

The role of secondary STEM teacher professional development in integrating critical thinking skills through teacher perception and classroom observation

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M.S., University of Wyoming, 2016

Plan B Project
Submitted in partial fulfillment of the requirements for the degree of
Masters in Science in Natural Science in the Science and Mathematics Teaching Center
at the University of Wyoming, 2016

Laramie, Wyoming

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Abstract

Following the adoption of the Next Generation Science Standards (NGSS), drastic shifts in science teaching will be necessary to meet the standards. Because critical thinking skills are an underlying component of the NGSS, examining how educators are teaching critical thinking skills to their students can help to identify what additional shifts in practice must occur. Given the theoretical connections between teacher beliefs and classroom instruction, this research examined the how secondary science teachers participating in professional development perceived their ability to integrate critical thinking skills in the classroom. A mixed-methods approach consisting of self-reported questionnaires measuring teacher perception and classroom observation was used. Results from this research suggest that secondary science teachers who participate in sustained, responsive professional development decrease their concerns while increasing their perceived confidence and commitment to implement new educational reform in their classroom. Additionally, teachers' perceptions corresponded with their in-class teaching to varying degrees, as indicated by observation. This type of professional development can change teacher perception and that change can correspond to some classroom instructional shifts.

Acknowledgements

I would like to thank my committee members for supporting my in this research endeavor. A special thanks to Ana Houseal, the committee chair, for her relentless support and dedication to my growth and this process. Thank you to all of those who supported the professional development workshops whether it be reserving rooms, leading sessions, being a mentor, or helping to plan sessions. Thank you to all of the teachers who chose to undertake the MSP grant and commit to considering a change in one's practice.

Table of Contents

LIST OF TABLES	v
LIST OF FIGURES	vi
CHAPTER 1: INTRODUCTION	1
Statement of Problem.....	1
Purpose.....	2
Research Questions.....	6
CHAPTER 2: LITERATURE REVIEW	7
The Next Generation Science Standards	7
Effective Professional Development	9
The intersection of NGSS and Professional Development.....	11
Professional Development backed by research	12
The importance of critical thinking skills.....	15
What is critical thinking?.....	16
The role of the teacher in enacting change	19
Theoretical foundation for questionnaire used	21
CHAPTER 3: METHODS	23
Introduction.....	23
Population	23
Setting	23
Professional Development Workshop Summary	24
Data Sources	28
CHAPTER 4: RESULTS	35
Quantitative Results	35
Qualitative Results	39
Case 1: Colin	42
Case 2: Shannon	44
Case 3: Lindsey	46
Case 4: Jonathon.....	48
Case 5: Erin	49
Cross-case Comparisons.....	51
CHAPTER 5: DISCUSSION.....	54
CONCLUSION.....	63
REFERENCES	66

APPENDIX A: Critical Thinking Skills from “The Delphi Project”.....	71
APPENDIX B: Outlines for Workshops.....	77
APPENDIX C: CCSD MSP Teacher Consent Form.....	79
APPENDIX D: Concerns-Confidence-Commitment Questionnaire.....	80
APPENDIX E: NAP Report Committee Conclusions and Workshop Alignment.....	82

List of Tables

Table		Page
1	Relevant conclusions from a comprehensive study on supporting K-12 science teachers.....	14
2	Alignment of MSP grant workshops with characteristics of effective K-12 science professional development.....	27
3	Summary of Concern-Commitment-Confidence score and observation trends of five observed teachers.....	31
4	An example of the a priori template coding scheme.....	34
5	Example of applying codes to the transcription data.....	34
6	Significant changes in teacher perceptions during a workshop.....	36
7	Significance of overall change in teacher perception from October 2015 to March 2016.....	38
8	Percentage of concern comments by Stages of Concern.....	39
9	Summary of Concern-Commitment-Confidence scores and classroom observation trends of five observed teachers.....	53
A1	Critical thinking skills defined as per “The Delphi Project”.....	72
E1	Conclusions from a comprehensive study on supporting K-12 science teachers.....	81-83

List of Figures

Figure		Page
1	The influence of standards on the educational system (Bybee, 2014, pg. 214).....	4
2	Critical thinking skills as defined by The Delphi Project.....	17
3	Breakdown of Science and Engineering Practices (SEP) by grade level.....	19
4	Sample section of the Triple C-Q.....	29
5	Teachers' average self-reported concerns over three workshops.....	36
6	Teachers' average self-reported confidence over three workshops.....	37
7	Teachers' average self-reported commitment over three workshops.....	37
8	Average self-reported concern scores for observed teachers.....	40
9	Average self-reported confidence scores for observed teachers.....	41
10	Average self-reported commitment scores for observed teachers.....	41

Chapter 1: Introduction

Statement of Problem

More than 30 years ago the National Commission on Excellence in Education released a report entitled *A Nation at Risk*, which cautioned the United States about the perils of neglecting teachers' professional development in public schools (National Commission on Excellence in Education, 1983). According to reports issued by the National Academies of Science (2007), the nation has not heeded these warnings and its international standing and economic welfare have been impacted. For the past several decades, national and state reform efforts have been enacted to improve the quality of science education. Yet, many students still fall behind their international counterparts (Martin, Mullis, Foy, & Stanco, 2012), score below average on general science literacy (Miller, 2010), and, in many cases, receive substantially less instructional time on science at the elementary level (Banilower, Smith, Weiss, Malzahn, Campbell, & Weis, 2013).

The National Research Council (NRC) refers to teachers as the “linchpin in any effort to [reform] K-12 science education” (NRC, 2012, p. 255). Teachers directly impact student learning and are the most direct link between students and their exposure to the standards (Borko, 2004; Fullan, Hill, & Crevola, 2006). As such, it is imperative that teacher training programs and continuing professional development be considered when any reform is enacted. Given that the US continues to lag behind other countries in scientific literacy, educational reform can be used to help change current practices. In April 2013, the National Academies Press published the Next Generation Science Standards (NGSS) based on the *Framework for K-12 Science Education* (NRC, 2012) and is the most recent effort to enact improvement in science education. NGSS provides the basis for a new era of educational reform at national, state, and local levels that

target this active engagement and represents a “significant departure from past approaches to science education” (Bybee, 2014, p. 213). Implications of the standards include science education that involves the learning of facts as needed to develop explanations rather than the rote memorization of facts and the use of systems thinking and modeling rather than the learning of ideas disconnected from phenomena (National Research Council (NRC), 2015). Additionally, science education should include less teacher-driven instruction, fewer closed-ended questions, and fewer “cookbook” labs with one correct answer provided by the teacher (NRC, 2015). Instead it should be taught through student investigations driven by student questions with teachers as a guide and open-ended questions with multiple potential responses (NRC, 2015). As such, the changes implied by the NGSS (NGSS Lead States, 2013) and *Framework for K-12 Science Education* (NRC, 2012) have implications for the education of teachers. With the release of the NGSS, the nation has an opportunity to change the direction of science education and, perhaps, ensure all students improve their scientific literacy and gain understandings of core concepts within the field of science. The successful integration of these new approaches into the classroom may be aided by research-based recommendations on developing appropriate and effective teacher professional development.

