think the hands-on aspect is important, and I think watching somebody do science, whether it's deriving things on chalkboard, whiteboard, watching a lab experiment, and then doing it as a homework assignment or a lab exercise is really important to get the knowledge." Other responses referenced that students learn best by applying their knowledge or by discussion with their peers, which codes as responsive (Figure 7e).

"How do you know learning is occurring in your classroom" resulted in mostly transitional responses (Figure 7f). Participants often mentioned they could tell learning was occurring by subjective conclusions such as "the looks on their faces" or by the level of activity in the classroom. Mike mentioned "People asking interested and informed questions is a good sign of learning. When I had complete silence I was most worried. That was not a good sign of learning." The question "How do you maximize learning in your classroom" also had a majority of transitional responses (Figure 6g), with participants mainly mentioning the importance of including multiple types of activities. Renea mentioned "I maximize learning by I think spending a lot of time, um, in class doing actual activities and stuff where students are actively involved" and Ben agreed by stating "I do different ways of presenting the material."

Only two variables had a statistically significant impact on TBI score: professional development and gender (Table 5). Participation in professional development related to teaching had the greatest effect on TBI score with a large effect size (p=0.035; Cohen's d=0.72). Individuals who had participated in any teaching-related PD had a TBI average of 21 compared with an average 19 for individuals with no PD experience (Figure 8). Again, we examined the duration of the professional development experience. Semester-long (or longer) PD experiences resulted in a statistically significant difference on TBI score compared to no PD experience with a large effect size (p=0.004, Cohen's d=1.04). Participants with semester-long PD experiences had a higher TBI average of 22, while participants with no PD experience had an average of 18 (Table 5). Participants with these semester-long PD

experiences also had a statistically significantly higher TBI score relative to participants with any PD experiences (p=0.035, Cohen's d=0.72). Participants with PD experiences shorter than a semester had an average of 20 compared to the semester-long PD experience average of 22 (Table 5). Semester long experiences included discipline-based education research graduate courses, Center for the Integration of Research, Teaching, and Learning (CIRTL) courses, graduate courses in education departments, and teaching certifications.

Table 5: TBI variables examined

Variable	***p*-value**	**Cohen's *d***
Semester long PD vs no PD	0.004	1.00
Semester long PD vs any PD	0.035	0.72
Any PD vs no PD	0.015	0.67
Gender	0.026	0.59
TA experience	0.650	0.17
PhD vs post-docs	0.125	0.56
Race	0.814	0.08
Ethnicity	0.933	0.04
Citizenship	0.065	0.61
Institution type	0.691	0.21
Years in graduate school	0.327	0.31
BS vs BA	0.167	0.47

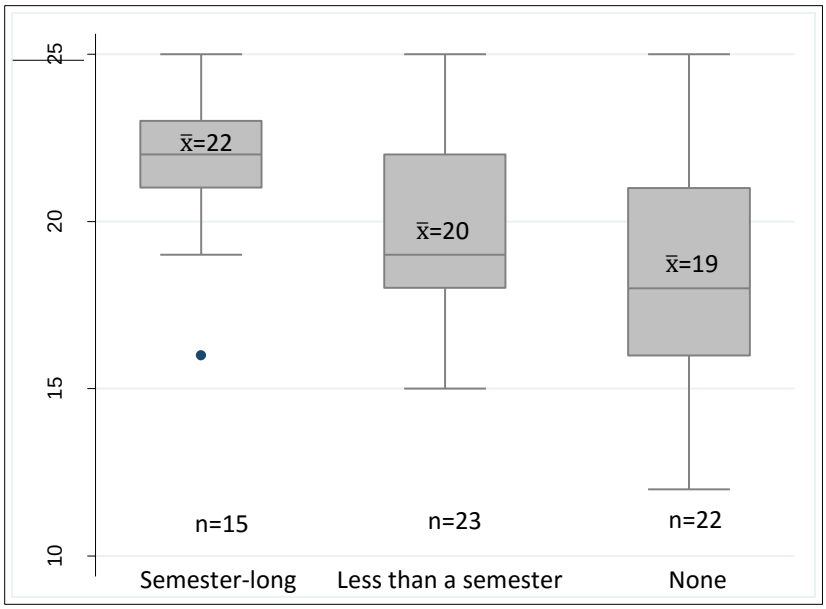


Figure 8: TBI scores of participants categorized by teaching-related professional development. Participants who had participated in semester-long PD had an average TBI score of 22, followed by an average of 20 for participants with PD less than a semester long. Participants with no PD had an average TBI score of 19.

The other variable with a statistically significant impact on TBI score was gender (p<0.026; Cohen's d=0.59). There was a statistically significant difference between females with an average TBI score of 21 and males with an average of 19 (Figure 9). Most of this contrast arose from differences in scores by gender among participants who had either no PD experience or who had participated in single-day PD (Table 6).

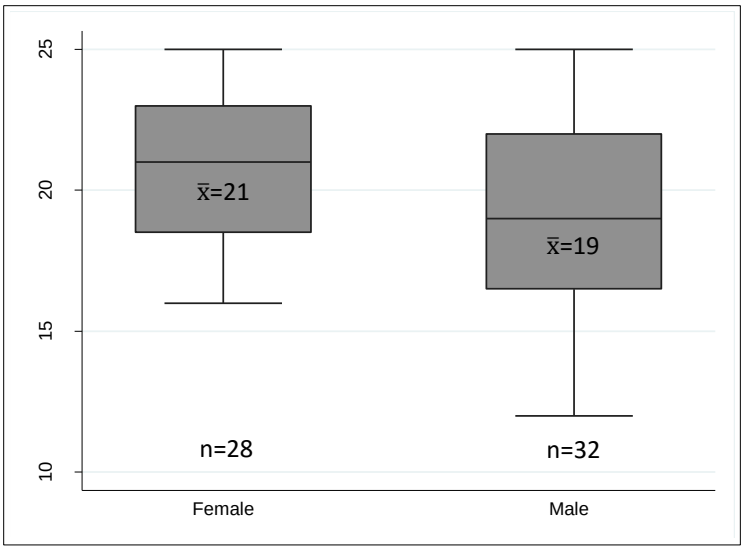


Figure 9: Average TBI scores of males versus females. Females had a higher average TBI score of 21 than males with an average of 19 (p=0.026; Cohen's d=0.59).

Table 6: Average TBI scores by gender and type of Professional Development (PD) experience.

	No PD	**Single-day PD**	**Multi-day PD**	**Semester PD**
Female	20 (n=10)	23 (n=1)	20 (n=6)	22 (n=11)
Male	17 (n=12)	18 (n=5)	20 (n=10)	22 (n=5)

Other variables were also examined for their effect on TBI score and were not found to be statistically significant (Table 5). Unlike the BARSTL, experience as a teaching assistant showed no statistically significant difference. Comparable to the BARSTL, the type of institution, race, ethnicity, citizenship, BS versus BA, or number of years in graduate school were not statistically significant.

We also grouped participants into bins of lowest 20% (most instructor-centered), middle 20%, and highest 20% (most student-centered) scores for the TBI. Two questions showed a large discrepancy between the lowest and highest scoring groups. In response to "How do you describe your role as a teacher" most in the high scoring group responded transitionally, while the majority in the low-scoring group responded with a traditional response (Figure 7; Table 7). Differences also arose in response to "How do you know learning is occurring in your classroom?" Almost everyone in the low-scoring group scored instructive, while the high-scoring group had transitional and responsive statements (Figure 7; Table 7).

Table 7: Average TBI scores by question among low, medium and high scoring participants.

TBI Question	**Population Mean**	**Standard deviation**	**Mean of lowest 20%**	**Mean of middle 20%**	**Mean of highest 20%**
How do you describe your role as a teacher?	2.45	0.91	1.58	2.50	3.0
How do you know when your students understand a concept in class?	2.88	0.98	2.17	2.75	3.42
How do you decide when to move on to a new topic in your class?	2.15	0.94	1.5	1.83	2.83
In your class, how do you decide what to teach and what not to teach?	2.62	1.01	2.33	2.75	3.58
How do your students learn science best?	3.48	0.85	2.83	3.50	3.92
How do you know learning is occurring in your classroom?	2.98	0.79	2.17	3.08	3.58
How do you maximize learning in your classroom?	3.3	0.89	2.58	3.42	3.67

Discussion

The primary goals of this research are to describe and explain the variation in pedagogical beliefs among geoscience graduate students and post-doctoral fellows. In this population, teaching beliefs ranged widely from traditional instructor-centered beliefs to reformed student-centered beliefs. Results from both self-report survey and interview data reveal that teaching-related professional development is the most influential factor shaping teaching beliefs. Students who have participated in semester long teaching-related professional development had higher BARSTL and TBI scores than those with little to no professional development. Emma, a graduate student who has taken a semester long course in teaching and learning in the geosciences responded to the TBI question "How do you maximize student learning in your classroom?" with "It's having them work together… explaining the concepts to their peers… a student working with other students who maybe have taken different classes and have a different background can be really helpful, actively talking about the material at hand." In contrast, Noah, a graduate student with no teaching-related professional development answered with a much more instructor-centered response, "It's to shift responsibility for learning onto the student in the sense for making a space for a lot of information to be presented." These examples highlight a substantial difference in teaching beliefs. While a single seminar or workshop may influence teaching beliefs and ultimately practice, results show that longer experiences are more likely to result in change. Actively participating in a semester-long or longer professional development experience is most likely to impact teaching beliefs. Many institutions have options for long-duration professional development, including teaching certifications through a teaching and learning

center, participation with CIRTL, or appropriate courses in the education department. Elsewhere, departments or colleges with a focus on discipline-based education research may offer courses that specifically address research on teaching and learning in college science classes.

The second most influential variable on teaching beliefs was gender. More females participated in the original BARSTL survey (56% female) and females were more likely to participate in long-term professional development (Table 3). However, female participants' higher scores in BARSTL and TBI cannot be attributed to a larger proportion of the population participating in semester-long PD. Females averaged higher scores than males on every PD category. Our results echo findings of Norton et al. (2005) who noted that female instructors at higher education intuitions in the United Kingdom were more likely to consider teaching as learner facilitation while males more often considered teaching as knowledge transmission. Regardless of experience, academic discipline, or institution, female instructors had statistically higher scores on problem solving, interactive teaching, and facilitative teaching, while men obtained higher scores on imparting information (Norton et al., 2005). Female participants' higher TBI and BARSTL scores may reflect differences in underlying beliefs about teaching on the basis of gender so that female instructors view their roles in more student-oriented terms than males.

While participant scores were relatively consistent among different sections of the BARSTL survey, participants scored lowest on the section about how people learn about science. In this section, a traditional perspective is that learning is accumulation of

information while a reformed perspective believes learning is the modification of existing ideas (Sampson et al., 2013). Consequently, while professional development programs may address a variety of pedagogical topics, we suggest that program leaders may wish to provide participants with access to research literature about how science is best learned (e.g., Singer et al., 2012).

The greatest contrast between low and high scoring participants on the BARSTL involve items dealing with lesson design. This may indicate the lack of experience graduate students and post-docs have in this area. Participants may have more reformed views on statements involving learning because they can think about how they themselves learn best. This finding indicates that it may be helpful for professional development programs to focus on effective lesson design and providing participants an outlet for sample lesson planning and piloting. On the TBI, the variation between low and high scoring participants was most pronounced on questions about the role of a teacher and when learning is occurring. It may be useful for programs to highlight effective teaching roles, such as mediating student prior knowledge and focusing on collaboration rather than simply delivering information. Low-scoring participants often mentioned that they knew learning was occurring due to exam or homework grades, while a more reformed view is that learning is occurring when students initiate discussions with their peers and the instructor. While it is likely that participants in this study lack experience observing student learning in a formal setting, PD can help by providing participants with literature discussing reformed practices linked to improved student performance.

This work is one of the first to study the teaching beliefs of geoscience graduate students and post-docs. The BARSTL and TBI have been infrequently employed to study the teaching beliefs of current science faculty. Howard (2014) utilized the BARSTL to study the teaching beliefs of 81 community college science faculty. The average BARSTL score of the community college instructors was 84.4 with a range from 70 to 105. Geoscience graduate students and post-docs in our study have similar teaching beliefs to this population ($\bar{x}$=85.3).

The TBI has been used previously to examine the teaching beliefs of geoscience faculty and can be used to compare our potential future faculty to current faculty. The average TBI score for a population of 17 geoscience faculty prior to attending a multi-day professional development workshop was 17.9, with a range from 11 to 23 (Czajka & McConnell, 2015). Pelch & McConnell (2016) assessed the teaching beliefs of 21 faculty who participated in a 2-year long materials development program. The pre-material development TBI average of this population was 25.8 with a range from 15 to 32 (Pelch & McConnell, 2016). The TBI average of the 60 graduate students and post-docs was 19.9 with a range of 12 to 25. These results indicate that the teaching beliefs of graduate students and post-docs overlap with current faculty. Our population has similar pedagogical beliefs to faculty attending a teaching workshop but lower average values than faculty authoring teaching materials. Attending semester-long professional development further closes the gap between current faculty authoring materials ($\bar{x}$=25.8) and future faculty who have taken part in significant professional development experiences ($\bar{x}$=21.8). These findings indicate that graduate students who have participated in professional development can begin their careers

as new faculty with reformed teaching beliefs at least on par with those of more experienced faculty.

Conclusions

Participation in long-term teaching-related professional development is the experience that is most likely to result in more student-centered, reformed pedagogical beliefs among graduate students and post-doctoral fellows. This finding indicates a need for more robust pedagogical training procedures for graduate students who aim for academic careers featuring teaching. Participants who have taken part in professional development experiences with a duration of a semester or longer exhibited the most reformed beliefs. While seminars and short workshops may be the most accessible way to experience professional development, graduate students and post-docs interested in an academic career that involves teaching should be encouraged to participate in longer experiences. Characterizing teaching beliefs represents an initial step toward determining the most effective method for developing reformed teaching beliefs and practices. The next step is to determine what specific types of experiences result in a shift toward more reformed beliefs.

Limitations

Results in this study are limited due to the non-random method participants were chosen. We attempted to have wide representation of geoscience graduate students and post-doctoral scholars, but there may be selection bias. Our survey response rate was

approximately 5-10 percent. Low response rates are typical of surveys, but may result in a lack of representation of all groups.

In addition, the BARSTL and TBI were not developed and validated for this population. The BARSTL was originally designed and validated for K-12 teachers, while the TBI was originally designed and validated for secondary science teachers. These tools were selected because the investigators feel that the items on both tools were applicable to graduate students and post-doctoral scholars and thus provided an accurate estimation of their pedagogical beliefs.

Acknowledgements

This research was approved by the North Carolina State University Institutional Review Board (IRB #3999).

References

AAAS. (2012). *Describing & Measuring Undergraduate STEM Teaching Practices*.

AGI. (2014). Ranking and Top 10 Degree Granting Institutions for Four-Year University Faculty. *Geoscience Currents*, (88).

Austin, A. E. (2010). Reform efforts in STEM doctoral education: Strengthening preparation for scholarly careers. In *Higher education: Handbook of theory and research* (pp. 91–128). Springer.

Boone, W. J., Townsend, J. S., & Staver, J. (2011). Using Rasch theory to guide the practice of survey development and survey data analysis in science education and to inform science reform efforts: An exemplar utilizing STEBI self-efficacy data. *Science Education*, *95*(2), 258–280.

Carnegie Foundation for the Advancement of Teaching. (2012). *Carnegie Classifications Data File*.

Czajka, C. D., & McConnell, D. A. (2015). Evaluating the Teaching Beliefs and Practices of Geoscience Faculty. *Geol. Soc. Am. Abst. with Prog.*, *47*(7), 254.

Derting, T., & Ebert-May, D. (2010). Learner-centered inquiry in undergraduate biology: positive relationships with long-term student achievement. *CBE-Life Sciences Education*, *9*, 462–472.

Dixon, W. J., & Massey Jr., F. J. (1969). *Introduction to statistical analysis* (3rd ed.). New York: McGraw-Hill Book Co.

Eagan, K., Stolzenberg, E. B., Lozano, J. B., Aragon, M. C., Suchard, M. R., & Hurtado, S. (2014). *Undergraduate Teaching Faculty: The 2013-2014 HERI faculty Survey*.

Eddy, S. L., & Hogan, K. A. (2014). Getting under the hood: How and for whom does increasing course structure work? *CBE Life Sciences Education*, *13*(3), 453–468.

Frechtling, J. (2002). *The 2002 User-Friendly Handbook for Project Evaluation*. *The 2002 User-Friendly Handbook for Project Evaluation*.

Freeman, S., Eddy, S., 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*(23), 8410–8415.

Freeman, S., Haak, D., & Wenderoth, M. P. (2011). Increased course structure improves performance in introductory biology. *CBE Life Sciences Education*, *10*(2), 175–186.