Purpose

With the release of the NGSS, the US is at the forefront of another educational reform effort focused specifically on science standards. Given the large scale of this enactment, best practices of science education reform can be elicited through targeted efforts that draw on historical knowledge and comparisons. Unlike past science education reform models, the NGSS represent a new vision, which expect students to view science as a complex and intricate process that marries a body of knowledge with a set of practices and places them in connection with a

broader context (Bybee, 2014). This is evidenced by the conjecture that the best way to learn science is through the integration of three dimensions: disciplinary core ideas (the core content in science), science and engineering practices (the process of doing science), and cross-cutting concepts (the concepts that span multiple disciplines) (NRC, 2012).

Given these new expectations, it is reasonable to wonder what implications these expectations will have on the curriculum and the teachers in districts that adopt NGSS. Bybee (2014), with guidance from a 2002 National Research Council report (NRC, 2002), created a model describing the main ways through which educational reform influences the tiered levels of the educational system (Fig. 1). According to the model, three channels will be affected by NGSS: curriculum, teacher development, and assessment and accountability. It is critical that tools are developed concurrently alongside NGSS adoption in order to assist in these three realms. Some researchers have suggested models for understanding NGSS (Houseal, 2015; Brunsell, E., Kneser, D., & Niemi, K., 2014; Pellegrino, J., Wilson, M., Koenig, J., & Beatty, A., 2014; Pratt, H., 2013; Bybee, R., 2013), assessing alignment of lesson and units with respect to NGSS (e.g., EQUIP model), or new curricula materials and assessments to help support teachers integrating NGSS (e.g., Keeley, 2016; NSTA, 2014). However, without an additional focus on professional development, these resources will be insufficient (Rieser, 2013; Bybee, 2014; Miller et al., 2014). According to Rieser (2013), the necessary shifts in teachers' practice will require a systematic shift in how teachers approach lessons. As such, successful implementation of NGSS must be driven by concerted efforts targeting teachers and their professional development. Therefore, it will be important to identify best practices in professional development that addresses the systematic shifts inherent in NGSS.

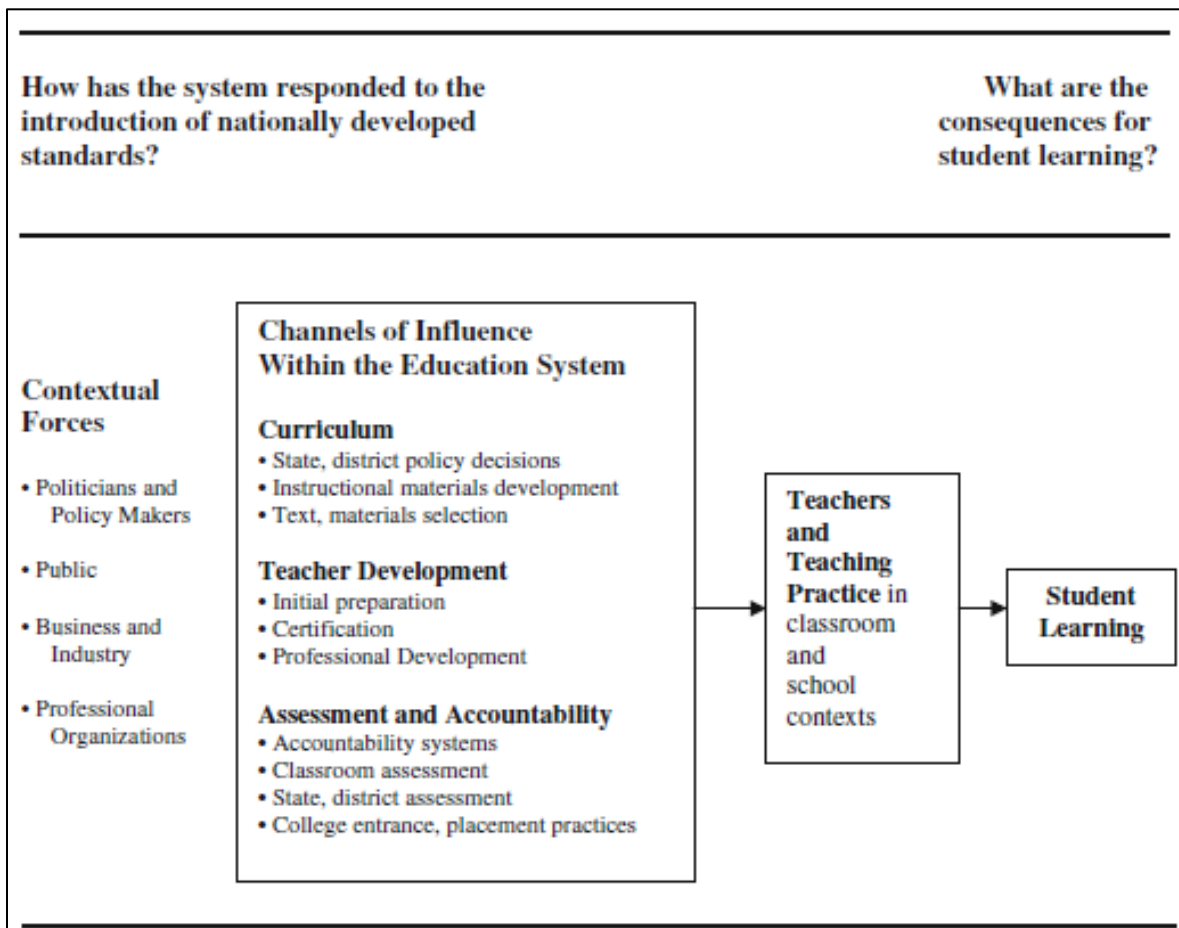


Figure 1: The influence of standards on the educational system. (Bybee, 2014, pg. 214) This figure illustrates the response of the system to the NGSS and consequences for student learning.

To assume that past professional development and implementation strategies will result in successful reform is unreasonable and unrealistic given the shift in emphasis of the standards and low science literacy currently documented in the literature (National Academies of Science (NAS), 2007). That said, teachers are largely responsible for successful implementation of NGSS because they are dictating and facilitating the standards for the students. Yet, many teachers may not be adequately equipped to teach in ways intended by NGSS, must alter the way in which they teach, and have limited experience in this kind of instruction (NAS, 2015). Therefore, teachers will need an intimate understanding of the standards and the ways in which they can be

successfully implemented. This understanding can be gained through intentionally designed professional development (NAS, 2015).

A 2012 National Survey of Science and Mathematics Education (NSSME) measuring teacher perception and self-reporting of instruction across a nationally representative sample at all grade levels found that teachers typically present material in more traditional ways, such as having the teacher explain a science concept or students completing worksheet problems (Banilower et al., 2013). This is counter to the vision of the NGSS, which seeks to engage students in investigating and discussing their emerging ideas. Therefore, reforming science instruction to fit the vision of the NGSS will depend on working with teachers to alter their current perceptions because a gap exists between the teacher practice and the vision of science learning in the NGSS (NAP, 2015).