Gess-Newsome, A. J., Southerland, S. A., Johnston, A., Woodbury, S., & Gess-newsome, J. (2014). Educational Reform , Personal Practical Theories , and Dissatisfaction : The Anatomy of Change in College Science Teaching. *American Educational Research Journal*, *40*(3), 731–767.

Golde, C. M., & Dore, T. M. (2001a). At Cross Purposes: What the Experiences of Today's Doctoral Students Reveal about Doctoral Education. *Pew Charitable Trusts*, *January*, 1–15.

Golde, C. M., & Dore, T. M. (2001b). *At Cross Purposes: What the Experiences of Today's*

Doctoral Students Reveal about Doctoral Education. (Vol. January).

Golde, C. M., & Dore, T. M. (2004). The survey of doctoral education and career preparation: The importance of disciplinary contexts. In *Paths to the professoriate: Strategies for enriching the preparation of future faculty* (pp. 19–45). Jossey-Bass San Francisco, CA.

Haak, D. C., HilleRisLambers, J., Pitre, E., & Freeman, S. (2011). Increased Structure and Active Learning Reduce the Achievement Gap in Introductory Biology. *Science*, *332*(6034), 1213–1216.

Halpern, D. F., & Hakel, M. D. (2002). Learning That Lasts a Lifetime: Teaching for Long-Term Retention and Transfer. *New Directions for Teaching and Learning*, *2002*(89), 3–7.

Hawkins, D. M. (1980). *Identification of outliers* (11th ed.). London: Springer.

Henderson, C., & Dancy, M. (2007). Barriers to the use of research-based instructional strategies: The influence of both individual and situational characteristics. *Physical Review Special Topics - Physics Education Research*, *3*(2), 20102.

Hoaglin, D. C., & Iglewicz, B. (1987). Fine-tuning some resistant rules for outlier labeling. *Journal of the American Statistical Association*, *82*(400), 1147–1149.

Howard, M. C. (2014). *A Study of the Teaching Beliefs of the Modern Post Secondary Science Instructor and Implications They May Hold for the Future of Science Education*. University of Southern Mississippi.

Hurtado, S., Eagan, M. K., Pryor, J. H., Whang, H., & Tran, S. (2012). *Undergraduate teaching faculty: The 2010–2011 HERI Faculty Survey*. Los Angeles: Higher Education Research Institute, UCLA.

Kagan, D. (1992). Implications of Research on Teacher Belief. *Educational Psychologist*, *27*(1), 65–90.

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.

Norton, L., Richardson, T. E., Hartley, J., Newstead, S., & Mayes, J. (2005). Teachers' beliefs and intentions concerning teaching in higher education. *Higher Education*, *50*(4), 537–571.

Pelch, M. A., & McConnell, D. A. (2016). Challenging instructors to change: a mixed methods investigation on the effects of material development on the pedagogical beliefs of geoscience instructors. *International Journal of STEM Education*, *3*(5).

Pfund, C., Mathieu, R., Austin, A., Connolly, M., Manske, B., & Moore, K. (2012). Advancing STEM Undergraduate Learning: Preparing the Nation's Future Faculty. *Change: The Magazine of Higher Learning*, *44*(6), 64–72.

Pollock, S. J., & Finkelstein, N. D. (2008). Sustaining educational reforms in introductory physics. *Physical Review Special Topics - Physics Education Research*, *4*(1), 1–8.

Russell, S. H., Hancock, M. P., & McCullough, J. (2007). Benefits of undergraduate research

experiences. *Science*, *316*, 548–549.

Ryker, K. (2014). *An Evaluation of Classroom Practices, Inquiry and Teaching Beliefs in Introductory Geoscience Classrooms*. North Carolina State University.

Ryker, K., McConnell, D., Bruckner, M. Z., Iverson, E., & Manduca, C. (2013). Teaching is believing: pedagogical beliefs, practices, and professional development. *Geol. Soc. Am. Abst. with Prog.*, *45*(7), 470.

Sampson, V., Enderle, P., & Grooms, J. (2013). Development and Initial Validation of the Beliefs About Reformed Science Teaching and Learning (BARSTL) Questionnaire. *School Science and Mathematics*, *113*(1), 3–15.

Singer, S. R., Nielsen, N. R., & Schweingruber, H. A. (Ed.). (2012). *Discipline-based education research: Understanding and improving learning in undergraduate science and engineering*. National Academies Press.

Southerland, S. A., Sowell, S., Blanchard, M., & Granger, E. M. (2010). Exploring the Construct of Pedagogical Discontentment: A Tool to Understand Science Teachers' Openness to Reform. *Research in Science Education*, *41*(3), 299–317.

Viera, A. J., & Garrett, J. M. (2005). Understanding Interobserver Agreement: The Kappa Statistic. *Family Medicine*, *37*(5), 360–363.

Woodbury, S., & Gess-Newsome, J. (2002). Overcoming the Paradox of Change without Difference: A Model of Change in the Arena of Fundamental School Reform. *Educational Policy*, *16*(5), 763–782.

Yerushalmi, E., Henderson, C., Heller, K., Heller, P., & Kuo, V. (2007). Physics faculty beliefs and values about the teaching and learning of problem solving. I. Mapping the common core. *Physical Review Special Topics - Physics Education Research*, *3*(2), 1–31.

Zolas, N., Goldschlag, N., Jarmin, R., Stephan, P., Owen-smith, J., Rosen, R. F., & Allen, B. M. (2015). Wrapping it up in a person: Examining employment and earnings outcomes for Ph.D. recipients. *Science*, *350*(6266).

CHAPTER 3: Tracking the evolution of teaching beliefs among future geoscience faculty

Abstract

Tomorrow's professors will be drawn from today's graduate students and post-docs. The pedagogical beliefs of instructors impact how they design their courses and whether they choose to use research-validated teaching methods that have been shown to improve student learning. We employed a longitudinal mixed-methods experimental design including both a survey and follow up interview to collect information on experiences that contributed to changes in the teaching beliefs of a group of geoscience graduate students and post-doctoral scholars over approximately 18 months. We collected pre- and post-surveys from more than 300 participants and conducted concurrent interviews with 31 of these individuals. Results indicate that participation in teaching-related professional development produces a statistically significant (p=0.01) impact on participants' teaching beliefs, with long-term experiences producing the greatest change.

Introduction

More than half (57%) of PhD students in all disciplines remain in academia after graduation (Zolas et al., 2015) and a large proportion will be responsible for teaching college courses. The pedagogical beliefs of instructors impact how they design their courses and whether they choose to use research-validated teaching methods proven to improve student learning (Woodbury & Gess-Newsome, 2002).

We sought to investigate the evolution of teaching beliefs among geoscience graduate students and post-doctoral scholars (post-docs) to determine what types of experiences lead to the development of reformed teaching beliefs. We used a longitudinal mixed-methods research design that included repeated surveys (n=308) and interviews (n=31) to characterize participants' teaching beliefs at the beginning and end of a 12-18 month period. The research questions guiding this study were: (1) To what degree did our populations' teaching beliefs shift toward a more reformed perspective during this time? (2) What experiences may have contributed to these changes?

Background

Discipline-based education research demonstrates that reformed, student-centered teaching practices help improve learning among STEM students (Freeman et al., 2014; Handelsman, Miller, & Pfund, 2004; Singer, Nielsen, & Schweingruber, 2012) reduce the achievement gap (Eddy & Hogan, 2014; Haak et al., 2011), and increase retention rates (Russell, Hancock, & McCullough, 2007). Reformed teaching practices provide opportunities for students to monitor their understanding of concepts during class by completing activities, responding to questions or engaging in discussions. These tasks typically involve students participating in the social construction of knowledge through peer interaction and individual, group or whole-class discussion with the instructor (Teasdale et al., 2017). In contrast, traditional teacher-centered methods primarily involve lecture and

information transmission from the “expert” instructor to the “novice” students (Singer et al., 2012).

An instructor’s teaching beliefs directly impact how knowledge is presented to students (Kagan, 1992) and are one of the fundamental constructs that control changes in practice (Woodbury & Gess-Newsome, 2002). Teaching beliefs have a significant correlation with classroom observations of teaching practice (Ryker et al., 2013). The teaching beliefs of faculty are often deeply engrained and resistant to change (Henderson & Dancy, 2007). However, the teaching beliefs of graduate students are evolving and may be more malleable and easier to influence through personal and professional experiences (Southerland, Sowell, Blanchard, & Granger, 2010). A majority of PhD students are motivated to become faculty due to their enjoyment of teaching (Golde & Dore, 2004), suggesting this population is open to adopting strategies that will result in positive changes of their teaching techniques. However, without some form of intervention, these new instructors are likely to teach as they were taught (Halpern & Hakel, 2002), leading approximately half of undergraduate teaching faculty to rely heavily on lecture (Eagan, et al., 2014).

Methods

The work described here is the second phase of a longitudinal study. This research follows a broad population of geoscience graduate students and post-docs over a 12-18 month period to evaluate changes in teaching beliefs and to determine the significance of experiences such as participation in professional development, experience as a teaching

assistant, or progression further into their graduate program. We employed a longitudinal mixed-methods experimental design consisting of the Beliefs About Reformed Science Teaching and Learning (BARSTL) survey (Sampson, Enderle, & Grooms, 2013), demographic questions, and an interview using the Teacher Belief Interview protocol (TBI; Luft & Roehrig, 2007).

The mixed-methods approach of this study involves quantitative measures (BARSTL) to obtain a broad look into the beliefs of hundreds of participants and qualitative responses (TBI) to provide deeper exploration of participants' teaching beliefs. In phase one during fall 2014 and spring 2015, 609 geoscience graduate students and post-docs from various institutions completed the BARSTL survey along with a suite of demographic questions (Chapman & McConnell, 2016). To further investigate the pedagogical beliefs of this population, a representative sample of ten percent of the initial population (n=60) were interviewed during phase one using the TBI, a semi-structured interview with coding maps designed to capture the epistemological beliefs of teachers (Luft & Roehrig, 2007). In phase two, twelve to 18 months after taking the initial survey (spring 2016), we asked participants to re-take the BARSTL and TBI to observe any change in the teaching beliefs of the population. More than half (308) of previous participants completed the BARSTL a second time and 31 representative individuals were re-interviewed using the TBI (52% of original population).

Population

Our population for phase two includes 308 master's students, PhD students, and post-docs from over 100 institutions across the United States and five international institutions. The majority (58%) of participants were PhD students at the time of the second round of data collection. Master's students comprised 15% of the population, 13% were post-docs, and 14% were no longer students. From phase one to phase two, 30% of our populations' academic status changed: 16% completed their master's, PhD, or post-doc program, 8% progressed from PhD to post-doc, 5% progressed from a master's to a PhD program, and 1% left their program. 15 of these individuals were hired as assistant professors or instructors.

Instruments

Beliefs About Reformed Science Teaching and Learning (BARSTL) survey

The BARSTL survey is a Likert-type self-report questionnaire designed to determine how aligned an instructor's pedagogical beliefs are to reformed-based teaching of science (Sampson et al., 2013). Participants indicate whether they strongly disagree, disagree, agree, or strongly agree to 32 statements divided among four sub-categories: 1: How people learn about science; 2: Lesson Design and Implementation; 3: Characteristics of Teachers and the Learning Environment; and 4: Nature of the Science Curriculum. Sixteen of the thirty-two BARSTL statements are traditionally-phrased and are reverse scored. Possible BARSTL scores range from 32 to 128 points, with higher scores reflecting more reformed, student-centered beliefs. The BARSTL is a validated, reliable (α=0.77, p=0.001) survey tool (Sampson et al., 2013).

Following completion of the BARSTL survey, we asked participants to complete a short demographic questionnaire to allow for comparison between groups. Demographic questions included personal characteristics of participants (e.g., gender, race), their academic experience (e.g., prior degrees, current academic status), their participation in professional development, and experience as a teaching assistant. In addition, participants were asked if they were willing to participate in a follow up interview about their teaching beliefs. The subset of participants who were interviewed using the TBI were chosen from those who indicated "yes" on this question.

Teacher Belief Interview (TBI)

The TBI (Luft & Roehrig, 2007) is a semi-structured interview with coding maps designed to capture instructors' beliefs about teaching and learning. The TBI consists of seven focused questions pertaining to teaching and learning (Table 1). Each answer to the seven questions is individually coded on a five point scale (1: traditional, 2: instructional, 3: transitional, 4: responsive, 5: reformed) using coding maps as a guide (Luft & Roehrig, 2007). Traditional responses emphasize the delivery of information; instructive answers focus on experiences provided by the teacher; transitional comments indicate interactions between students and the instructor; responsive statements stress student collaboration and feedback; and reformed responses emphasize student opportunities to monitor and reflect on their learning (Luft & Roehrig, 2007). Possible TBI scores range from 7 to 35, with a maximum score of 35 representing the most reformed pedagogical beliefs.

All interviews were conducted via phone by the first author, were recorded and transcribed using an online transcription service, and were coded using the protocol outlined by Luft and Roehrig (2007). One third of the interviews were co-coded by with an independent colleague not involved in the research to assess research reliability. Inter-rater reliability analysis found a weighted Cohen's Kappa value of 0.89 between raters which qualifies as "almost perfect agreement" (Viera & Garrett, 2005). Due to strong agreement, the remaining interviews were coded by the first author alone.

Table 1: TBI questions

1. How do you describe your role as a teacher?
2. How do you know when your students understand a concept in class?
3. How do you decide when to move on to a new topic in your class?
4. In your class, how do you decide what to teach or what not to teach?
5. How do your students learn science best?
6. How do you know when learning is occurring in your classroom?
7. How do you maximize learning in your classroom?

Data Analysis

Phase one and phase two data were compared to determine statistically significant change in participants' pedagogical beliefs. The quantitative data generated by the BARSTL and TBI were analyzed by Stata. Data satisfied all parametric assumptions including normal distribution and homogeneity of variance. Paired sample t-tests were used to determine

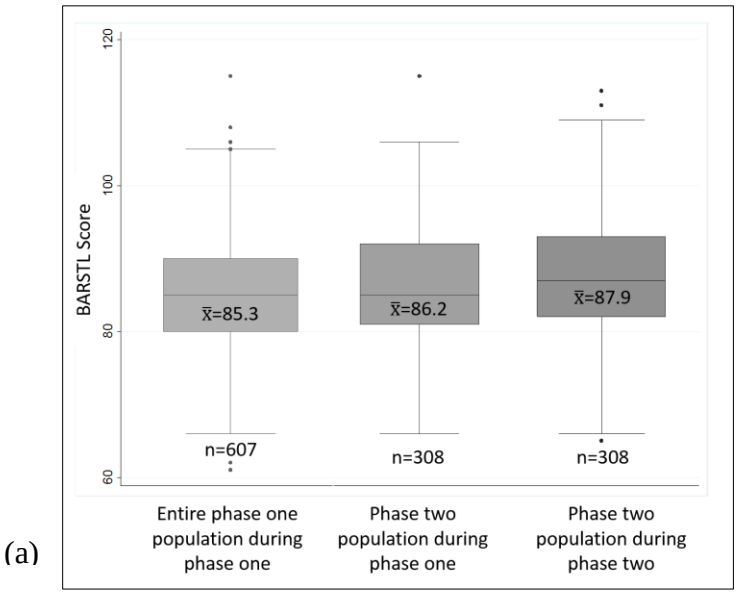
whether there was a statistically significant difference in BARSTL and TBI scores between phase one and phase two on the basis of factors such as participation in professional development opportunities related to teaching, experience as a teaching assistant, number of years in graduate school, academic status (master's, PhD, post-doc), gender, ethnicity, race, and citizenship. One-way ANOVAs were performed to check for type I error. ANOVA results agree with t-test results, therefore we present t-test results.

Results

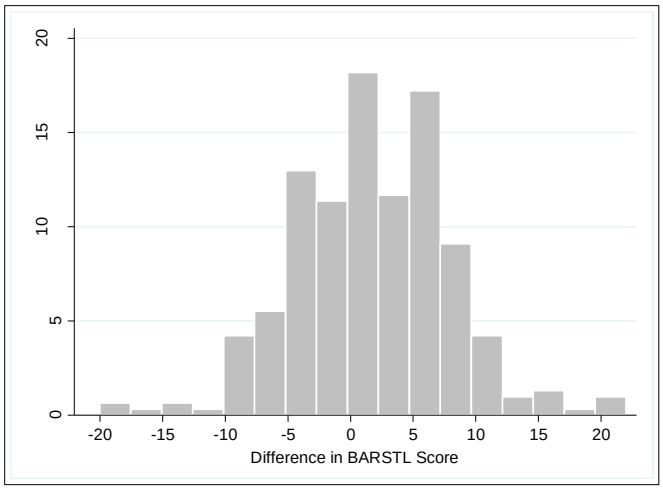
BARSTL Survey Results

The average phase one BARSTL score of the 308 participants who participated in both phases was 86.2 with a 49 point range (Figure 1a). The phase two BARSTL score of this population was 87.9 with a 48 point range (Figure 1a). This 1.74 increase in the mean BARSTL score of the population was a statistically significant gain with a small effect size ($p<0.001$; Cohen's $d=0.21$). This finding indicates that participants' teaching beliefs became slightly more student centered over the study period. We used the difference in BARSTL score from phase one to phase two (BARSTL difference) as our comparison variable (Figure 1b). Based on visual inspection of the BARSTL difference quantile-quantile (Q-Q) plot, data are normally distributed. A kurtosis value of 3.81 with a skewness value of -0.04 also support the assumption of a normal distribution. The minimum BARSTL difference was -20 (participant scored 20 points lower in phase two than phase one), maximum was 22 (participant scored 22 points higher in phase two than phase one), and standard deviation was

6.36 (Figure 1b). Using the outlier labeling rule and g-factor described in Hoaglin and Iglewicz (1987), no outlier values were detected.