The purpose of this research was to examine the impact of professional development workshops on teachers' perceptions of their ability to integrate innovative skills into the classroom. Specifically, the skills associated with critical thinking were chosen as the area in which to focus because they are embedded in the NGSS and prove to be an integral component in understanding the three dimensions of learning. Given the emphasis NGSS places on science as the integration of content and practice, it is important that students develop critical thinking skills in order to *do* science. This paper addresses what critical thinking skills are being implemented in the classroom, as a result of the professional development workshops and as evidenced by teacher perception and classroom observation.

Given that the NGSS is the most current reform effort to transform K-12 science education, a close examination of how supports such as professional development are being used to help educators adopt these new standards is imperative. Therefore, it is important to

understand how teachers are utilizing professional development and gaining the confidence to implement the skills required for the NGSS.

Research Questions

This pilot study explored how secondary science teachers who participated in a year-long voluntary, district-funded Math and Science Partnership Grant perceived their ability to integrate critical thinking skills, as outlined by The Delphi Project (in Appendix A). Specifically, this research focused on longitudinal data of teacher perceptions on integrating critical thinking skills after participating in a 1-day workshop emphasizing critical thinking in the classroom.

Additionally, it incorporated classroom observations of a lesson in which teachers attempted to integrate critical thinking skills to corroborate their self-reported perceptions. A mixed-methods approach was employed to help validate self-reported perceptions with actual teacher action in the classroom. The research questions that guided this study were:

- a. After participating in the CCSD MSP workshops, how has teacher perception of critical thinking skills changed over time based on self-reported Concerns-Confidence-Commitment Questionnaires?
- b. Based on classroom observations, how do teacher perception and teacher practice compare after participating in the CCSD MSP workshops?

Chapter 2: Literature Review

The Next Generation Science Standards

The release of the Next Generation Science Standards (NGSS) was the result of a 3-year process involving a collaboration led by the National Academy of Sciences. Development began in 2010 when the National Research Council (NRC) convened 18 prominent national and international experts to create *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* (NRC, 2012). This document, using current research in science and learning, was released in 2012 and outlined the science concepts and science and engineering practices in which every K-12 student should be proficient. Specifically, the *Framework* posits learning as a developmental progression in which core conceptual ideas build on each other in complexity as students advance through the grade levels. It was from this *Framework* that the NGSS were developed.

The NGSS (NGSS Lead States, 2013) were written by a committee of 41 scientists, educators, researchers, and state leaders, and 26 lead states that provided feedback on drafts of the standards. The process was facilitated by Achieve, Inc., a bi-partisan, not-for-profit organization that also supervised the creation of the Common Core State Standards in English/language arts and mathematics. Similar to the *Framework*, the NGSS emphasize the development of coherent learning progressions with deep conceptual understandings. Additionally, the standards are comprised of three dimensions of learning (disciplinary core ideas (DCI), science and engineering practices (SEP), and cross-cutting concepts (CCC)) (NRC, 2012) that necessarily must to be taught in context, integrated, and imparted through repeated experience (NGSS Lead States, 2013; Brunsell et al., 2014). The final version of the NGSS was released in 2013 and, as of February 2016, has been adopted officially by 16 states (National

Association of State Boards of Education (NASBE), 2016) and unofficially by many districts, schools, or individual teachers throughout the country (Pruitt, 2015). The integration of the three dimensions of learning represents a new way of teaching and learning science and has been described as one of the most challenging aspects of implementing the NGSS (Bybee, 2013).

Current attempts to implement professional development supporting the integration of the NGSS have been challenging because of the stark difference between the NGSS and past reform efforts. The expectations defined by NGSS emphasize the integration of all three dimensions of learning within the context of content (NGSS Lead States, 2013). Although the *National Science Education Standards* (NRC, 1996) termed “inquiry” (referring to inquiry teaching) as a cornerstone for science instruction, many teachers do not practice scientific inquiry, and it is often taught in isolation of any contextual relevance (Brunsell, E., Kneser, D., & Niemi, 2014). The emphasis on practice rather than solely content requires a shift in the way teachers think about teaching and, in turn, the ways in which professional development facilitators support that shift. Therefore, the release of the NGSS requires US educational systems to change the way in which they facilitate science professional development. In addition, Brunsell et al. (2014) conclude that “realizing the vision of *A Framework for K-12 Science Education* and the *Next Generation Science Standards* will require professional development of an unprecedented scale” (p. 2).

With the stage set for an overhaul of science teacher professional development, we have an opportunity to develop an understanding of science through a more integrated approach than in previous standards. As noted above, the NGSS are comprised of three dimensions of learning, which allow for the learning of science through the integration of content knowledge (DCI), scientific and engineering processes (SEP), and the application of cross-curricular themes

(CCC), such as identifying “patterns” or “cause and effect”, that can be transferred across disciplines. Although the CCC were present in the National Science Education Standards and American Association for the Advancement of Science Benchmarks, the emphasis was never enforced (NGSS Lead States, Appendix G, 2013). With this new understanding that science should be taught through three dimensions, the adoption of these distinctive and complex standards implies a considerable change in teaching practice and in the professional development required to implement these (Brunsell et al., 2014; Penuel, 2015; NGSS Lead States, 2013; Bybee, 2014).

There already has been a push to develop professional development related to NGSS (NRC, 2007; NGSS Lead States 2013; Brunsell et al., 2014). By and large, the focus of this professional development has been on building awareness of the standards. The NGSS are a set of standards that tell teachers *what* to teach, not curriculum or guidelines for *how* to teach (NRC, 2012). Therefore, it is time to shift the emphasis to professional development that builds teachers’ content and pedagogical knowledge in a way that they foster the implementation of NGSS into the classroom. Becoming aware of the standards and learning what they seek to accomplish is insufficient to effectively integrate them into the classroom. According to Pruitt (2015), “simply reading the NGSS does not lead to NGSS expertise” (p. 18). Therefore, there must be a more hands-on approach in which educators engage in curriculum design and discussion.

Effective Professional Development

As noted earlier, in comparison to past approaches to science education, the NGSS represent a new vision of science education reform. Teacher professional development is one channel through which such reform can be effectively integrated (Bybee, 2014). To evaluate

professional development, it is useful to first examine the context and guiding principles in which teacher professional development has been used and found effective. Although professional development will need an overhaul, professional development specific to the NGSS can be informed by these principles.