(a)



(b)

Figure 1: Average BARSTL scores among all 607 phase one participants during phase one, 308 phase two participants during phase one, and 308 phase two participants during phase two (a); difference in phase one and phase two (phase two – phase one) BARSTL scores between phase two participants (b).

To determine what influenced BARSTL score change between phases, we examined the BARSTL score difference and several demographic variables. Only items related to professional development (PD) correlated with increases in BARSTL scores (Table *2* 2). Participation in any PD related to teaching beyond a required teaching assistant orientation session was statistically significant (p=0.001) with a medium effect size (Cohen's d=0.39). Participants who had taken part in any teaching-related PD had a statistically higher average BARSTL gain of 3.3 compared to 0.9 of those with no PD.

Table 2: BARSTL and TBI variables examined (PD = professional development).

Variable	**BARSTL *p*-value**	**BARSTL Cohen's *d***	**TBI *p*-value**	**TBI Cohen's *d***
Any PD	0.001	0.39	0.32	0.20
Gender	0.97	0.14	0.21	0.48
Teaching assistant experience	0.23	0.29	0.50	0.25
PhD vs master's students	0.77	0.05	-	-
PhD vs post-docs	0.87	0.03	0.58	0.22
Race	0.14	0.28	0.39	0.47
Ethnicity	0.85	0.06	-	-
Citizenship	0.26	0.18	0.44	0.34
US vs international institution	0.86	0.07	-	-

We further examined the impact of PD on BARSTL difference by duration of the PD experience. Generally, the longer the PD experience, the more impact it had on BARSTL score (Table 3; Figure 2). Participants with no PD showed a statistically significant BARSTL gain of 0.9 points, though the effect size is very small (Cohen's d=0.12), indicating little

practical significance. Participants (n=78) who took part in a short-term PD experience over the study period such as a seminar or workshop experienced a statistically significant increase of 2.3 points in their average BARSTL score (p=0.007; Cohen's d=0.27). Participants with long-term PD such as a semester long teaching methods course had a statistically significant average BARSTL gain of 5.7 with a large effect size (p=0.0002; Cohen's d=0.67).

Table 3: BARSTL score change by professional development (PD) type.

Variable	BARSTL phase one	BARSTL phase two	BARSTL *p*-value	BARSTL Cohen's *d*
Participants with no PD (n=197)	85	86	0.04	0.12
Participants with short-term PD (n=78)	87	89	0.007	0.27
Participants with long-term PD (n=33)	90	96	0.0002	0.67

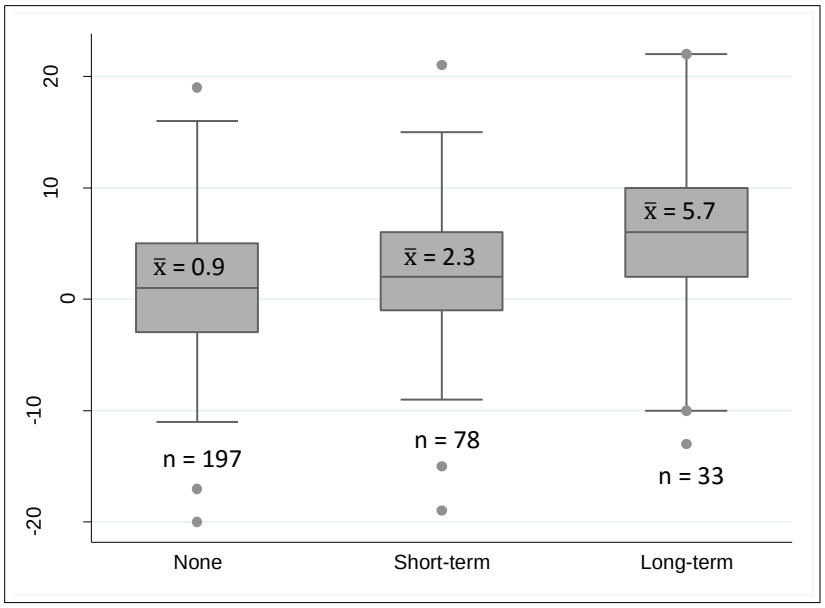


Figure 2: Average gain in BARSTL score from phase one to phase two by duration of professional development experience. Participants who took part in long-term PD experienced much higher BARSTL gains than those with shorter or no PD experiences.

TBI Results

For the TBI, we again use difference in score from phase one to phase two as our variable of interest. Based on visual inspection of the TBI quantile-quantile (Q-Q) plot, data are normally distributed. A kurtosis value of 3.11 with a skewness value of 0.39 also support the assumption of a normal distribution. Using the outlier labeling rule and g-factor described in Hoaglin and Iglewicz (1987), there are no outliers. Changes of TBI scores for this population (n=31) range from -3 (TBI score decreased 3 points from phase one to phase two) to 8 (TBI score increased 8 points from phase one to phase two) with an average of 1.5 and standard deviation of 2.5 (Figure 3). The average phase one TBI score was 20.0 with a 12 point range. The phase two TBI score of this population was 21.5 with a 16 point range. This

1.5 increase in the mean TBI score of the population was a statistically significant gain with a medium effect size (p=0.002; Cohen's d=0.45).

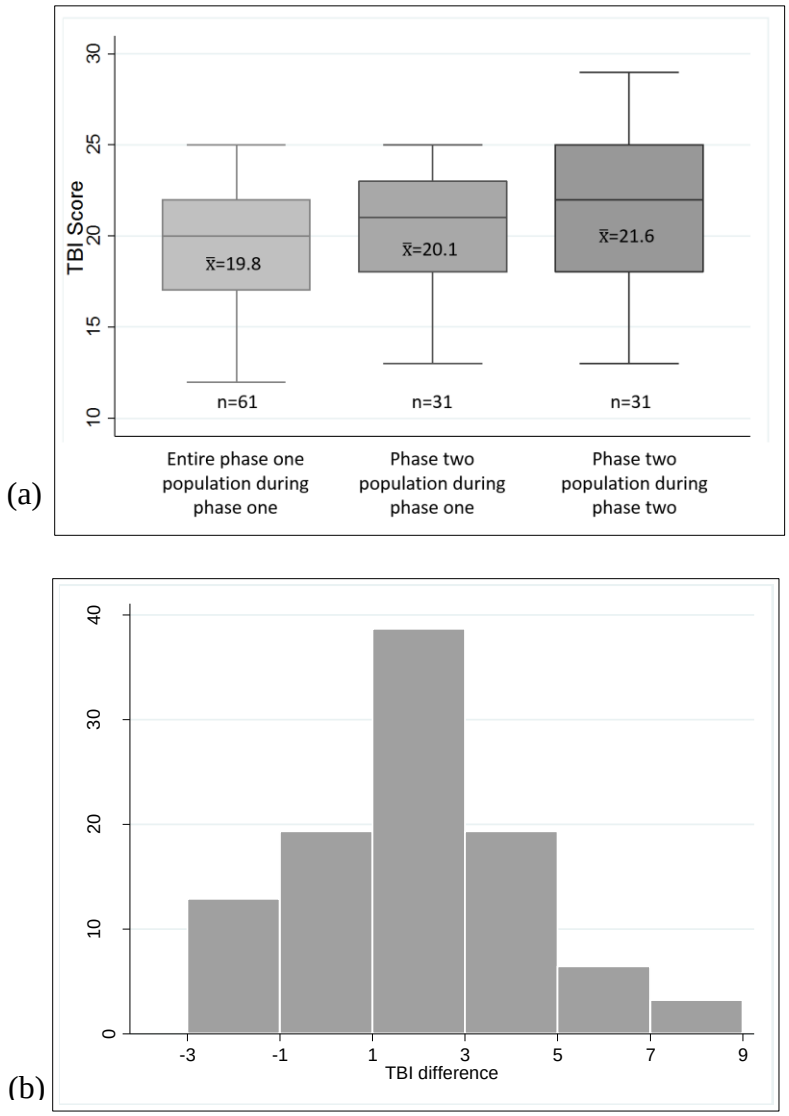


Figure 3: Average TBI scores among all 61 phase one participants during phase one, 31 phase two participants during phase one, and 31 phase two participants during phase two (a); difference in phase one and phase two (phase two – phase one) BARSTL scores between phase two participants (b).

Most TBI participants did not take part in PD over the study period (n=19), yet experienced a slight (statistically significant) TBI score increase of 1.1 (Table 4; Figure 4). Average TBI score increased with short-term PD, but the sample population was small (n=7) and gains were not statistically significant (p=0.52; Table 4). Individuals who participated in long-term teaching-related PD had an average TBI gain of 3.8, a statistically significant change with a very large effect size (p=0.03; Cohen's d=1.24). Most participants with this type of PD took part in a teaching related course at their institution. TBI participants were asked if they desired a future academic career, but this variable was not statistically significant with regard to TBI score difference.

Table 4: TBI score change by professional development (PD) category

Variable	**TBI phase one**	**TBI phase two**	**TBI *p*-value**	**TBI Cohen's *d***
Participants with no PD (n=19)	19.3	20.4	0.01	0.34
Participants with short-term PD (n=7)	21.6	22.4	0.52	0.37
Participants with long-term PD (n=5)	21.0	24.8	0.03	1.24

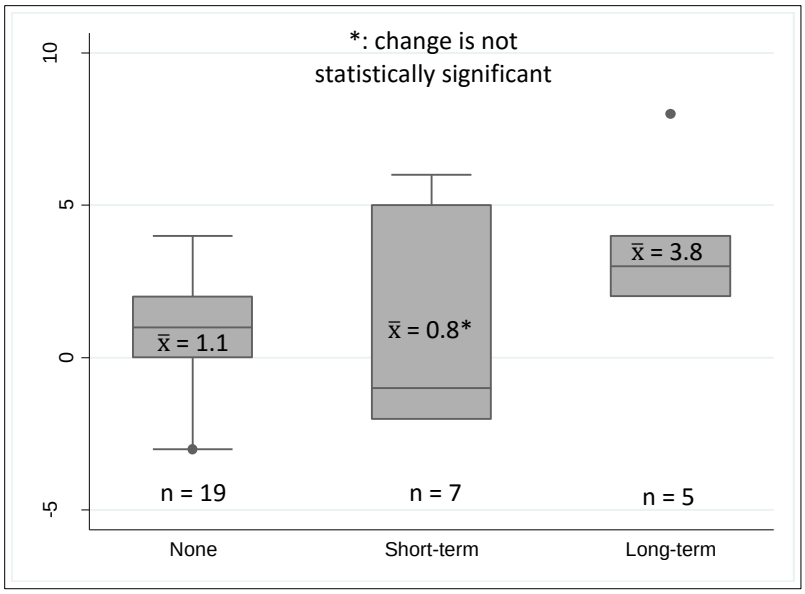


Figure 4: Difference in TBI score from phase one to phase two by duration of professional development. Participants who have taken part in long-term PD had a statistically significant higher TBI gain than participants with shorter or no PD.

The TBI question that resulted in the largest gain from phase one to phase two (Table 5) was "How do you know learning is occurring in your classroom?" This question resulted in an average gain of 0.61 in phase two over phase one. Every individual with long-term PD answered this question in a more reformed fashion in phase two, with an average gain of 1.5 points. For example, in phase one Paul (all names are pseudonyms) provided a transitional response "from the way they talk and their mannerisms, and then the expressions on their faces, whether – you know, whether they're happy, whether they're thinking that this is cool, or whether they're getting frustrated". In phase two, his response mentions students initiating significant interactions, a reformed view: "One of the big tip-offs to me that a lot of learning is happening is that if students . . . come up with insightful questions . . . that are sort of a

logical outgrowth of the things that they've been learning. And when that happens I know, okay, these students are getting this."

Table 5: Average population difference between TBI phase one and TBI phase two by question.

TBI Question	**Mean Change**	**Standard deviation**
1. How do you describe your role as a teacher?	0.01	1.04
2. How do you know when your students understand a concept in class?	0.29	0.97
3. How do you decide when to move on to a new topic in your class?	0.19	0.95
4. In your class, how do you decide what to teach and what not to teach?	0.45	1.36
5. How do your students learn science best?	0.06	1.00
6. How do you know learning is occurring in your classroom?	0.61	0.95
7. How do you maximize learning in your classroom?	-0.19	1.01

The maximum gain seen on a single TBI question was Ruth's response to "In your class, how do you decide what to teach and what not to teach?" Between the two phases, Ruth's response shifted from traditional to reformed. In phase one, Ruth had no experience choosing what to teach: "Whatever the material is they give to me, I have to teach them that." In phase two, even though Ruth still did not have control of the topics taught, she focused on student interest and current events: "From my experience so far, the lectures have been handed to me or the lab books, but I can pick which topics it that lab or lecture that I want to

focus on more. So I like to do ones that are more relatable to the students. Like okay, there's a lot of business students in the class so I'll try to bring in a business example. Something that they might've heard of outside of class, events like the BP Oil spill or environmental issues."

To further characterize change in TBI scores, we categorized differences into: no change (change of -1, 0, or 1 point), increase (increase of 2 or 3 points), large increase (increase of 4 or more points), decrease (decrease of 2 or 3 points), or large decrease (decrease of 4 or more points). Out of the 31 participants, 11 classified as no change, 10 increased, 6 had a large increase, four had a decrease, and 0 had a large decrease in TBI score. The individual with the largest gain, Amy, had a TBI score increase of 8 points from phase one to phase two. Amy had gains on each of the first four questions and no change on the last three questions. In between the phases, Amy participated in a semester-long course involving discipline-based education research in the geosciences, served as instructor of record for an introductory course, and was a teaching assistant for a laboratory course. In phase one, to the question "How do you know when your students understand a concept in class?," Amy responded "When they can explain it back to you or explain it back to somebody else in their own words… have them go around and each explain in their own words before we'd move on to the next topic." This response represents an instructive viewpoint. Amy's phase two response, "If someone brings up a topic again or maybe emails you later to ask about it, I would say that that would show they understood. Or if they ask a question like, 'Okay, if relative humidity increases as air rises, then that would mean it

decreases when it sinks,' they're kind of like twisting the question around and furthering their understanding of the concept" represents a responsive view, a TBI gain of 2 points. In contrast to Amy, Cara did not participate in any teaching-related PD and had no teaching assistant or teaching responsibilities between administration of the phase one and 2 interviews. Cara's TBI score decreased three points from phase one to phase two. Cara's scores stayed the same on questions 1, 3, 5, and 6, increased on question 2, and decreased on questions 4 and 7.

Discussion

In the theory of the innovation-decision process, teachers go through five steps before adopting a new technique: knowledge, persuasion, decision, implementation, and confirmation (Rogers, 2003). The longer the PD opportunity, the more steps of the innovation-decision process PD has an opportunity to influence, ultimately playing a large role in the change of pedagogical beliefs. Long-term PD such as a semester-long pedagogy course may account for at least three components of this cycle. Long-term PD provides knowledge of effective practices and techniques, persuasion in the form of findings from data or research literature, and advice for effective implementation from instruction and readings on practitioner wisdom. In addition, PD is likely to influence the decision step by providing evidence that these methods are worth trying. Some PD programs also provide outlets for implementation, such as an opportunity to guest lecture a course or design an instruction module.

The BARSTL and TBI have been previously employed to identify change in teaching beliefs. For example, Pelch and McConnell (2016) found that the teaching beliefs of 20 of 21 college faculty involved with a project guiding them to develop reformed introductory science material became more student-centered as determined through the BARSTL and/or TBI. Participants gained an average of 2.4 TBI points, which falls within the range we found TBI scores to increase with teaching-related PD experiences (2.0-3.8). Czajka and McConnell (2016) used the BARSTL and TBI to measure change in a case study of situated instructional coaching. Over the coaching semester, the BARSTL score of the instructor in the study increased 6 points, very similar to the 5.7 point gain seen by our population who participated in long-term PD. The instructor's TBI score increased 7 points, larger than the average gain we saw in our population. However, individuals with the largest changes in our population did see similar gains (i.e., Amy's TBI score increase of 8 points).