Little (1993) describes effective professional development as that which has the capacity to enable teachers to be “shapers, promoters, and well-informed critics of reform” (p. 130). Professional development can be divided into two models: External Expert Model (EEM) and Job-Embedded Professional Development (JEPD) (Strieker et al., 2012). The EEM uses external consultants to offer their expertise, with the expectation that teachers will return to the classroom and change their practices accordingly. A JEPD model emphasizes the need for on-going support, forums, and student-focused learning (Strieker et al., 2012). In the 1970’s and 1980’s, professional development began to shift from a reliance on the EEM to the JEPD model. Subsequent research indicated that the EEM model is unsuccessful (Calhoun & Allen, 1994; Whinnery, 1991) and that teacher knowledge and instruction and student achievement improved with sustained JEPD (Darling-Hammond & Ball, 2004; Darling-Hammond, Chung Wei, Andree, Richardson, & Orphanos, 2009; Garet, Porter, Desimone, Birman, & Suk Yoon, 2001; Guskey, 2003, 2009; Althausser, 2015; Fogarty & Pete, 2010; Hunzicker, 2011; Loucks-Horsley et al., 2003; Elmore, 2002; Darling-Hammond & Sykes, 1999). In 1994, the US Department of Education’s Office of Educational Research and Improvement declared JEPD as a means by which to connect teacher learning to student achievement (Vaughn, 1995).

Science professional development remains a promising means by which to change the direction of science education and increase science literacy. A growing body of research has identified several emergent characteristics that lead to high-quality, effective professional

development for K-12 science educators. The literature reveals the key components, which are valuable strategies for enabling growth in teachers. These components include: (a) collaboration (Beaudoin et al., 2013; Hestness et al., 2014; Houseal & Ellsworth, 2014; Hunzicker, 2011; Miller et al., 2014; Nagle, 2013; Passmore, 2015; Reiser, 2013; Wilson, 2013; Loucks-Horsley et al., 2003; Elmore, 2002; Darling-Hammond & Sykes, 1999), (b) active learning and modeling of content/strategies/ activities (Beaudoin et al, 2013; Hestness et al., 2014; Houseal & Ellsworth, 2014; Miller et al, 2014; Nagle, 2013; Reiser, 2013; Wilson, 2013; Loucks-Horsley et al., 2003; Elmore, 2002; Darling-Hammond & Sykes, 1999), and (c) integrated or interdisciplinary approaches to teaching (Beaudoin et al., 2013; Bybee, 2014; Fogarty & Pete, 2010; Hestness et al., 2014; Houseal & Ellsworth, 2014; Miller et al., 2014; Nagle, 2013; Passmore, 2015; Reiser, 2013; Wilson, 2013).

The intersection of NGSS and Professional Development

In summary, the NGSS is trying to shift science education from an emphasis on the content, or the *what*, in science to an integrated focus on the practice, or the *how*, of science. As described above, effective professional development incorporates collaboration, active learning, modeling, and job-embedded, sustained trainings. The professional development examined in this study blends the effective strategies of professional development found in the literature, with a concentrated emphasis on the shift required to implement the NGSS successfully.

This research examined a district-wide professional development workshop that received a Mathematics and Science Partnership (MSP) Grant for 3 years of sustained workshops in collaboration with university professors who were all seeking to achieve the same goal: to increase student achievement in the area of science. Specifically, the grant has three focal areas:

“...Investigating the essential role of reasoning, inquiry, and thinking in science; increasing the understanding of science content knowledge and skills and the implementation of the district science curriculum; and deepening the knowledge of staff on the development, use, and application of both formative and summative assessment”

The MSP program is a formula grant program to individual states that funds professional development designed to “increase academic achievement of students in mathematics and science by enhancing the content knowledge and teaching skills of classroom teachers” (U.S. Department of Education, 2015). The program centers on the premise that the collaboration of K-12 education and higher education institutions will benefit everyone. Thus, the partnerships must include faculty working at a science, technology, engineering, and/or mathematics institution of higher education and a “high needs” (not clearly defined in statute but used in relation to schools with a high number of uncertified teachers) school district. State education agencies may apply for an award, and local education agencies may apply for subgrants. Once states are granted funds, the state is responsible for administering a competitive grant competition. Grants are made to the partnership with which the state intends to work in order to improve teacher knowledge in mathematics and science education.

Professional Development backed by research

In an effort to identify how coherent support for elementary and secondary science teachers can be provided, a comprehensive study was conducted by a committee from the Board of Science Education (a sector of the Division of Behavioral and Science Sciences) and the Education of the National Academies of Science, Engineering, and Medicine (NAP, 2015).

Among other findings, the committee found that opportunities to collaborate with peers can best support learning. It also highlighted a current lack of exposure by the teachers to scientific and engineering practices and rich science experiences, the need of teachers to alter their teaching style, the benefits of involving administrators, and the need for long term, contextualized professional development that is driven by teacher learning needs and involves active participation of the teachers. In comparing the professional development associated with this research study and the committee's conclusions on effective teacher learning, there is much overlap. The workshops targeted components of all but one of the 13 conclusions recommended in the NAP report (NAP, 2015). For the purposes of discussion, the three most applicable conclusions have been selected and Table 1 shows the ways in which the MSP professional development aligned with these conclusions. For a complete list of the conclusions and alignment, refer to Appendix D. As is evidenced in both Table 1, there is a high degree of overlap between the emergent themes of high-quality professional development in the literature with the MSP Grant professional development workshops. Thus, one might expect that the professional development under study would result in effective teacher change according to the content discussed.

Table 1. Relevant conclusions from a comprehensive study on supporting K-12 science teachers (NAP, 2015).

The overlap between three of the committee’s conclusions and the research study’s professional development workshops.

Committee’s Conclusions	Professional Development Connections
<p>Conclusion 3: Typically, the selection of and participation in professional learning opportunities is up to individual teachers. There is often little attention to <i>developing collective capacity for science teaching</i> at the building and district levels or to <i>offering teachers learning opportunities tailored to their specific needs</i> and offered in ways that <i>support cumulative learning over time</i>.</p>	<ul style="list-style-type: none"> • This grant was a district-wide initiative with teacher from different schools around the district • Workshop sessions were planned in response to previous workshops and teacher surveys, such as the Triple C-Q. • The teachers committed to a year-long experience with professional development sessions scheduled at multiple times throughout the year
<p>Conclusion 5: The best available evidence based on science professional development programs suggests that the following features of such programs are most effective:</p> <ul style="list-style-type: none"> • <i>active participation of teachers</i> who engage in the <i>analysis of examples</i> of effective instruction and the analysis of student work, • <i>a content focus</i>, • <i>alignment</i> with district policies and practices, and • <i>sufficient duration</i> to allow repeated practice and/or reflection on class-room experiences. 	<ul style="list-style-type: none"> • Teachers were active participants in workshops as they observe and were observed in classroom settings and participated in debriefs and reflections of observed lessons • Teachers took on the role of students during modeling simulations (all lessons used in modeling were solicited lessons from the teachers or of standards directly applicable to teachers); teacher reflection discussions were used to analyze effective instruction and applicability to their content/class • Teachers create/modify curriculum to be used in their classroom. • Teacher discussion and activities often revolve around their curriculum and their content • The professional development sessions are facilitated by the District Secondary Science Coordinator; district policies and practices are considered in planning sessions • The workshops run from August 2015 – June 2016 with five total meeting periods and the grant was renewed for another year (sustained) • Classroom observations of participating teachers are conducted by other participating teachers and facilitators (feedback sessions follow all observations) to allow for repeated practice and reflection
<p>Conclusion 12: Closing the gap between the new way of teaching science and current instruction in many schools will require <i>attending to individual teachers’ learning needs</i>, as well as to <i>the larger system of practices and policies</i> (such as allocation of resources, use of time, and provision of <i>opportunities for collaboration</i>) that shape how science is taught.</p>	<ul style="list-style-type: none"> • Individual teachers’ learning needs are attended to by modifying workshops based on teacher feedback and concern (ex. Triple C-Q, teacher logs, prior workshops, informal interviews). • Some sessions are centered on discussion of what these changes mean for teachers and how they can move forward accordingly. • Access to resources and lesson alterations based on resources are considered in workshop sessions; Time management in planning and executing lessons was discussed • Teachers collaborated consistently with peers from schools around the district throughout the workshops