This study found that the experience likely to result in the greatest shift toward more student-centered teaching beliefs is participation in teaching-related professional development. In addition, we found that the longer the experience, the more beliefs are likely to shift. These results are in line with the theory of the innovation-decision process, since longer experiences have more opportunities to address knowledge, persuasion, decision, implementation, and confirmation (Rogers, 2003). Participants who showed larger gains toward more reformed teaching beliefs took part in long-term experiences including courses or re-occurring seminars on topics including communicating science, teaching science, course development, secondary science education (learning theory focused), experiential

learning, science education and communication practices, teaching methods, and formative assessment techniques. Participants were involved in these experiences a variety of ways including courses offered through their science department, the education department, and the teaching center at their institution.

Conclusions

Our findings suggest that participation in teaching-related professional development is the experience most likely to result in change toward more student-centered, reformed pedagogical beliefs among graduate students and post-doctoral fellows. Participants who have taken part in professional development experiences with a duration of a semester or longer exhibited the most robust change toward more reformed beliefs. Although the evolution of teaching beliefs is thought to be a slow process, often taking years, this study provides evidence that beliefs can begin to change in as little as one semester.

Limitations

Participants in this study were limited to those that previously participated in phase one. Our survey response rate of approximately 50 percent may have resulted in a lack of representation of all groups.

The BARSTL and TBI were originally designed and validated for K-12 teachers. These instruments were chosen to survey and interview graduate students and post-doctoral

scholars because the investigators feel that the items on both tools are appropriate to provide an accurate estimation of their pedagogical beliefs.

Acknowledgements

This research was approved by the North Carolina State University Institutional Review Board (IRB #3999).

References

Chapman, L. Y., & McConnell, D. A. (2016). Experiences influencing the development of reformed teaching beliefs among future geoscience professors. *Geol. Soc. Am. Abst. with Prog.*, *48*(7).

Eagan, K., Stolzenberg, E. B., Lozano, J. B., Aragon, M. C., Suchard, M. R., & Hurtado, S. (2014). *Undergraduate Teaching Faculty: The 2013-2014 HERI faculty Survey*.

Eddy, S. L., & Hogan, K. A. (2014). Getting under the hood: How and for whom does increasing course structure work? *CBE Life Sciences Education*, *13*(3), 453–468.

Freeman, S., Eddy, S., 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*(23), 8410–8415.

Golde, C. M., & Dore, T. M. (2004). The survey of doctoral education and career preparation: The importance of disciplinary contexts. In *Paths to the professoriate: Strategies for enriching the preparation of future faculty* (pp. 19–45). Jossey-Bass San Francisco, CA.

Haak, D. C., HilleRisLambers, J., Pitre, E., & Freeman, S. (2011). Increased Structure and Active Learning Reduce the Achievement Gap in Introductory Biology. *Science*, *332*(6034), 1213–1216.

Halpern, D. F., & Hakel, M. D. (2002). Learning That Lasts a Lifetime: Teaching for Long-Term Retention and Transfer. *New Directions for Teaching and Learning*, *2002*(89), 3–7.

Handelsman, J., Miller, S., & Pfund, C. (2004). Scientific teaching. *Science*, *304*(5670), 521–522.

Henderson, C., & Dancy, M. (2007). Barriers to the use of research-based instructional strategies: The influence of both individual and situational characteristics. *Physical Review Special Topics - Physics Education Research*, *3*(2), 20102.

Hoaglin, D. C., & Iglewicz, B. (1987). Fine-tuning some resistant rules for outlier labeling. *Journal of the American Statistical Association*, *82*(400), 1147–1149.

Kagan, D. (1992). Implications of Research on Teacher Belief. *Educational Psychologist*, *27*(1), 65–90.

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.

Rogers, E. M. (2003). *Diffusion of innovations* (5th ed.). New York, NY: Free Press.

Russell, S. H., Hancock, M. P., & McCullough, J. (2007). Benefits of undergraduate research experiences. *Science*, *316*, 548–549.

Ryker, K., McConnell, D., Bruckner, M. Z., Iverson, E., & Manduca, C. (2013). Teaching is believing: pedagogical beliefs, practices, and professional development. *Geol. Soc. Am. Abst. with Prog.*, *45*(7), 470.

Sampson, V., Enderle, P., & Grooms, J. (2013). Development and Initial Validation of the Beliefs About Reformed Science Teaching and Learning (BARSTL) Questionnaire. *School Science and Mathematics*, *113*(1), 3–15.

Singer, S., Nielsen, N., & Schweingruber, H. (Eds.). (2012). *Discipline-based education*

research: Understanding and improving learning in undergraduate science and engineering. National Academies Press.

Southerland, S. A., Sowell, S., Blanchard, M., & Granger, E. M. (2010). Exploring the Construct of Pedagogical Discontentment: A Tool to Understand Science Teachers' Openness to Reform. *Research in Science Education*, *41*(3), 299–317.

Teasdale, R., Viskupic, K., Bartley, J. K., McConnell, D.A. Manduca, C., Bruckner, M., Farthing, D., & Iverson, E. (2017). A multidimensional assessment of reformed teaching practice in geoscience classrooms. *Geosphere*, *13*(2), 260–268.

Viera, A. J., & Garrett, J. M. (2005). Understanding Interobserver Agreement: The Kappa Statistic. *Family Medicine*, *37*(5), 360–363.

Woodbury, S., & Gess-Newsome, J. (2002). Overcoming the Paradox of Change without Difference: A Model of Change in the Arena of Fundamental School Reform. *Educational Policy*, *16*(5), 763–782.

Zolas, N., Goldschlag, N., Jarmin, R., Stephan, P., Owen-smith, J., Rosen, R. F., & Allen, B. M. (2015). Wrapping it up in a person: Examining employment and earnings outcomes for Ph.D. recipients. *Science*, *350*(6266).

CHAPTER 4: What? When? How? Case studies exploring experiences motivating the development of reformed teaching beliefs among future geoscience faculty.

Abstract

An instructor's teaching beliefs influence whether they use research-validated teaching methods that have been shown to improve student learning. Ten geoscience PhD students, post-doctoral scholars, or beginning professors participated in detailed interviews to determine what experiences led them to become interested in an academic career and contributed to the development of their teaching beliefs. A grounded-theory approach was used to analyze interview transcripts and determine relevant themes that influenced teaching beliefs, interest in teaching, or interest in an academic career. We present findings that emerged from these case studies and highlight academic and personal experiences such as teaching-related professional development that encourage the development of teaching beliefs that support the use of use research-validated instruction. In addition, we discuss personal and academic experiences that lead to participants' interest in teaching and influences on their interest in an academic career.

Introduction

Calls for U.S. science education reform at colleges and universities have been widespread for decades (e.g., AAAS, 1990; Gess-Newsome, Southerland, Johnston, & Woodbury, 2014; Handelsman, Miller, & Pfund, 2004; NRC, 1996; Schwab, 1962). Traditional instructor-centered practices primarily involve lecture and the passive

transmission of information from the instructor to students (Singer, Nielsen, & Schweingruber, 2012). In contrast, in reformed, student-centered environments, students are active participants in their learning and have opportunities to monitor their understanding of concepts by participating in peer interaction and instructor-guided discussion (e.g., Handelsman et al., 2004; Teasdale et al., 2017). Research-validated reformed teaching methods improve learning and student performance (Handelsman et al., 2004; Pollock & Finkelstein, 2008; Singer et al., 2012), reduce the achievement gap (Eddy & Hogan, 2014; Haak et al., 2011), and decrease attrition rates (Freeman et al., 2014).

Changes in teaching practice are closely linked to change in instructors' teaching beliefs (Woodbury & Gess-Newsome, 2002), tacit assumptions about course content and situational factors including student experiences. These pedagogical beliefs influence whether instructors choose to use research-validated teaching methods in their classrooms (Woodbury & Gess-Newsome, 2002). The teaching beliefs of university STEM faculty are resistant to change (e.g., Henderson & Dancy, 2007) and may take years to contribute to changes in practice (Pfund et al., 2009). In contrast, the teaching beliefs of graduate students and post-doctoral fellows are still evolving and these future faculty may more readily incorporate aspects of reformed instruction into their conceptions of teaching (Chapman & McConnell, 2016; Southerland, Sowell, Blanchard, & Granger, 2010).

In a large survey of doctoral students in all disciplines (n=4114), 58% of geology students (n=147) and 63% of students in all disciplines mentioned an interest in a faculty career (Golde & Dore, 2001). A substantial majority (83%) of participants noted that they

were motivated to become faculty due to their enjoyment of teaching, yet only 36% believed that their program of study adequately prepared them to teach a lecture course (Golde & Dore, 2001).

We examined the circumstances and experiences that lead to the development of a range of teaching beliefs among graduate students and post-docs in an effort to discover which factors lead participants to consider an academic career involving teaching and were most likely to contribute to the growth of reformed teaching beliefs among these future geoscience faculty.

Purpose of this study

This study seeks to address three questions:

1. What led to participants' interest in an academic career?
2. How do participants with reformed and traditional teaching beliefs differ?
3. What experiences contributed to the development of reformed teaching beliefs?

Methods

We conducted detailed interviews with ten individuals who were PhD students, post-doctoral scholars (post-docs), or beginning faculty in the geosciences as phase three of a longitudinal study. Phase one of the study used surveys and short interviews to characterize the teaching beliefs of more than 600 graduate students (Chapman & McConnell, 2014). Phase two repeated this process to determine change in teaching beliefs for more than 300 of

the original participants more than a year later (Chapman & McConnell, 2016). Phase one and phase two utilized the Beliefs About Reformed Science Teaching and Learning survey (BARSTL; Sampson, Enderle, & Grooms, 2013) and the Teacher Belief Interview (TBI; Luft & Roehrig, 2007). The BARSTL is a questionnaire designed to determine the alignment of instructors' pedagogical beliefs with reformed-based teaching of science. Participants indicate their level of agreement with 32 statements involving how people learn about science, lesson design and implementation, characteristics of effective teachers, and the nature of the science curriculum (Sampson et al., 2013). Possible BARSTL scores range from 32 to 128 points, with higher scores reflecting more reformed, student-centered beliefs. The TBI is a semi-structured interview which was conducted over the phone. The TBI is composed of seven questions designed to capture instructors' beliefs about teaching and learning. Each answer is individually coded and placed in one of five categories (1: traditional, 2: instructional, 3: transitional, 4: responsive, 5: reformed) using coding maps (Luft & Roehrig, 2007). Possible TBI scores range from 7 to 35, with higher scores representing more reformed, student-centered pedagogical beliefs (Chapman & McConnell, 2014, 2016).

The findings from phase one and phase two were used to select the population for phase three which involved more detailed case study interviews. Interviews were conducted by phone and lasted approximately one hour. Participants were compensated with a gift card. Case study interviews consisted of twenty-two open-ended questions which allowed themes to emerge during open coding. Interview questions were selected and reviewed by a team of

four geoscience education researchers. Pilot interviews were conducted with three participants not in the case study population to test the interview protocol. Interview questions were revised with input from pilot participants. Interview questions were divided into three topic areas including questions about: 1) when participants began thinking about teaching as a potential career; 2) participants' academic experiences; and, 3) participants' individual experiences (Appendix 5). The interviews were semi-structured in nature. Depending on participants' response, follow up questions were asked by the primary investigator to expand on the answer or clear up confusion. Interviews were transcribed using an online transcription service then inspected for accuracy by the primary investigator.

A grounded theory approach (Oktay, 2012) was used to identify recurring themes among responses. From these themes, open codes were compiled and revised in a recursive manner as interview transcripts were analyzed. After reviewing each transcript multiple times, a codebook with primary codes and sub-codes was developed and used to code each interview (Appendix 6). The results from coding were examined to determine the number of unique code incidents by each participant to allow for theme comparison, comparison between individuals, and comparison between groups.

To establish inter-rater reliability, two independent researchers were asked to read and code transcript excerpts from multiple participants using the codebook. Through discussion between the primary investigator and the two independent researchers, 100% consensus was reached. The remaining interviews were then coded by the primary

investigator. Interview transcripts were coded twice by the primary investigator using the codebook to establish 100% intra-rater reliability.

Participants

We used results from phase one and phase two (Figure 1; Chapman & McConnell, 2014, 2016) to select ten representative individuals who expressed interest in an academic career involving teaching for participation in detailed case study interviews. These ten individuals were selected because they represented a range of beliefs along the spectrum of the larger population in previous phases. All ten individuals invited to participate accepted. Names of all participants have been replaced with pseudonyms (Table 1). We selected participants to represent three populations: 1) participants who exhibited reformed beliefs in both initial phases as determined by the survey and interview results; 2) participants who exhibited traditional beliefs in both of the phases; or 3) participants who exhibited significant change in beliefs between phase one and phase two.

To ensure representation of the spectrum of beliefs, we divided BARSTL and TBI scores into statistical quartiles. Individuals who scored within the highest quartile of the phase one and phase two population on the basis of TBI scores (>22.5) and who also had high BARSTL scores (>88) were designated as "reformed." Individuals who scored within the lowest quartile of TBI (<18.5) and had low BARSTL scores (<80) were defined as "traditional." "Change" participants were designated as those whose TBI phase two score was at least three points higher or lower than their TBI score during phase one. A total of 10

individuals agreed to participate in case study interviews: four individuals with reformed beliefs during both phases, two with traditional beliefs, three with significant change toward more reformed beliefs, and one with significant change toward more traditional beliefs (Table). Seven participants were female and three were male. All participants were either PhD students or post-docs during the first two study phases, though two had transitioned to tenure-track faculty at the time of the case study interview (Table 1).

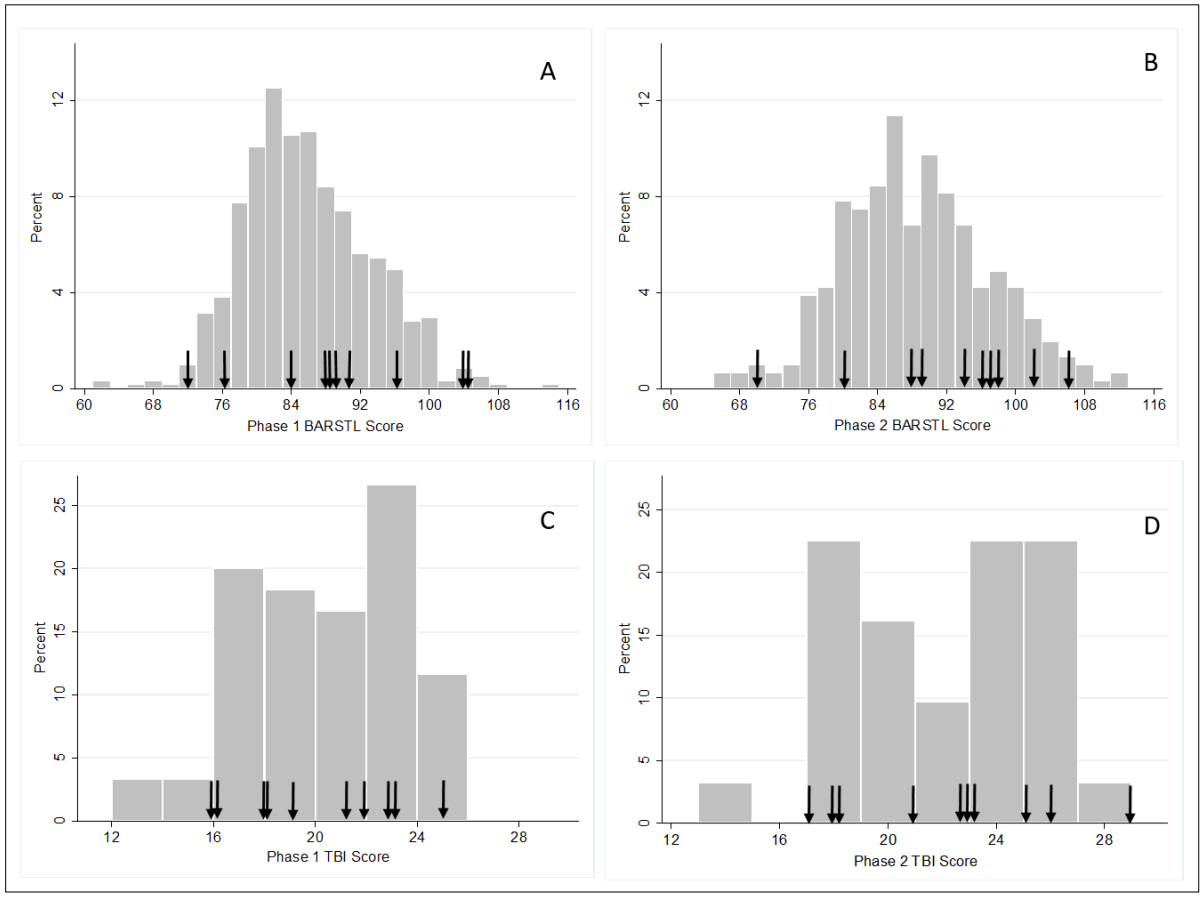


Figure 1: A: Phase one BARSTL scores of the entire study population (n=609); B: Phase two BARSTL scores (n=308); C: Phase one TBI scores of the entire study population (n=61); D: Phase two TBI scores (n=31). Arrows indicate score of each case study participant.