Note: Italicization added for emphasis to highlight components of the committee’s conclusions

The importance of critical thinking skills

The NGSS bring critical thinking to the forefront of science education (Alexander, 2014). Science is more than a series of facts that are used to understand natural systems. “At the core, science is fundamentally about establishing lines of evidence and using the evidence to develop and refine explanations using theories, models, hypotheses, measurements and observations” (NRC, 2008, p.18). “When learning science, one must come to understand both the body of knowledge and the process by which it is established, extended, refined and revised” (NRC, 2007, p. 26). Science involves the implementation of critical thinking skills to identify, evaluate, and refine these lines of evidence (NRC, 2007). Therefore, an individual must be able to think critically in order to do science (i.e., use evidence to create explanations). Given the emphasis NGSS places on science as the integration of DCI, CCC, and SEP, it is important that students develop critical thinking skills, so as to effectively understand the interaction between these three dimensions.

“Critical thinking is vitally important in the personal and civic life of all members of society. A significant percentage of the citizenry will not graduate from high school, or if they graduate, will not have the benefit of post-secondary education” (Facione, 1998, p.15). Therefore, explicit attention to fostering critical thinking skills should be a goal of K-12 education. Critical thinking is scattered throughout the NGSS implicitly with language such as *provide evidence that, support a claim, revise explanations based on evidence, evaluate the evidence for, engage in argument from evidence, and analyze data to...* The NGSS even state that the fundamental skills of critical thinking are “wedded to content...[and] intertwined in the standards” (NGSS Lead States, 2013b), yet they fail to elaborate on what critical thinking skills are or how they are to be taught.

The implicit quality of this language and the lack of definite explanation of what critical thinking entails is insufficient in helping teachers accomplish what is set forth in the NGSS. Teachers need explicit descriptions of critical thinking skills in order to implement NGSS because there is no direction in the standards as to how students should build the skills of critical thinking in order to *support, evaluate, and revise a claim*, let alone *develop coherent arguments* to participate in a productive discussion. As such, we need to know the extent to which teachers are able to change their practice to incorporate more critical thinking in the classroom.

What is critical thinking?

According to Bloom (1976) and Thompson (2011), critical thinking skills are a cognitive process that is achieved only through active methods of training; they are not a set of skills that can be developed through automatic and random experience (Oğuz & Sariçam, 2016). According to the NGSS Lead States FAQs (2013b), the scientific practices within the NGSS implicitly include and encompass the critical thinking skills used by scientists and engineers, but at no point in the standards are these skills defined. Therefore, an outside resource is needed to explicitly define what critical thinking entails. In 1990, a landmark report published by The Delphi Project delineated the findings of a two-year project defining critical thinking by consensus of international experts using the Delphi methodology. Figure 2 outlines the subskills that comprise critical thinking.

Cognitive Skills:
Skill 1: Interpretation
Subskill A: Categorization
Subskill B: Decoding Significance
Subskill C: Clarifying meaning
Skill 2: Analysis
Subskill A: Examining Ideas
Subskill B: Identifying Arguments
Subskill C: Analyzing Arguments
Skill 3: Evaluation
Subskill A: Assessing Claims
Subskill B: Assessing Arguments
Skill 4: Inference
Subskill A: Querying Evidence
Subskill B: Conjecturing Alternatives
Subskill C: Drawing Conclusions
Skill 5: Explanation
Subskill A: Stating Results
Subskill B: Justifying Procedures
Subskill C: Presenting Arguments
Skill 6: Self-Regulation
Subskill A: Self-Examination
Subskill B: Self-Correction

Figure 2: Critical thinking skills as defined by The Delphi Project. This figure breaks down the skills and subskills comprised in the term “critical thinking skills” as determined by the Delphi Project.

This set of skills, as described in the Delphi Report (APA, 1990), provides a framework that can help teachers more explicitly learn and teach the transferable critical thinking skills embedded within the NGSS. In examining the three dimensions of the standards with the skills of critical thinking defined by the Delphi Project, there is extensive overlap among the SEP’s. A breakdown of the SEPs associated with Middle School and High School standards can be found in Figure 3. As is evident by the table, there is an emphasis at these grade levels on SEP#2, 5, and 6 as well as SEP #4 and 7. Critical thinking skills are necessary for, and foundational to, effectively achieving these SEPs. The critical thinking skills outlined by the Delphi Project represent prerequisite or supporting skills to those of the SEPs, which students are expected to

understand. The Delphi Project provides a list of skills that, if mastered, will provide the means by which to achieve proficiency in the SEPs. For example, SEP #4 centers on the ability to analyze and interpret data. Two of the goals set forth by NGSS for this practice are that, by grade 12, students should be able to “analyze data systematically...” (NRC, 2012, pp. 62) and to “evaluate the strength of a conclusion that can be inferred from any data set...” (NRC, 2012, pp.63). In order to *analyze data*, one must be able to interpret the data (Skill 1 of the Delphi Project) before they can examine, identify, and analyze it (Skill 2 of the Delphi Project). “*Evaluating the strength of a conclusion*” requires that one assess claims and arguments (Skill 3 of the Delphi Project), infer how those arguments support or refute the current explanation (Skill 4 of the Delphi Project), and explain how those arguments might change or further solidify the working explanation (Skill 5 of the Delphi Project). Lastly, throughout the process of progressing through SEP #4, using metacognition to examine one’s interpretations and correct one’s model is vital to analyzing and interpreting data within a larger context of meaning (Skill 6 of the Delphi Project).

As is evidenced in this example, the critical thinking skills presented in the Delphi Project represent a highly integral and foundational component to achieving mastery of the SEP, as they are the underlying skills and thought processes necessary for being able to achieve such mastery. Similar connections can be drawn between the other SEP and the Delphi Project’s critical thinking skills. Therefore, it is important that educators are building in opportunities for students to learn about and practice critical thinking skills, if students are to become proficient at the SEP outlined in the NGSS. They are intertwined in the standards (NGSS, 2013), and the SEPs overlap extensively with the Delphi Project’s delineation of critical thinking skills.