Table 1: Description and scores of case study participants.

Pseudonym	Current Academic Status	Phase one BARSTL score	Phase two BARSTL score	Phase one TBI score	Phase two TBI score	Category
William	Postdoc	104	102	23	23	Reformed
Lisa	Faculty	104	96	22	23	Reformed
Danielle	PhD Student	96	94	25	29	Reformed
Jennifer	Postdoc	91	89	23	25	Reformed
Ashley	PhD Student	76	80	16	18	Traditional
Thomas	Postdoc	72	70	16	17	Traditional
Robert	PhD Student	84	106	18	21	Change (+)
Sarah	PhD Student	88	97	18	26	Change (+)
Mary	Postdoc	89	97	19	23	Change (+)
Melissa	Faculty	89	88	21	18	Change (-)

Results: Emergent Themes

Three primary themes emerged during coding: 1) factors contributing to a desire to pursue a career involving teaching; 2) factors influencing a desire to teach; and, 3) factors that influenced participants' teaching beliefs.

Influences on wanting a career involving teaching

During interviews, participants were asked to discuss why they are interested in an academic career. The primary teaching-related career motivation expressed by participants

focused on the potential impact on students. Change participant Mary discussed her impact in students' personal lives: "You get to introduce students to this new area and this new topic that they may not have thought about… It may mean that 10 years from now when they go to buy a house they think 'This might not be the best location.' There's things like that where you can have an unintended impact on someone's life. I think it's really important." Mary continued by pointing out her potential impact on students' career choices: "Another cool thing with teaching is that you really can get those students who are really passionate about it [the subject area]. It can just change everything for them." Reformed participant William focused his impact around general skill acquisition: "I like watching [students] not just learn things, but learn skills and critical thinking… The chance to work with young people at a critical moment of their lives."

Our population often discussed their perception of the benefits an academic career provides to their faculty role models. The flexibility and independence of an academic position was the most commonly cited benefit identified by participants. This flexibility was often mentioned in passing such as by traditional participant Ashley: "Being in control of your own lab and being able to plan what you do and your hours and such seems really nice." Some participants like William applied the notion of flexibility more explicitly: "The meaning of intellectual freedom that being an academic enables… There are these questions that are fun and fascinating. I like the opportunity to pursue at my leisure and to follow them where you go. That is the freedom you can have in academia." Sometimes individuals have

the opportunity to witness the benefits of firsthand like Mary, who "grew up with my parents getting their PhDs, my mother being a professor in academia."

Having the opportunity to teach, whether formally or informally, influenced some participants to focus on a career involving teaching. An informal experience of being a math tutor influenced reformed participant Lisa's desire to teach: "I think that experience as a tutor merely got me excited about thinking of myself [teaching] as a full-time job because I enjoyed it so much." Change participant Sarah was first introduced to teaching through tutoring classmates, but "being a TA [teaching assistant] throughout graduate school solidified that interest [in teaching as a career]."

Another large influence on participants' interest in an academic career is the potential for continuous learning and the opportunity to develop expertise in their field. Continuous learning is vital for Lisa: "What interests me in that goal [of an academic career] the most is this idea of a job where you can have continual learning opportunities." Ashley expands upon this notion: "When you teach, it makes you know the information differently and it helps you to constantly be really solid in the first order fundamental things in your field." Research opportunities are also important to Lisa: "Having your own research group where you can lecture different students on a wide range of projects just seems so fun."

Although all of our participants desire an academic career, the job search process can be daunting and may negatively influence teaching beliefs. Change participant Melissa's TBI score decreased 3 points in between phase one and two. The only influential experience she mentioned occurring in this time period was a job search, "I've been applying to jobs. I had

to write teaching statements." Melissa's TBI score decreased on two questions that dealt with deciding what to teach and how to maximize learning. In phase one, she mentioned that she adjusted concepts to match student interest, a responsive response. In phase two, she says she decides what to teach depending on what she thinks students need to know for their future careers, an instructive response. William also feels the challenge of the job search: "I had an incredibly naïve impression that my success as a professor would be predicated on my ability to teach effectively. Maybe that's true but to get a job in the first place you have to demonstrate that you can research effectively. Isn't that irony?"

Influences on wanting to teach

There was considerable variation among the factors that lead participants to want to teach. Every participant mentioned the potential to have an influence on students or to help students learn as a main attraction to teaching. Reformed participant Danielle noted "There's something so empowering about helping another person better understand the world around them… The ability to empower others is like a high. There's this wonderful feedback cycle that occurs when you're teaching, where you see the light in the kid's eyes when they get it, and then suddenly, you're just all that much more engaged and they're all that much more engaged." Traditional participant Thomas realizes his potential impact on students' lives: "If you really sell a topic in a certain area, you can provoke a lifelong interest in that. [Students] can go on to achieve potentially great things in whatever field that may be. You can have quite a profound impact." Danielle agreed by saying "You're looking at bright kids that are between the ages of 18 and 24 and they already have some opinions and they already have

some ideas of how the world works, but they haven't figured it all out yet. You can still make a lasting impact on students of that age in a really cool way."

A difference between traditional and reformed participants' interest in teaching emerged around the concept of student feedback. All of the reformed but none of the traditional participants mentioned the role of feedback on their desire to teach. Lisa noted both informal and formal student feedback: "The feedback that I got was very fulfilling… [My students] would provide a lot of feedback and say 'I get it now!'"

All participants also discussed how their experiences as a student led to their interest in teaching, however, the experiences were as likely to be negative as positive. Change participant Robert discussed the role of positive teaching examples: "When I have had better teaching and I've seen professors employing active learning methods in their class, and flipping the class, things like that, have made me want to go back to other areas and try to improve my teaching." Often participants mentioned feeling that they could do a better job teaching than their instructors. Sarah noted "I just wanted to fix things that I saw my teachers doing wrong. I have this idea of how things should be taught or how classrooms should be run."

Every participant mentioned support and encouragement from at least one source within or beyond academia. Support from an advisor or mentor was most commonly cited. Danielle often discussed the importance of her advisor's support: "My advisor is a wonderful teacher. He is extraordinarily supportive of me wanting to teach. He is a very loyal advocate of me, really backing my passion… I know that so many of my colleagues don't have that

support but I just happened to land with the one guy that's like, 'Oh yeah, teaching is super important. That's why I'm in a university.'" Change participant Melissa's advisor was not supportive of her interest in teaching, but she obtained a supportive mentor. Melissa noted: "[My mentor] was a big advocate for teaching… I would definitely say she strengthened my desires to teach." Participants also received support for their interest in teaching from their family, peers, community, or non-advisor faculty. However, reformed individuals were more likely to mention supportive instructors or faculty than traditional participants. Lisa mentioned that she received encouragement from multiple sources including the director of teaching assistants in her department: "[After getting my course reviews], some of my teachers would say, 'Wow! You have great reviews. You look like you're a good teacher. That felt like verbal affirmation that I was doing the right thing."

Every person interviewed mentioned discouragement in some form, often due to lack of time. Mary felt this time crunch: "You don't necessarily have enough time to focus [on teaching] given the reality of other things you're supposed to be doing as a professor… It can become this huge time sink if you're not careful." Mary also felt that spending too much time on teaching could have dramatic impacts. She mentioned "I would like to spend a lot of time on teaching and really working on crafting interactive and meaningful lectures and working with students but I also have the reality of I want to be able to keep my job."

The next most common source of discouragement was from participants' department. Reformed participants noted that department representatives suggested that they are spending too much time on teaching. Danielle often felt pressure not to teach from her department:

"The department doesn't want me to teach and I basically just hold my breath until I turn blue and pass out in front of the department chair's office and then he eventually caves and let me teach. It's been interesting because I have perhaps the opposite problem of many of my peers in that, I want to teach more and the department is saying, 'Nope, you can't.' Please." PhD and post-doc advisors are also common sources of teaching discouragement. Reformed participant Jennifer "felt a little bit of an obligation to hide how interested I was in teaching [from her PhD advisor]." Traditional participant Ashley also felt pressure to hide her interest in teaching because her advisor "has the mindset of 'you only need to teach unless you have to. Research is priority... It's not like 'yeah, go teach,' it's 'yeah, go do awesome research.'" Sometimes it is the entire university that has an anti-teaching atmosphere. Mary's advisor felt this was the case: "[At my institution], there was a teaching prize that faculty could get. Rumor was that if you got that before tenure you didn't get tenure. It was this well-known statement to the point where my undergraduate advisor who was pre-tenure told me not to nominate her for the teaching prize."

Often graduate students and post-docs do not know if they enjoy teaching until they simply do it. Experiences teaching, both formal (e.g., teaching assistant, instructor) and informal (e.g., tutor, coach) were influential on participants' desire to teach. Melissa noted the influence of her experience as a teaching assistant, "I didn't know [if teaching was something I'd be good at] until I was thrown into the deep end. I didn't seem to damage any of the students and enough of them came out the other side with some knowledge." Mary had informal teaching experiences as a tutor throughout her undergraduate experience. It was not

until she had a formal teaching assistant position that she thought "I thought I liked teaching, but now I'm pretty sure I really do."

Ashley, Danielle, and Melissa all received teaching assistant awards which they mentioned encouraged them to keep teaching. In addition, a few participants noted that teaching helped them improve their knowledge and skills in the discipline. Mary explained this impact: "[Teaching] definitely helps me understand the material a lot better… It's improved my recall and understanding of the material significantly."

Influences on teaching beliefs

Participants' teaching beliefs are shaped by numerous experiences during their academic career. Most often, professional development was where participants believed they acquired their teaching beliefs, though many different types of professional development were cited. Lisa noted that a training course "was taught by a brilliant pedagogist. She turned my world upside down in terms of how to teach a student... [the course] opened up this whole world to me about thinking about how to instill higher levels of thinking and knowledge transfer in higher education." The influence of professional development was mentioned by all four of the reformed participants and the four change participants, but was not cited by traditional participants (Figure 2). For example, William noted that he had completed multiple courses in the education department and Jennifer described making an effort to take workshops and seminars on teaching. Two of the three change participants cited professional development opportunities that introduced them to literature on teaching research and to

reformed teaching strategies as the experience that most influenced their beliefs over the study period. These two participants, Robert and Sarah, took a semester-long discipline-based pedagogy course. Robert mentioned "Reading papers on the research for teaching was very helpful. I saw from a scientific perspective how these different teaching methods can improve student learning. It's nice to see the data and that motivated me to teach in that way [in a reformed style]." Sarah noted the impact of learning student-centered teaching strategies: "It made me realize especially with teaching a big class and with non-majors how much you really need to diversify the lectures and the class material to really keep people interested and engaged… make sure that you have think-pair-shares and clicker questions. Also some more discussion and interactive activities."

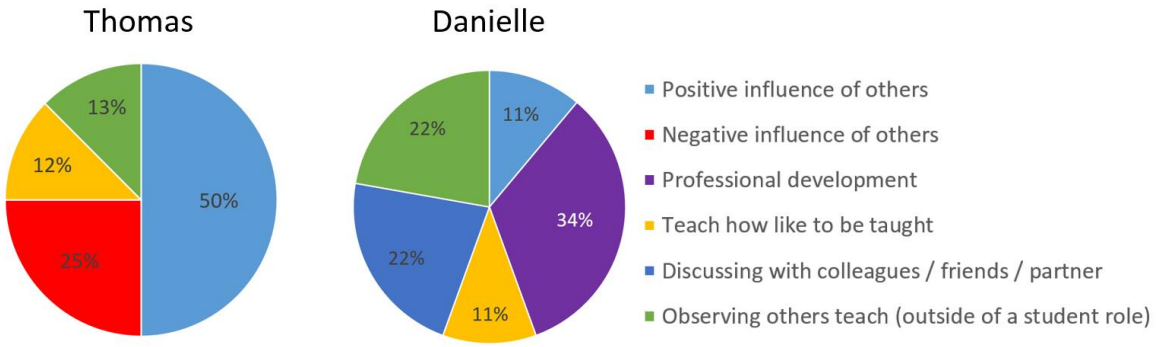


Figure 2: The differences between influences on the teaching beliefs of Thomas and Danielle model the differences between reformed and traditional participants, respectively. Percentages correspond with number of mentions of each influence during interview. Danielle's teaching beliefs are most influenced by professional development, observation, and discussion with colleagues while Thomas' teaching beliefs are most influenced by positive and negative influences of his instructors.

Almost all of the participants, regardless of beliefs, mentioned the positive influence of others on the development of their views on teaching. Positive influences originated from instructors, advisors, and mentors ranging from their K-12 education through their post-doc experience. Thomas felt that he acquired his teaching beliefs through example: "Having seen other people give lectures… it's through seeing good teaching is what's most effective." Jennifer learned a lot "just by watching teachers who I really liked even at the K-12 level. There's some people in the classroom who just do a really lovely job teaching with their students and I think 'What are they doing that's so engaging?'"

Half of our participants also mentioned the influence of negative experiences on their teaching beliefs. William noted "I had some abysmal instruction throughout. The result was subjects I knew in my heart should have been fascinating and captivating became neither fascinating nor captivating. When I had my first opportunity to teach one of those classes I really wanted my students to have a different experience than that." Because of William's negative experience, he sought out opportunities to learn different ways to teach the material. Seven of the ten participants remarked that they want to teach as they like to be taught. For example, traditional participant Thomas said "Intuitively, I teach that way because it seems like a way I would like to teach and be taught." Lisa mentioned the influence of both positive and negative experiences on her teaching beliefs: "Having very good teachers and then being able to contrast that with very bad teachers. For a while, I actually kept a notebook where I would write down those qualities. I would write things down things that I really, really liked and then I would write down things that I really, really didn't like."

Experiences in the classroom, either as a teaching assistant or an instructor of record, can play a role in teaching beliefs. Two of the three change participants mentioned the influence of teaching experience. Sarah stated "Teaching the [lecture] class definitely impacted my thoughts in a positive way…. Having the complete autonomy was really daunting, of course, but really rewarding, knowing that I was trusted to do a good job and just having the flexibility to change lecture materials as I saw fit." Teaching a lab section allowed Robert to put what he learned in professional development into practice: "Teaching my own [lab] class has… turned ideas more into some different small things I can add in that are useful to students."

Discussion with peers or family can also be a powerful tool in transforming teaching beliefs. Mary's wife was involved with a project that sought to maximize adults' retention and recall through the application of specific teaching methodologies. Mary noted "I was her guinea pig. I had to do everything so that I could test it. We ended up reading and talking a lot about different teaching methodologies." Mary expanded by saying "Definitely being exposed to different styles of teaching [affected my teaching beliefs]. Finding what worked well."

The last experience influencing teaching beliefs mentioned by multiple participants was the impact of observing others teach outside of a student role. When Danielle first began teaching, she had a few influential mentors whom she observed teach before teaching herself. Danielle notes "A lot of the habits that I got into, I got into because I watched [my mentor]

do it and she had such success. Those habits then in turn colored my beliefs because, of course, the things that I do, those become part of what I believe."

Implications

The results from this study can help inform how to better prepare future faculty so that they can begin their work as instructors with the information necessary to design student-centered lessons that ensure student learning. For example, professional development emerged as the primary influence on teaching beliefs separating the reformed group from the traditional group (Figure 2). This theme indicates the need for teaching-related professional development aimed at graduate students and post-docs.

We asked participants why they decided to participate in professional development. Participants mentioned that they participated in professional development because; a) they wanted to develop specific skills and sought out the opportunity; b) it was required by their department before teaching; or, c) they were referred to a particular program by someone. William actively sought out a course to improve his teaching: "I took the courses in the Graduate School of Education. The courses are offered to anyone at the university… [my decision to participate was influenced by] my desire to be better at teaching." Often an institutional or departmental requirement is the only way individuals will participate in training. Thomas revealed "I just did the one day course… there's more after that like a lot longer course to help you with designing courses, lectures, and things like that. I just did the first step, because it's all I needed to do at that time." While almost all future professors are

currently graduate students and post-docs in research intensive universities, many will take jobs in academic institutions with a lesser emphasis on research and a greater focus on teaching. Consequently, departments with a history of placing graduates in jobs at four-year colleges, community colleges, or institutions with high teaching loads may find benefit in placing greater emphasis on encouraging their graduate students to complete more comprehensive professional development programs.

Some institutions encourage professional development by requiring semester-long pedagogy courses before allowing graduate students to be teaching assistants. Lisa noted that her institution has such a requirement "You have to take the course on how to be a TA before you can become a TA. The class was intense." Robert took a discipline-based pedagogy course because it was advertised and available in his department. He noted, "I was interested in learning more about teaching… I had some TA duties, so I figured it'd be nice just to improve my own teaching."

During interviews, negative university experiences and the constant battle of discouragement from teaching were prominent. These types of discouragements may be inadvertent but can have significant implications for the pool of graduate students and post-docs who are interested in teaching. This finding highlights the need to make faculty aware of the need for mentoring that provides support and encouragement for potential teaching-related career choices. Without someone encouraging their interest in teaching and developing teaching skills, potential future faculty with less interest in positions with research-emphasis may abandon their desire to become a professor. Mentoring is crucial

throughout the entire graduate student career. Melissa's teaching beliefs may have become more traditional due to her struggle with her own job search. Effective mentoring can not only help support future faculty in their desire to teach, they can also help graduate students and post-docs navigate the stressful job search process.

Many graduate students and post-docs are not offered the opportunity to teach and have to deliberately seek out the majority of their teaching opportunities. Our participants highlighted the powerful influence of teaching experiences on desire to teach in the future as well as in developing an interest in an academic career focused on teaching. Student feedback and validation for their teaching appears to be a driver in this regard with reformed individuals describing a more open dialog with students and greater interest in soliciting feedback and related changes. Therefore, it is vital to offer teaching opportunities for graduate students who have an interest in a future academic career. In addition, departmental or universities can provide encouragement by offering recognition of teaching excellence. Sometimes seemingly small experiences such as teaching awards influence a graduate student's desire to teach or to continue teaching.

Since our population engaged on reflection about their teaching, we asked participants about topics they would include if they were designing a course to prepare new instructors. A plethora of topics were proposed ranging from learning quantitative skills to conflict resolution. Topics that were mentioned by multiple participants included (in order from most often mentioned to least mentions): active learning strategies, class organization and logistics, communication and presentation skills, designing effective assessments, and

incorporating diversity. Differences emerged between the traditional and reformed groups. Traditional individuals most often mentioned the importance of class organization and logistics while reformed participants discussed how to support the development of pedagogical skills such as active learning. These topics are in line with Fuller's model for teacher development (Fuller, 1969). Fuller found that beginning teachers are primarily concerned about survival or topics dealing with "self" such as knowledge of the content and self-protection. Our traditional individuals' identification of "self" topics involving logistics fit this model. In contrast, later-stage teachers are concerned more about their students' learning (Fuller, 1969). Our reformed population was interested in active learning and designing effective assessments which help students succeed. When we turned the question around and asked about useful topics if the participants were taking a class for new instructors rather than designing the class, there was little difference in the responses. One additional theme emerged about learning what to do when difficulties emerge or when things go wrong in the classroom.

Conclusions

The teaching beliefs of our geoscience graduate students and post-docs are most strongly influenced by professional development and instructors who they have encountered during their academic experience, with both positive and negative consequences. Participants are most likely to want to teach because of their potential impact on students, their own student experience, and external encouragement. However, they also encounter instances of

teaching discouragement. Graduate students and post-docs are interested in an academic career because of the impact they can have on students and because of the perceived flexibility and autonomy associated with such careers. To best prepare graduate students and post-docs for future careers in academia, effective professional development, positive mentoring, and opportunities to teach are crucial.

Limitations

The study described here is limited by its population of ten individuals whom had previously participated in phase one and phase two of the research. This small population was necessary to have interviews of sufficient detail to allow themes to emerge. However, this population is considered representative of a larger population involved in phase one (n=609) and phase two (n=308). In addition, as is the case when utilizing interview data, responses were limited by the primary questions asked as well as the follow-up questions. Responses also had the potential to be biased by previous interactions and knowledge of the primary investigator's research as indicated by two earlier Teacher Belief Interviews, the most recent of which was conducted approximately seven months before the case study interviews.

This study was unable to determine quality of professional development experiences. Future research is needed to determine specific elements that made professional development influential.

Acknowledgements

This research was approved by the North Carolina State University Institutional Review Board (IRB #3999).

References

AAAS (American Association for the Advancement of Science). (1990). *Science for all Americans*. New York: Oxford University Press.

Chapman, L. Y., & McConnell, D. (2014). Characterizing the teaching beliefs of future geoscience professors. *Geol. Soc. Am. Abst. with Prog.*, *46*(6), 647.

Chapman, L. Y., & McConnell, D. A. (2016). Experiences influencing the development of reformed teaching beliefs among future geoscience professors. *Geol. Soc. Am. Abst. with Prog.*, *48*(7).

Eddy, S. L., & Hogan, K. A. (2014). Getting under the hood: How and for whom does increasing course structure work? *CBE Life Sciences Education*, *13*(3), 453–468.

Freeman, S., Eddy, S., 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*(23), 8410–8415.

Fuller, F. F. (1969). Concerns of Teachers: A Developmental Conceptualization. *American Educational Research Journal*, *6*(2), 207–226.

Gess-Newsome, J., Southerland, S. A., Johnston, A., & Woodbury, S. (2014). Educational Reform , Personal Practical Theories , and Dissatisfaction : The Anatomy of Change in College Science Teaching. *American Educational Research Journal*, *40*(3), 731–767.

Golde, C. M., & Dore, T. M. (2001). At Cross Purposes: What the Experiences of Today's Doctoral Students Reveal about Doctoral Education. *Pew Charitable Trusts*, *January*, 1–15.

Haak, D. C., HilleRisLambers, J., Pitre, E., & Freeman, S. (2011). Increased Structure and Active Learning Reduce the Achievement Gap in Introductory Biology. *Science*, *332*(6034), 1213–1216.

Handelsman, J., Miller, S., & Pfund, C. (2004). Scientific teaching. *Science*, *304*(5670), 521–522.

Henderson, C., & Dancy, M. (2007). Barriers to the use of research-based instructional strategies: The influence of both individual and situational characteristics. *Physical Review Special Topics - Physics Education Research*, *3*(2), 20102.

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.

NRC (National Research Council). (1996). *National science education standards*. Washington D.C.: National Academies Press.

Oktay, J. S. (2012). *Grounded Theory*. Oxford University Press.

Pfund, C., Miller, S., Brenner, K., Bruns, P., Chang, A., Ebert-May, D., … Handelsman, J. (2009). Summer Institute to Improve University Science Teaching. *Science*, *324*(5926), 470–471.

Pollock, S. J., & Finkelstein, N. D. (2008). Sustaining educational reforms in introductory physics. *Physical Review Special Topics - Physics Education Research*, *4*(1), 1–8.

Sampson, V., Enderle, P., & Grooms, J. (2013). Development and Initial Validation of the Beliefs About Reformed Science Teaching and Learning (BARSTL) Questionnaire. *School Science and Mathematics*, *113*(1), 3–15.

Schwab, J. J. (1962). The teaching of science as enquiry. In J. J. Schwab & P. F. Brandwein (Eds.), *The teaching of science* (pp. 3–103). Cambridge: Harvard University Press.

Singer, S., Nielsen, N., & Schweingruber, H. (Eds.). (2012). *Discipline-based education research: Understanding and improving learning in undergraduate science and engineering*. National Academies Press.

Southerland, S. A., Sowell, S., Blanchard, M., & Granger, E. M. (2010). Exploring the Construct of Pedagogical Discontentment: A Tool to Understand Science Teachers' Openness to Reform. *Research in Science Education*, *41*(3), 299–317.

Teasdale, R., Viskupic, K., Bartley, J. K., McConnell, D.A. Manduca, C., Bruckner, M., Farthing, D., & Iverson, E. (2017). A multidimensional assessment of reformed teaching practice in geoscience classrooms. *Geosphere*, *13*(X), 260–268.

Woodbury, S., & Gess-Newsome, J. (2002). Overcoming the Paradox of Change without Difference: A Model of Change in the Arena of Fundamental School Reform. *Educational Policy*, *16*(5), 763–782.

APPENDICES

Appendix 1: Beliefs About Reformed Science Teaching and Learning (BARSTL) Survey

Survey Part I: How People Learn About Science

The statements below describe different viewpoints concerning the ways students learn about science. Based on your beliefs about how people learn, indicate if you agree or disagree with each of the statements below. Please answer all questions.

1. Students develop many beliefs about how the world works before they ever study about science in school.

☐ Strongly Disagree ☐ Disagree ☐ Agree ☐Strongly Agree

2. Students learn in a disorderly fashion; they create their own knowledge by modifying their existing ideas in an effort to make sense of new and past experiences.

☐ Strongly Disagree ☐ Disagree ☐ Agree ☐Strongly Agree

3. People are either talented at science or they are not, therefore student achievement in science is a reflection of their natural abilities.

☐ Strongly Disagree ☐ Disagree ☐ Agree ☐Strongly Agree

4. Students are more likely to understand a scientific concept if the teacher explains the concept in a way that is clear and easy to understand.

☐ Strongly Disagree ☐ Disagree ☐ Agree ☐Strongly Agree

5. Frequently, students have difficulty learning scientific concepts in school because their beliefs about how the world works are often resistant to change.

☐ Strongly Disagree ☐ Disagree ☐ Agree ☐Strongly Agree

6. Learning science is an orderly process; students learn by gradually accumulating more information about a topic over time.

☐ Strongly Disagree ☐ Disagree ☐ Agree ☐Strongly Agree

7. Students know very little about science before they learn it in school.

☐ Strongly Disagree ☐ Disagree ☐ Agree ☐Strongly Agree

8. Students learn the most when they are able to test, discuss, and debate many possible answers during activities that involve social interaction.

☐ Strongly Disagree ☐ Disagree ☐ Agree ☐Strongly Agree

Part II: Lesson Design and Implementation

The statements below describe different viewpoints concerning the ways students learn about science. Based on your beliefs about how people learn, indicate if you agree or disagree with each of the statements below. Please answer all questions.

9. During a lesson, students should explore and conduct their own experiments with hands-on materials before the teacher discusses any scientific concepts with them.

☐ Strongly Disagree ☐ Disagree ☐ Agree ☐Strongly Agree

10. During a lesson, teachers should spend more time asking questions that trigger divergent ways of thinking than they do explaining the concept to students.

☐ Strongly Disagree ☐ Disagree ☐ Agree ☐Strongly Agree

11. Whenever students conduct an experiment during a science lesson, the teacher should give step-by-step instructions for the students to follow in order to prevent confusion and to make sure students get the correct results.

☐ Strongly Disagree ☐ Disagree ☐ Agree ☐Strongly Agree

12. Experiments should be included in lessons as a way to reinforce the scientific concepts students have already learned in class.

☐ Strongly Disagree ☐ Disagree ☐ Agree ☐Strongly Agree

13. Lessons should be designed in a way that allows students to learn new concepts through inquiry instead of through a lecture, a reading or a demonstration.

☐ Strongly Disagree ☐ Disagree ☐ Agree ☐Strongly Agree

14. During a lesson, students need to be given opportunities to test, debate and challenge ideas with their peers.

☐ Strongly Disagree ☐ Disagree ☐ Agree ☐Strongly Agree

15. During a lesson, all of the students in the class should be encouraged to use the same approach for conducting an experiment or solving a problem.

☐ Strongly Disagree ☐ Disagree ☐ Agree ☐Strongly Agree

16. Assessments in science classes should only be given after instruction is completed; that way the teacher can determine if the students have learned the material covered in class.

☐ Strongly Disagree ☐ Disagree ☐ Agree ☐Strongly Agree

Part III: Characteristics of Teachers and the Learning Environment

The statements below describe different viewpoints concerning the ways students learn about science. Based on your beliefs about how people learn, indicate if you agree or disagree with each of the statements below. Please answer all questions.

17. Students should do most of the talking in science classrooms.

☐ Strongly Disagree ☐ Disagree ☐ Agree ☐Strongly Agree

18. Students should work independently as much as possible so they do not learn to rely on other students to do their work for them.

☐ Strongly Disagree ☐ Disagree ☐ Agree ☐Strongly Agree

19. In science classrooms, students should be encouraged to challenge ideas while maintaining a climate of respect for what others have to say.

☐ Strongly Disagree ☐ Disagree ☐ Agree ☐Strongly Agree

20. Teachers should allow students to help determine the direction and the focus of a lesson.

☐ Strongly Disagree ☐ Disagree ☐ Agree ☐Strongly Agree

21. Students should be willing to accept the scientific ideas and theories presented to them during science class without question.

☐ Strongly Disagree ☐ Disagree ☐ Agree ☐Strongly Agree

22. An excellent science teacher is someone who is really good at explaining complicated concepts clearly and simply so that everyone understands.

☐ Strongly Disagree ☐ Disagree ☐ Agree ☐Strongly Agree

23. The teacher should motivate students to finish their work as quickly as possible.

☐ Strongly Disagree ☐ Disagree ☐ Agree ☐Strongly Agree

24. Science teachers should primarily act as a resource person; working to support and enhance student investigations rather than explaining how things work.

☐ Strongly Disagree ☐ Disagree ☐ Agree ☐Strongly Agree

Part IV: The Nature of the Science Curriculum

The statements below describe different viewpoints concerning the ways students learn about science. Based on your beliefs about how people learn, indicate if you agree or disagree with each of the statements below. Please answer all questions.

25. A good science curriculum should focus on only a few scientific concepts a year, but in great detail.

☐ Strongly Disagree ☐ Disagree ☐ Agree ☐Strongly Agree

26. The science curriculum should focus on the basic facts and skills of science that students will need to know later.

☐ Strongly Disagree ☐ Disagree ☐ Agree ☐Strongly Agree

27. Students should know that scientific knowledge is discovered using the scientific method.

☐ Strongly Disagree ☐ Disagree ☐ Agree ☐Strongly Agree

28. The science curriculum should encourage students to learn and value alternative modes of investigation or problem solving.

☐ Strongly Disagree ☐ Disagree ☐ Agree ☐Strongly Agree

29. In order to prepare students for future classes, college, or a career in science the science curriculum should cover as many different topics as possible over the course of a school year.

☐ Strongly Disagree ☐ Disagree ☐ Agree ☐Strongly Agree

30. The science curriculum should help students develop the reasoning skills and habits of mind necessary to do science.

☐ Strongly Disagree ☐ Disagree ☐ Agree ☐Strongly Agree

31. Students should learn that all science is based on a single scientific method—a step-by-step procedure that begins with ‘define the problem’ and ends with ‘reporting the results.’

☐ Strongly Disagree ☐ Disagree ☐ Agree ☐Strongly Agree

32. A good science curriculum should focus on the history and nature of science and how science affects people and societies.

☐ Strongly Disagree ☐ Disagree ☐ Agree ☐Strongly Agree

Appendix 2: Additional survey questions included in the BARSTL survey

33. Bachelor's Degree:
☐BS ☐BA ☐Other: _____

34. Bachelor's Major (concentration): _____

35. Master's Degree:
☐MS ☐MA ☐None ☐Other: _____

36. Master's Degree Major (concentration): _____

37. Current academic status:
☐Master's Student ☐PhD Student ☐Post-doc ☐Other: _____

38. Years in current academic program:
☐1st year ☐2nd year ☐3rd year ☐4th year ☐>4 years

39. Have you been or are you currently a TA? If so, please check your responsibilities.
☐Completing TA training ☐Grading (but no teaching responsibilities)
☐Teaching a lab section ☐Teaching a lecture section
☐I have been a TA but had no training ☐I have never been a TA
☐Other TA training: _____

40. Please indicate total years with TA responsibilities and the approximate number of students per class in lecture and lab sections you TA (if applicable):
_____

41. Have you participated in professional development related to teaching?
☐Yes, a multi-day event (e.g., workshop) ☐Yes, a semester long event (e.g., course)
☐Yes, one or more individual events (e.g., seminar) ☐No

42. If you answered yes on the previous question, please explain your participation in this professional development (e.g., type, name of event, duration, example activities)
_____
_____

43. Gender:

☐Male ☐Female

44. Race (select one or more):

☐American Indian or Alaska Native

☐Asian

☐Black or African American

☐Native Hawaiian or other Pacific Islander

☐White

☐Other: _____

45. Ethnicity

☐Hispanic or Latino ☐Not Hispanic or Latino

46. Citizenship:

☐US Citizen ☐Permanent Resident ☐Other non-US Citizen

47. Would you be willing to be contacted for a follow up interview about your teaching beliefs?

☐Yes, I would be willing to be contacted for a follow up interview.

☐Perhaps, you can contact me but I would need to know more about the follow up interview.

☐No, I am not interested.

48. After data have been collected and analyzed, an aggregate analysis report will be made available online. I would like access to this report when it is available.