Scientific and Engineering Practices (SEPs)								
Grade level	SEP #1- Asking questions (science)/Defining problems (engineering)	SEP #2 - Developing and using models	SEP #3 - Planning and carrying out investigations	SEP #4 - Analyzing and interpreting data	SEP #5 - Using mathematical and computational thinking	SEP #6 - Constructing explanations (science)/Designing solutions (engineering)	SEP #7 - Engaging in arguments from evidence	SEP #8 - Obtaining, evaluating and communicating information
K	X	X	X (2)	X (4)		X	X	X
1	X	X	X (3)	X		X (4)		X
2	X	X (3)	X (3)	X (2)		X (3)	X	X
3	X (2)	X	X (2)	X (3)		X (2)	X (4)	X
4	X	X (3)	X (3)	X		X (5)	X	X
5		X (4)	X (2)	X	X (2)		X (3)	X
Focus by grade	3	2, 4, & 5	K-5	K, 2, & 3	5	1, 2, 3, & 4	3 & 5	K-5
M.S.	X (3)	X (16)	X (5)	X (9)	X (2)	X (12)	X (7)	X (4)
H.S.	X (3)	X (15)	X (5)	X (5)	X (14)	X (17)	X (7)	X (5)

Developed by A. Houseal and M. Inouye for the CCSD MSP grant 2015-2016

Figure 3: Breakdown of Science and Engineering Practices (SEP) by grade level. This table illustrates the number of times each SEP appears in the standard as indicated by the X (number in parentheses indicates number of occurrences) in Kindergarten (K) through 5th grade, middle school (M.S.) and high school (H.S.).

The role of the teacher in enacting change

NSTA (2013) notes that teachers’ professional development is a critical factor in delivering science. Thus, achieving the goals of the NGSS will require a concerted effort to assist teachers not only in understanding the implications of the NGSS for student learning, but also in building a range of instructional strategies that will support students in all three dimensions of the NGSS as they progress toward mastery of the new standards. As part of building instructional strategies, current teacher

instructional strategies must be considered and vetted against the shift in science education that is required to adopt NGSS.

A wealth of literature provides evidence that individuals are guided by their beliefs and that teachers, specifically, are guided by their beliefs when developing curriculum and instructing in the classroom (Sandholz et al., 1997; Guskey, 2002b; Fullan, 2003; Palak & Walls, 2009). Additionally, when individuals are confronted with an innovation (e.g., a new strategy or conceptual shift), they proceed through stages of acceptance as they tackle concerns at individual and then social levels (Hall & Loucks, 1977); teachers undergo a similar process (Hall, Wallace, & Dosett, 1973). In fact, a major guiding principle of effective professional development is that professional development should engage teachers in experiences that cause them to confront their beliefs, knowledge, and habits of practice (Loucks-Horsley et al., 2003; Elmore, 2002; Darling-Hammond & Sykes, 1999). Desimone (2009) proposed a model of professional development emphasizing affective variables as part of teachers' process of development, while Loucks-Horsley et al. (2003) contend that teacher beliefs directly impact goals, planning, and instruction.

To provide insight into how best to support teachers in adopting the NGSS without considering the affective components of teacher practice would be to disregard a major potential impediment to change. Therefore, studies examining teacher practice must include an exploration of teachers' perceptions because they influence how teachers act in the classroom (Pajares, 1992). This research examined teachers' affective perceptions as related to their concerns, confidence, and commitment to integrating critical thinking skills into their classroom.

Theoretical foundation for questionnaire used

Ford's (1992) Motivation Systems Theory acknowledges two types of personal agency beliefs that play crucial roles in achieving one's desired goals. The first type of belief is that of capability belief (synonymous with Bandura's (1997) concept of self-efficacy), which are beliefs about one's ability to achieve an intended goal. Further, these beliefs may be the best indicator of the decisions individuals make (Bandura, 1997). In terms of the current research study, capability beliefs would be a teacher's belief that he/she can effectively integrate critical thinking into the classroom. Corroborating the importance of considering teacher beliefs, Rosenfeld and Rosenfeld (2008) recommend that professional development and teacher belief systems be linked. In other words, beliefs affect actions, so teacher beliefs play a critical role in effectively implementing any education reform efforts brought to the forefront of K-12 education. Given the important role that capability beliefs play in determining teachers' instruction and the role that professional development can play in assisting teachers in changing beliefs, teachers' affective self-perceptions as a result of the professional development workshops need to be assessed.

By also using direct observation of classroom instruction, this mixed-methods approach provided a means by which to compare teachers' self-perception with actual practice. Influenced by Good and Brophy's (1974) findings that teachers' self-reports and actual behavior do not always align, Estacion et al. (2004) emphasized the importance of direct classroom observations to capture a more complete picture of teacher practice. Classroom observations were used as a form of data triangulation to substantiate the self-reported questionnaire data (Merriam, 1998). As such, the observations served as a more objective examination of subjective self-perceptions (Fraenkel & Wallen, 2003).

When canons and procedures are explicit, qualitative data can be systematically evaluated (Corbin & Strauss, 1990). In this research, grounded theory (Corbin & Strauss, 1990; Glaser, 1978; Glaser & Strauss, 1967; Strauss, 1987) was used as the foundation from which classroom observational data were collected and analyzed. Grounded theory arose in 1967 and was designed to provide a theoretical explanation of social phenomena that explains as well as describes (Strauss & Corbin, 1990). As a researcher applying grounded theory, one is responsible for capturing the interplay between relevant conditions and a subject's response to change (Strauss & Corbin, 1990). To assure credibility of data collected via classroom observations and to avoid research bias, methods described in the literature were utilized and/or modified when necessary.

Chapter 3: Methods

Introduction

To better understand how teacher perception has changed over time in association with professional development, a mixed-methods study was conducted through the use of self-reported questionnaires, classroom observations, and teacher correspondence. IRB approval for all data collection and methodology was received in the fall of 2015 prior to the start of the study. Consent forms were obtained from all participants (see Appendix C). Additionally, copies of lesson materials from the teachers who were observed were collected.

Population

The criteria for participation in the study were secondary STEM teachers from the Campbell County School District who self-selected to participate in a series of professional development workshops funded through a Math and Science Partnership grant in the district. After attending an informational meeting in the spring of 2014, interested teachers voluntarily enrolled in the program. All teachers who participated were given a stipend for their time and effort and the option to receive graduate level credits. A total of 27 teachers participated in the workshops. The grant itself began in 2012 with initial work focused on elementary teachers, so the six 6th grade teachers who participated in the grant had been attending workshops for the previous two years, while this was the first year that teachers in older grades were able to participate.

Setting

Campbell County School District was located in the sparsely populated, rural western state of Wyoming. As of 2014, it was the third largest school district in the state with close to 9,100 students. The largest town in the district has a population of approximately 32,000, with

smaller towns across 4,761 square miles and a total county population of approximately 48,000. It was designated as *high needs*¹ by the state in 2009, 2010, 2011, 2012, and 2014 for five of the last six reported years. As reported on the Wyoming Department of Education-684 (a collection of student demographic, enrollment, and course information), the district serves 26.0% free and 10.2% reduced lunch, 10.6% Hispanic or Latino, 14.1% SPED, and 6.6% Gifted and Talented Education students.