☐Yes ☐No thanks

Appendix 3: Teacher Belief Interview (TBI) Questions

1. How do you maximize learning in your classroom (Environment)?

2. How do you describe your role as a teacher (Student Knowledge)?

3. How do you know when your students understand a concept in class (Understanding)?

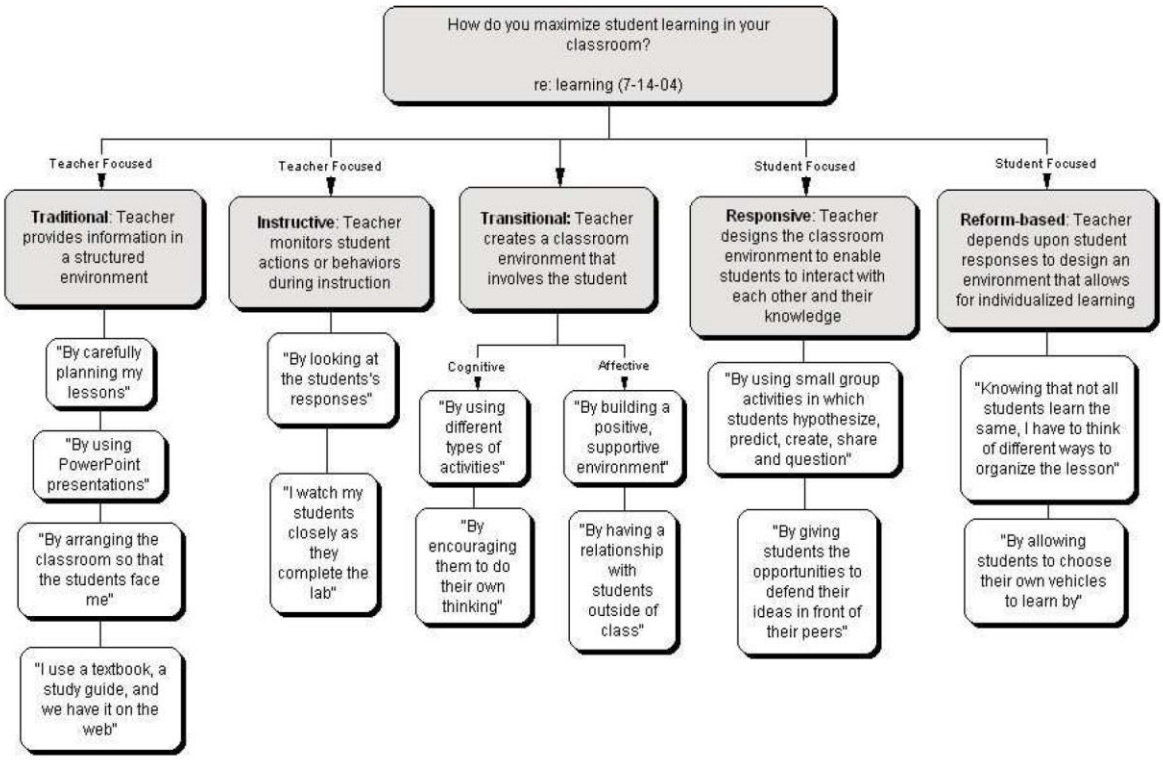
4. In your class, how do you decide what to teach or what not to teach (Attention to students and Standards)

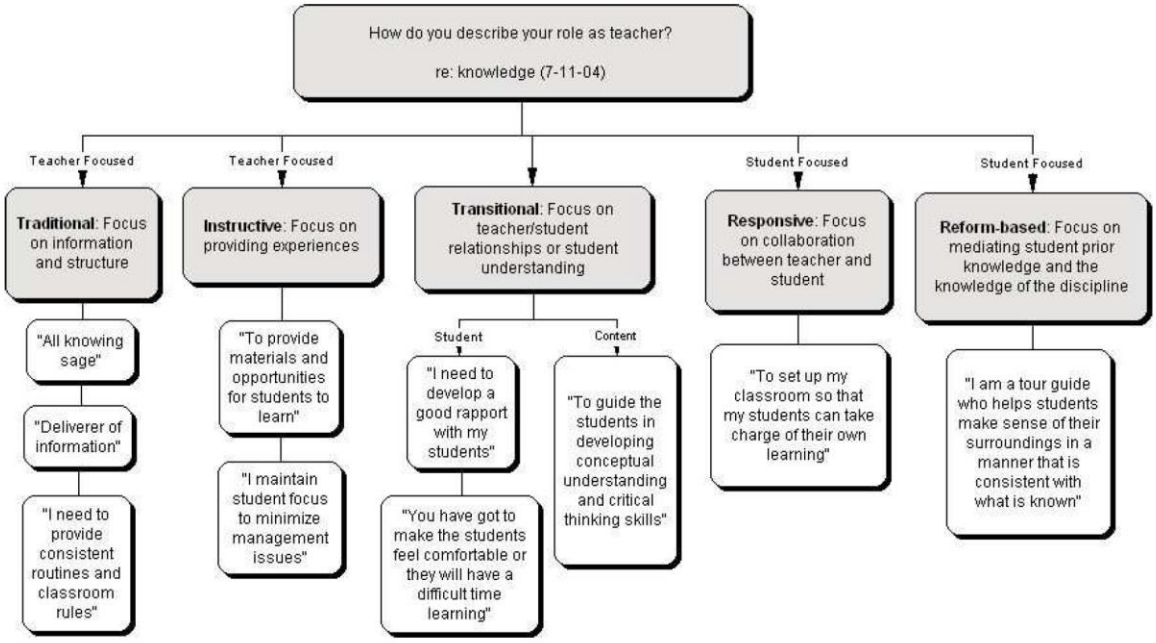
5. How do you decide when to move on to a new topic in your class (Assessment)?

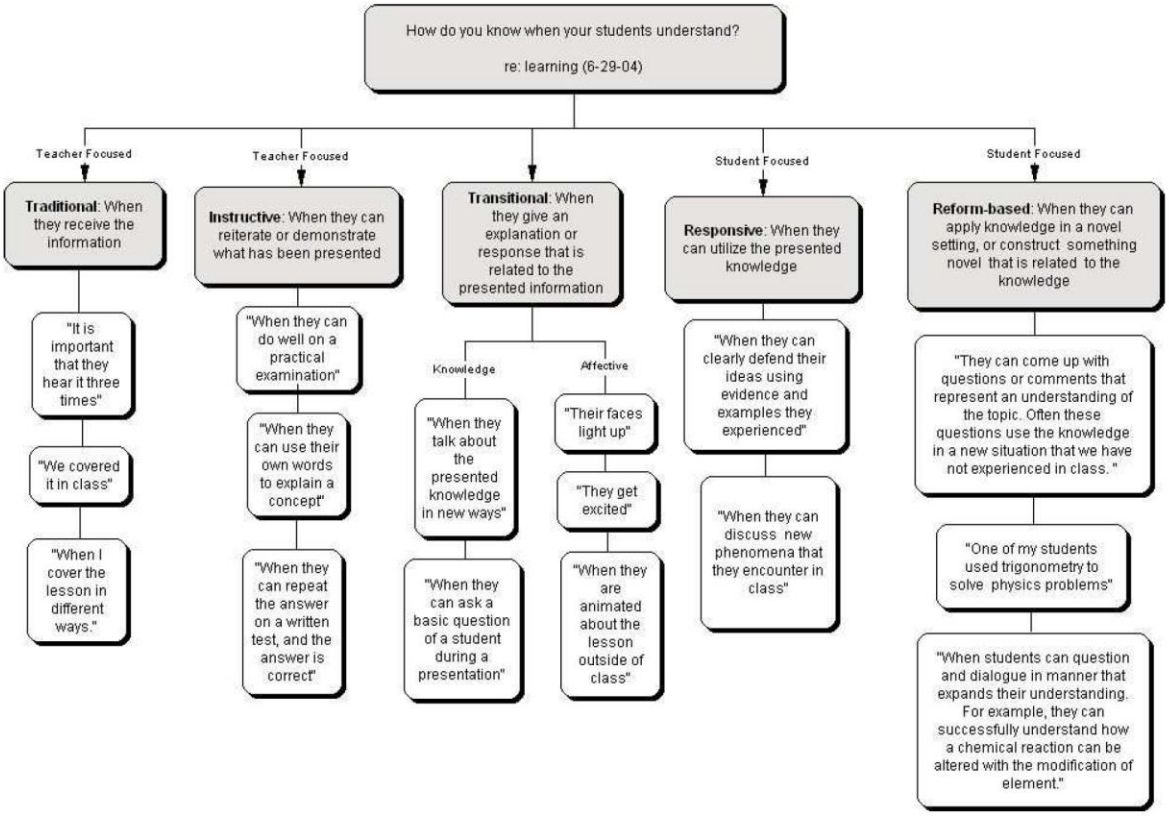
6. How do your students learn science best (Learning)?

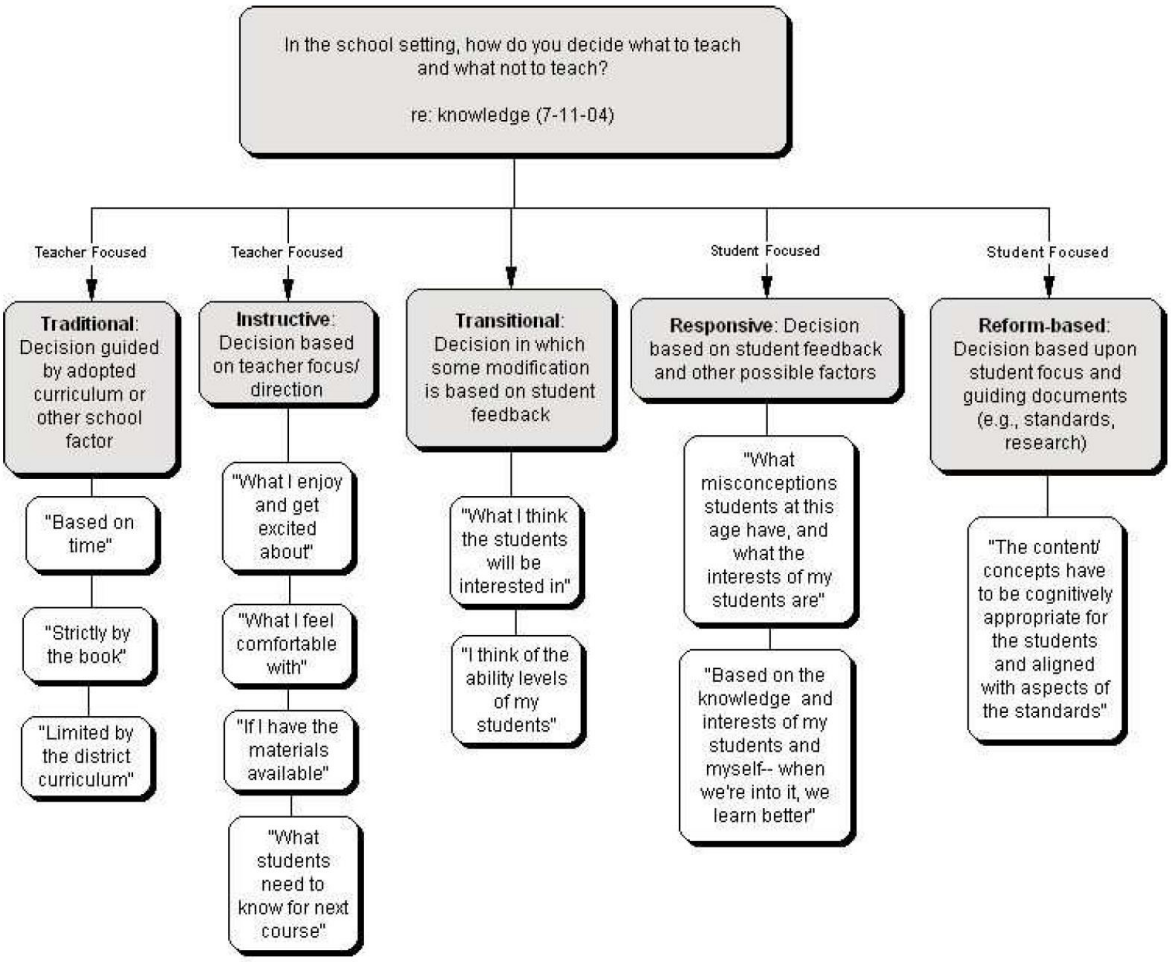
7. How do you know when learning is occurring in your classroom (Student Response)?

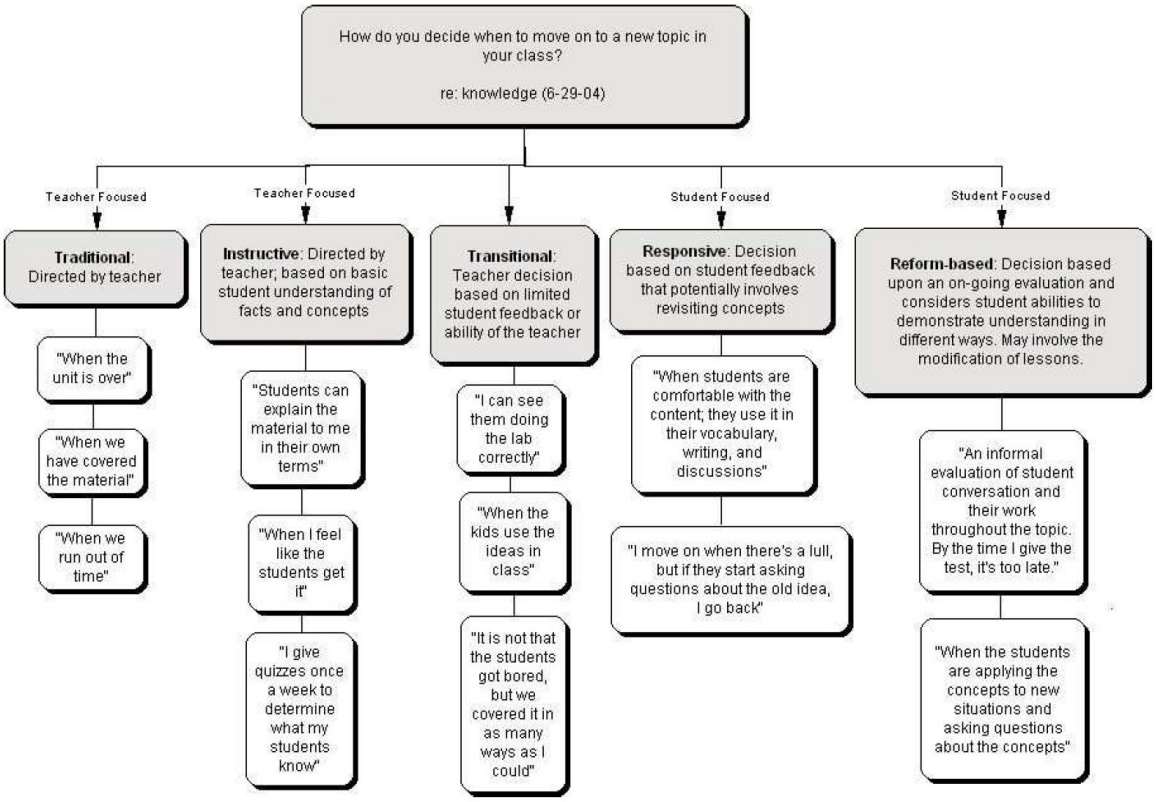
Appendix 4: Teacher Belief Interview (TBI) Coding Maps