The professional development workshop sessions took place at the Ocean Breeze Education Center in Gillette, which houses the central administration offices and provides a professional development venue for the district. All classroom observations were conducted in Gillette at six different schools ranging from elementary (6th grade) to high school.

Professional Development Workshop Summary

The target of this study was a professional development project made feasible by a Math and Science Partnership grant and organized by the district's secondary science coordinator and University of Wyoming faculty and staff. Research was conducted during the third year of the grant, although it was the secondary science teachers' first year in the grant. The participating 6th grade teachers, the science coordinator, and University faculty and staff had been involved in the grant prior to the study year. The professional development sessions under study were created and facilitated by the District Science Coordinator for Secondary education alongside numerous faculty and staff within the Colleges of Education and Arts and Science at the state's land-grant university.

¹ As defined by the No Child Left Behind Act of 2001, "high needs" refers to a school that falls under one of the following categories: (a) is within the top quartile of elementary and secondary schools statewide; (b) is located in an area where at least 30 percent of students come from families with incomes below the poverty line; or (c) is located in an area with a high percentage of out-of-field-teachers, high teacher turnover rate, or a high percentage of teachers who are not certified or licensed.

The professional development experience was organized as a year-long commitment in which participants would meet for five, multi-day workshops beginning in August before the school year started and ending in June after the school year ended. The primary facilitator, who was the district's secondary science coordinator, held the overall vision for the professional development and sought assistance from university faculty and staff for instruction, facilitation, and session development. Prior to the March 2015 workshop, the science coordinator chose The Delphi Project as the primary source for defining, understanding, and creating a common language around critical thinking skills. As a way to introduce teachers participating in the MSP Grant to the elements of critical thinking, workshop facilitators provided them with the full report to read, discuss, identify, and practice ways in which to teach to it. By emphasizing critical thinking skills in teacher professional development, workshop facilitators promoted the integration of skills that will help students master the dimensions of NGSS, highlighting specifically the SEP.

Guskey (1995) and Hargreaves (1995) posit that teachers are less likely to embody school innovations when they are denied input into their own professional development. Therefore, facilitators of the workshop sought opinions from the participants and used their input when planning future workshops. Specifically, Triple C-Q results were analyzed after each workshop and used to inform the next workshop along with prior experience working with these teachers. An agenda of the sessions specific to the March 2016 workshop can be found in Appendix B.

Professional Development alignment

In this study, a set of yearlong, professional development workshops associated with a district-wide MSP grant were used as the vehicle through which to measure teacher perceptions. The workshops were organized and facilitated by faculty and staff at the University of Wyoming

and by the secondary science coordinator for the school district under study. Throughout the year, they emphasized collaboration and peer-observation, the modeling of critical thinking integration, exposure to the standards through modeling and discussion, active participation of the teachers, attention to the teachers' learning needs with the use of surveys, and the incorporation of classroom observations. All of this was done within the context of job-embedded professional development, which was sustained over the entire 2015-2016 academic year. Each session was planned with the individual teachers in mind and informed by the teachers' feedback. Teachers were also supported by being provided substitute teachers during the workshops. In considering the characteristics of effective K-12 science professional development found in the literature (collaboration, active learning, modeling, and integrated approaches to teaching), the workshops aligned strongly. Table 2 depicts this alignment, which reinforces the overlap described in the Literature Review between the professional development workshops and the NAP conclusions (refer to Table 1 and Appendix D).

Table 2. Alignment of MSP grant workshops with characteristics of effective K-12 science professional development

Characteristics of effective professional development	Professional development connections
External Expert Model (EEM)	Faculty from the state land-grant University were brought in to offer their expertise
Job-Embedded Professional Development Model (JEPD)	On-going support for teachers with focus on increasing student learning of NGSS
Collaboration**	Teachers worked collaboratively with their peers to gain a better understanding of the standards and effective instructional strategies, participate in discussions, plan lessons, and reflect upon classroom observations.
Active learning and modeling of content/ strategies/ activities**	Teachers were active participants in all sessions as they became students in model lessons and were asked to engage through writing, discussing, reflecting, and doing. Teachers practiced metacognitive skills by reflecting upon the efficacy of a modeled activity or strategy and analyzed the target content material for that modeled activity or strategy.
Integrated or interdisciplinary approaches to teaching***	The integration of content and skill are inherent in the NGSS, so this integration was modeled, explicitly discussed, and used to assess lesson ideas. Discourse on the ability to integrate math and language arts into science curriculum was one tool facilitators used to promote interdisciplinarity and integration.

* Beaudoin et al., 2013; Hestness et al., 2014; Houseal & Ellsworth, 2014; Miller et al., 2014; Nagle, 2013; Reiser, 2013; Wilson, 2013

+Darling-Hammond & Sykes, 1999; Elmore, 2002; Loucks-Horsley et al., 2003

**Bybee, 2014; Fogarty & Pete, 2010; Passmore, 2015

DATA SOURCES

A study examining human subjects and self-perceptions has inherent potential for bias. A mixed methods approach was used to minimize potential errors arising from a single technique, and to maximize the conclusions drawn from data analysis (Palak and Walls, 2009; Patton, 2002; Tashakkori & Teddlie, 2003). Additionally, a mixed method approach was utilized to triangulate data and increase the validity and reliability of the data and their interpretations (Zohrabi, 2013). Quantitative data collected via a questionnaire were used to answer research question (a). Qualitative data from classroom observations and open-ended questionnaire responses were used to deepen the answer to research question (a) as well as to answer research question (b).

Quantitative sources. Quantitative data were collected for the study using the Concerns-Confidence-Commitment Questionnaire (Triple C-Q) in order to target the affective component of teacher change. Specifically, the questionnaire measured teacher concern about, confidence in, and commitment to developing, integrating, and evaluating a particular skill in the classroom. The questionnaire made use of both closed-ended questions (scale) and open-ended questions (Blaxter et al., 2006) because close-ended questions lend themselves easily to analysis (Seliger & Shohamy, 1989) while open-ended questions more accurately represent a respondent's opinions (Nunan, 1999). The Triple C-Q is a self-reporting survey composed of three sections of three, 10-point Likert-scale statements each accompanied by an open-response prompt to elaborate on reported scores. Figure 4 provides an example of what teachers would see on the questionnaire. For a complete questionnaire, see Appendix C.

Using a scale of 1 to 10 described below, enter your level of **concern** for each item in the table.

1 ←-----→ 10

		Rating
1	When it comes to DEVELOPING science lessons that incorporate CRITICAL THINKING SKILLS (as defined by The Delphi Report), my level of concern is ...	
2	When it comes to IMPLEMENTING science lessons that incorporate CRITICAL THINKING SKILLS (as defined by The Delphi Report), my level of concern is ...	
3	When it comes to EVALUATING science lessons that incorporate CRITICAL THINKING SKILLS (as defined by The Delphi Report), my level of concern is ...	
Comment section: Briefly describe any concerns that influenced your rating above My concerns are.....		