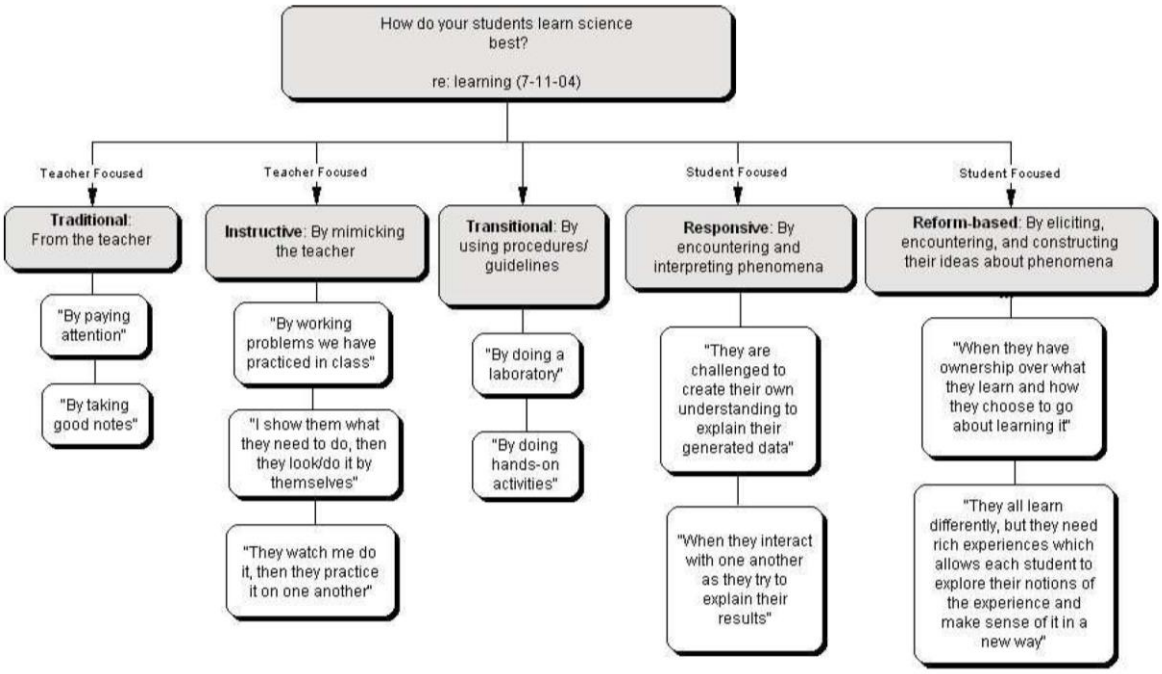


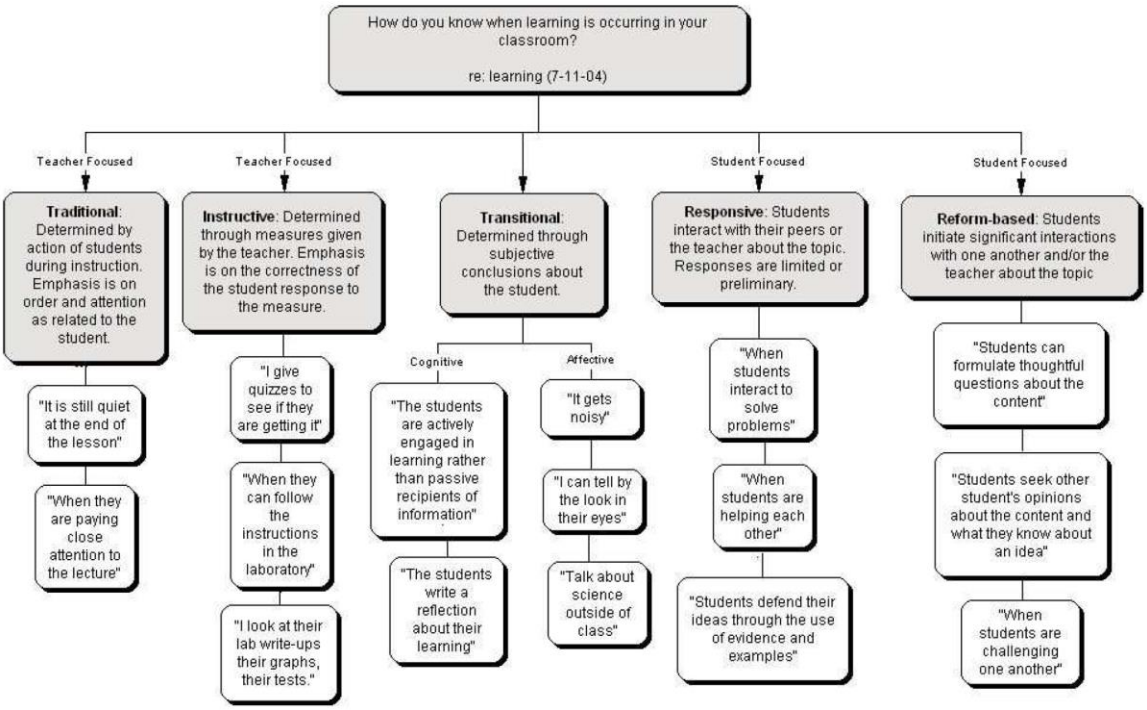

How do you describe your role as teacher?
re: knowledge (7-11-04)
Teacher Focused
Traditional: Focus on information and structure
"All knowing sage"
"Deliverer of information"
"I need to provide consistent routines and classroom rules"
Teacher Focused
Instructive: Focus on providing experiences
"To provide materials and opportunities for students to learn"
"I maintain student focus to minimize management issues"
Transitional: Focus on teacher/student relationships or student understanding
Student
"I need to develop a good rapport with my students"
"You have got to make the students feel comfortable or they will have a difficult time learning"
Content
"To guide the students in developing conceptual understanding and critical thinking skills"
Student Focused
Responsive: Focus on collaboration between teacher and student
"To set up my classroom so that my students can take charge of their own learning"
Student Focused
Reform-based: Focus on mediating student prior knowledge and the knowledge of the discipline
"I am a tour guide who helps students make sense of their surroundings in a manner that is consistent with what is known"


How do you know when your students understand?
re: learning (6-29-04)
Teacher Focused
Traditional: When they receive the information
"It is important that they hear it three times"
"We covered it in class"
"When I cover the lesson in different ways."
Teacher Focused
Instructive: When they can reiterate or demonstrate what has been presented
"When they can do well on a practical examination"
"When they can use their own words to explain a concept"
"When they can repeat the answer on a written test, and the answer is correct"
Transitional: When they give an explanation or response that is related to the presented information
Knowledge
"When they talk about the presented knowledge in new ways"
"When they can ask a basic question of a student during a presentation"
Affective
"Their faces light up"
"They get excited"
"When they are animated about the lesson outside of class"
Student Focused
Responsive: When they can utilize the presented knowledge
"When they can clearly defend their ideas using evidence and examples they experienced"
"When they can discuss new phenomena that they encounter in class"
Student Focused
Reform-based: When they can apply knowledge in a novel setting, or construct something novel that is related to the knowledge
"They can come up with questions or comments that represent an understanding of the topic. Often these questions use the knowledge in a new situation that we have not experienced in class. "
"One of my students used trigonometry to solve physics problems"
"When students can question and dialogue in manner that expands their understanding. For example, they can successfully understand how a chemical reaction can be altered with the modification of element."


In the school setting, how do you decide what to teach and what not to teach?
re: knowledge (7-11-04)
Teacher Focused
Traditional: Decision guided by adopted curriculum or other school factor
"Based on time"
"Strictly by the book"
"Limited by the district curriculum"
Teacher Focused
Instructive: Decision based on teacher focus/ direction
"What I enjoy and get excited about"
"What I feel comfortable with"
"If I have the materials available"
"What students need to know for next course"
Transitional: Decision in which some modification is based on student feedback
"What I think the students will be interested in"
"I think of the ability levels of my students"
Student Focused
Responsive: Decision based on student feedback and other possible factors
"What misconceptions students at this age have, and what the interests of my students are"
"Based on the knowledge and interests of my students and myself-- when we're into it, we learn better"
Student Focused
Reform-based: Decision based upon student focus and guiding documents (e.g., standards, research)
"The content/ concepts have to be cognitively appropriate for the students and aligned with aspects of the standards"


How do you decide when to move on to a new topic in your class?
re: knowledge (6-29-04)
Teacher Focused
Traditional: Directed by teacher
"When the unit is over"
"When we have covered the material"
"When we run out of time"
Teacher Focused
Instructive: Directed by teacher; based on basic student understanding of facts and concepts
"Students can explain the material to me in their own terms"
"When I feel like the students get it"
"I give quizzes once a week to determine what my students know"
Transitional: Teacher decision based on limited student feedback or ability of the teacher
"I can see them doing the lab correctly"
"When the kids use the ideas in class"
"It is not that the students got bored, but we covered it in as many ways as I could"
Student Focused
Responsive: Decision based on student feedback that potentially involves revisiting concepts
"When students are comfortable with the content; they use it in their vocabulary, writing, and discussions"
"I move on when there's a lull, but if they start asking questions about the old idea, I go back"
Student Focused
Reform-based: Decision based upon an on-going evaluation and considers student abilities to demonstrate understanding in different ways. May involve the modification of lessons.
"An informal evaluation of student conversation and their work throughout the topic. By the time I give the test, it's too late."
"When the students are applying the concepts to new situations and asking questions about the concepts"


How do your students learn science best?
re: learning (7-11-04)
Teacher Focused
Traditional: From the teacher
"By paying attention"
"By taking good notes"
Teacher Focused
Instructive: By mimicking the teacher
"By working problems we have practiced in class"
"I show them what they need to do, then they look/do it by themselves"
"They watch me do it, then they practice it on one another"
Transitional: By using procedures/ guidelines
"By doing a laboratory"
"By doing hands-on activities"
Student Focused
Responsive: By encountering and interpreting phenomena
"They are challenged to create their own understanding to explain their generated data"
"When they interact with one another as they try to explain their results"
Student Focused
Reform-based: By eliciting, encountering, and constructing their ideas about phenomena
"When they have ownership over what they learn and how they choose to go about learning it"
"They all learn differently, but they need rich experiences which allows each student to explore their notions of the experience and make sense of it in a new way"


How do you know when learning is occurring in your classroom?
re: learning (7-11-04)
Teacher Focused
Traditional: Determined by action of students during instruction. Emphasis is on order and attention as related to the student.
"It is still quiet at the end of the lesson"
"When they are paying close attention to the lecture"
Teacher Focused
Instructive: Determined through measures given by the teacher. Emphasis is on the correctness of the student response to the measure.
"I give quizzes to see if they are getting it"
"When they can follow the instructions in the laboratory"
"I look at their lab write-ups their graphs, their tests."
Transitional: Determined through subjective conclusions about the student.
Cognitive
"The students are actively engaged in learning rather than passive recipients of information"
"The students write a reflection about their learning"
Affective
"It gets noisy"
"I can tell by the look in their eyes"
"Talk about science outside of class"
Student Focused
Responsive: Students interact with their peers or the teacher about the topic. Responses are limited or preliminary.
"When students interact to solve problems"
"When students are helping each other"
"Students defend their ideas through the use of evidence and examples"
Student Focused
Reform-based: Students initiate significant interactions with one another and/or the teacher about the topic
"Students can formulate thoughtful questions about the content"
"Students seek other student's opinions about the content and what they know about an idea"
"When students are challenging one another"

Appendix 5: Case study interview questions

I'm interested in learning about specific things that prompt some people to have a greater interest in teaching than others. Everything you tell me during the interview is strictly confidential and your cooperation is totally voluntary. I'd like to tape this interview, so that I can focus on what you are saying and accurately record what you tell me. Is this okay?

The questions are broken down into three sections: questions about when you began thinking about teaching, your university experiences, and your individual experiences.

1. To begin, can you tell me a bit about your research?
    a. The last time we spoke you were a PhD student/post-doc. Has your status changed since we last spoke?

2. Who have you discussed career options with?
    a. What options have you discussed or considered?
    b. Which of these options appeal to you?

3. Why does a future academic career interest you?

4. (If they did not mention teaching… Academic careers often involve teaching)… Can you think of something that happened in your life that helped you develop your interest in teaching?
    a. (If do not mention pre-graduate school experiences…) In your pre-graduate school life, were there experiences that caused you to consider teaching?
    b. (If do not mention graduate school experiences…) In your graduate school career, were there things that led you to consider or continue to consider a career involving teaching? (How did those things influence you to consider teaching?)
    c. How did you know that teaching was something you might like or be good at?
    d. Has anyone supported or encouraged your interest in teaching? What did they say or do to support you?

5. In your entire experience as a student from K-12 to now, can you think of any specific experiences that impacted your current views on teaching or learning?

6. What do you consider to be the pros/cons of teaching in a college setting?

Ok, so we talked a little about how you became interested in teaching. Now, I'd like to focus on the way you teach and your teaching beliefs that cause you to teach that way.

7. I'd like you to describe the way you teach a class. What might I observe you doing if I were to sit in on your class?
    a. Why do you teach that way?

8. How do you think you acquired your teaching beliefs?
    a. What were some of the biggest influences on these teaching beliefs?

9. Have you participated in any professional development that may impacted your views on teaching? Can you describe this/these experience(s)?
    a. What were the themes/topics?
    b. How long was the workshop/course?
    c. What influenced your decision to participate?
    d. Why did you choose that specific opportunity?

For change participants: Did you participate in any other experiences between approx. March 2015 to March 2016 that may have impacted your views on teaching?

10. In your experience, do you feel that all departments view teaching the same way? (current institution vs undergraduate institution) Have you had experience with departments that view teaching different ways?
    a. Do you think any of that influenced your views on teaching?

11. Has your level of interest in teaching been influenced by any factors in your department or program?

12. How does your advisor view teaching?
    a. Is your advisor supportive of you seeking out opportunities to improve your teaching? Can you give me an example of their support?

13. Are there faculty members in your department who advocate for teaching? Have they influenced your interest in teaching in any way?

14. Have you actively sought out teaching opportunities or were they assigned?
    a. How did you view your role as a TA among all your other responsibilities?

15. Are you a part of a broader group or community that advocates or supports teaching?
    a. Why did you decide to be a part of this/these groups?

Now we're going to move on to more individual experiences.

16. What do you consider to be the rewards of teaching?
    a. Have you received any teaching related awards/recognition? Did that influence your interest or view on teaching?

17. How do you view your potential impact on students?
    a. What evidence do you have for this impact?
18. Has teaching had an impact on you personally? How?

19. Have there been any particular events that reinforce your beliefs about teaching or your teaching style?

20. DBER, discipline-based education research, studies the effectiveness of teaching practices in specific disciplines. Do you consider yourself informed about DBER in your field?
    a. Where/how were you exposed to DBER?
    b. Has the exposure to DBER influenced your classroom teaching? How?
    c. Could you provide an example of how you would implement a DBER supported teaching strategy in your classroom?

21. If you could design a program for new instructors, what are 3-5 topics you think it should feature? If you were to take a class for new instructors, what information would be useful to you?

22. If you received a faculty position, would you consider pursuing research on teaching or student learning?
    a. What aspects of teaching and learning would you be interested in researching?

Appendix 6: Case Study Codebook

1. **Influences on teaching beliefs**
    - 1.1 Positive influence of others (mentors, teachers, advisors)
        - 1.1.1 Graduate experience
        - 1.1.2 Undergraduate experience
        - 1.1.3 Earlier than undergraduate
        - 1.1.4 Unspecified
    - 1.2 Negative influence of others (mentors, teachers, advisors) unspecified
        - 1.2.1 Graduate experience
        - 1.2.2 Undergraduate experience
        - 1.2.3 Earlier than undergraduate
        - 1.2.4 Unspecified
    - 1.3 Professional development
        - 1.3.1 Exposure to literature on teaching / student learning
        - 1.3.2 Exposure to active learning
    - 1.4 Teach how they like to be taught
    - 1.5 Discussing with colleagues / friends / partner
    - 1.6 Observing others teach (outside of a student role)
    - 1.7 Experiences in the classroom as an instructor
    - 1.8 Working outside academia

2. **Influences on wanting to teach**
    - 2.1 Experience as a student
        - 2.1.1 Positive experiences from instructor
        - 2.1.2 Negative experiences from instructor
        - 2.1.3 Peer learning
    - 2.2 Experience in a teaching role
        - 2.2.1 Formal setting (TA)
        - 2.2.2 Informal setting (tutor, coach)
    - 2.3 Support/encouragement
        - 2.3.1 Family
        - 2.3.2 Mentor / advisor
        - 2.3.3 Instructor / other faculty
        - 2.3.4 Group / community that supports teaching

2.3.5 College / department
2.3.6 Growing up with teachers (e.g., mom was a teacher)
2.3.7 Peers

2.4 Discouragement from teaching
2.4.1 From advisor / mentor
2.4.2 From family / friends
2.4.3 From coach
2.4.4 From experiences as an instructor / TA
2.4.5 Lack of time
2.4.6 From college/department

2.5 Professional development experience
2.6 Students
2.6.1 Feedback by students
2.6.2 Impacting / Influencing students / helping students learn
2.7 Teaching award
2.8 Experience in a research-focused world
2.9 Flexibility
2.10 Improve self-knowledge / personal skills of the discipline

3. Influences on wanting a career involving teaching

3.1 Experience teaching
3.1.1 Formal (instructor / TA)
3.1.2 Informal (tutor / coach)

3.2 Perceptions or models
3.2.1 Flexibility
3.2.2 Enjoyment
3.2.3 Family in academia

3.3 Expertise
3.3.1 Creating own research group
3.3.2 Continuous learning

3.4 Own experience as a student
3.4.1 Positive
3.4.2 Negative

3.5 Impacting students
3.6 Working with peers
3.7 Professional development

4. Professional development and teaching opportunities

4.1 Finding and choosing

- 4.1.1 Referred by someone
- 4.1.2 Found by self
- 4.1.3 Chosen based on location
- 4.1.4 Required

4.2 TA/teaching opportunities

- 4.2.1 Assigned
- 4.2.2 Sought out

5. Useful topics for PD for new instructors

5.1 If participant were designing a course for new instructors:

- 5.1.1 Active learning
- 5.1.2 Assessments
- 5.1.3 Class organization/design/logistics
- 5.1.4 Communication/presentation skills
- 5.1.5 Diversity
- 5.1.6 Conflict resolution
- 5.1.7 Critical thinking
- 5.1.8 Comprehension
- 5.1.9 Determining your bias
- 5.1.10 Experiential learning
- 5.1.11 Employable skills
- 5.1.12 Group work
- 5.1.13 Learning objectives
- 5.1.14 Mentoring
- 5.1.15 Observing effective instructors
- 5.1.16 Quantitative tools
- 5.1.17 When things go wrong

5.2 If participant were taking a course for new instructors:

- 5.2.1 Active learning
- 5.2.2 Planning/organizing a class/logistics
- 5.2.3 Assessments
- 5.2.4 Diversity
- 5.2.5 When things go wrong
- 5.2.6 Creative exercises

5.2.7 Current info on pedagogy
5.2.8 Interdisciplinary learning
5.2.9 Teaching large classes
5.2.10 Teaching non-scientists
5.2.11 Time management