Figure 4. Concerns section of the Concerns-Confidence-Commitment Questionnaire given to teachers during the professional development workshops.

The questionnaire was developed with large influence from the Concerns-Based Assessment Model (CBAM). The CBAM grew out of Francis Fuller’s studies exploratory and descriptive studies on concerns theory, which was the foundation for Hall & Hord’s (1987) widely cited model for teacher development used to assess teacher concerns with regard to the adoption of an innovation (Conway & Clark, 2003). The CBAM is a valid and reliable model that has been used extensively within the United States (e.g., Hord & Hall, 2000; Anderson, 1997; Hall & Hord, 1987; James & Hall, 1981; Hall, 1979; Hall & George, 1979; Hall & Loucks, 1978), Western Europe (e.g., van den Berg & Ros, 1999; van den Berg, 1993; Huberman & Miles, 1984), and Australia (e.g., Marsh & Penn, 1988; Marsh, 1987).

In addition to tracking concerns when measuring change as a result of exposure to an innovation, both social cognitive theory (Bandura, 1977; Bargh et al., 2010) and the transtheoretical model (Prochaska et al., 1992), two widely acknowledged theories of change posit that motivation (i.e., a desire, need, intention, readiness, or commitment to change; DiClemente et al., 2004) and self-efficacy (i.e., a belief in one’s ability or confidence; Bandura, 1977; Bandura, 1982) are necessary for behavioral change. As a result, both commitment and confidence, indicators of motivation and self-efficacy, respectively, were included as indicators of change in the Triple C-Q.

Given the reliability and validity of the CBAM and the support of motivation and self-efficacy as indicators of change, the Triple C-Q is adapted from the CBAM and includes components in which teachers rated their concerns, confidence, and commitment with regard to developing, integrating, and evaluating the innovation of critical thinking skills into their classroom.

The questionnaire was presented using the self-administered method (Brown, 2001) via an email link. The link was electronically sent to teachers' school email accounts the day before the workshop began and again the afternoon the workshop ended. All teachers were verbally reminded the morning the workshop began and during the last hour of the workshop to complete the questionnaire. One follow-up email was sent two days after the workshop ended to participants who had not yet completed it.

Participants were given the Triple C-Q prior to and immediately following the workshops in October 2015, January 2016, and March 2016. All questionnaires were analyzed for all participants who attended these workshops and completed the questionnaire. The Triple C-Q was analyzed using descriptive statistics. The hierarchical Stages of Concern (SoC), as developed by Hall et al. (1973) were used to analyze participants' open-ended comments with regard to their concerns. The SoC is divided into seven stages that reflect three dimensions: self (awareness, informational, and personal), task (management), and impact (consequence, collaboration, and refocusing). "As the adoption process unfolds, each individual's use of the innovation should progress toward sophisticated levels, and concomitantly, the stage of concern should progress toward renewal concerns" (Hall et al., 1973, p.17).

Validity. Content validity of the questionnaire was sought by creating the questionnaire based on the widely-accepted CBAM questionnaire. Internal validity was addressed through:

triangulation of questionnaire, observation, and pre-observation summary; member checks; examination of data by others professionals involved in the grant.

Qualitative Sources. Qualitative data were collected through direct classroom observation, arising from purposeful or convenience sampling. At the end of the March 2016 workshop, teachers were tasked with creating/modifying a lesson of their choosing to incorporate at least one critical thinking subskill as outlined in The Delphi Project. The researcher obtained the consent of five teachers to be observed when they executed this modified lesson. These teachers varied in teaching experience (2 years to >15 years), time involved in the grant (1st – 3rd year), gender (2 males, 3 females), grade level taught (6th, 6th, 7th, 7th, and 9th grade), and subject matter taught (Earth Science, Biology, Physical Science); see Table 3 for a summary. These five teachers were observed within two weeks of the March 2016 workshop.

Table 3. Summary of five observed teachers

	Teacher 1: Colin	Teacher 2: Shannon	Teacher 3: Lindsey	Teacher 4: Jonathon	Teacher 5: Erin
Years taught	3 years	8 years	6 years	17 years	4 years
Grade Level/Subject	7 th Physical Science	6 th Earth Science	9 th Biology	7 th Physical Science	6 th Earth Science
Time involved in grant	1 year	3 years	1 year	1 year	3 years

The research utilized the method of non-participant, narrow-focused observation, as defined by Fraenkel and Wallen (2003). The information collected in the classroom observations included high-inference items, as defined by Estacion et al. (2004). To make sound judgments on the extent to which teachers employed critical thinking skills in their lesson, a detailed running record of notes on what the teacher said was taken by the observer, and all lessons were audio recorded. All teacher comments were transcribed by the researcher using a word processor and

with the aid of Express Scribe Transcription Software v 5.85. All coding was done after transcription was complete.

Reliability, validity, and consistency. The study attempted to increase reliability and validity by incorporated a mixed-methods approach and triangulation to data collection. To increase content validity of the questionnaire, the questions were reviewed by university faculty and informed by the literature. One limitation of the study is that it only sought information from one source, that of the participants, or teachers. Classroom observations were all conducted by one person, which negated any worry of inter-rater reliability. The observations were not blind, so the potential for bias associated with researcher knowledge must be acknowledged. External reliability was sought by heeding to Nunan's (1999) five aspects of inquiry: the status of the researcher, the choice of informants, the social situation and conditions, the analytic constructs and premise, and the methods of data collection and analysis. The observer also coded all transcribed observations; to guard against threats to internal reliability when coding the observations, an outside reviewer coded and interpreted two transcripts independently and the coded transcriptions were compared with those of the observer. All classroom observations were recorded for ease of reanalysis.

Statistical analyses. Paired T-tests were run on participants pre- and post-questionnaires associated with each workshop. Single-factor ANOVA were run on participants' open-ended responses to their concerns in order to determine statistically significant changes.

Coding. Classroom observation transcriptions were coded using a priori codes (the Delphi critical thinking skills) with constant comparison, as recommended by grounded theorists. A template approach, as outlined by Crabtree & Miller (1999), allowed for a means by which to organize the text for subsequent analysis. In this study, the template was created a priori, based

on the Delphi cognitive skills (Fig. 2). Thus, the six cognitive skills served as the broad code categories (code 1, 2, 3,...), while the subskills and description of each subskill, as described in the Delphi Report (pertinent excerpt found in Appendix A), were used to define the code. An example of the coding scheme related to ***Skill 6: Self-Regulation*** are in Table 4. The codes from the template were used to categorize teacher dialogue in all five observation transcripts. An example of this can be found in Table 5. After analyzing the transcripts for a priori codes, several emergent themes arose upon compiling the coded transcript data. These were defined and applied to other transcripts when applicable. Themes within and between transcripts were identified and described.

Table 4. An example of the a priori template coding scheme

Code 6A	
Label	Self-Regulation: Self-Examination
Definition	<p>* to reflect on one's own reasoning and verify both the results produced and the correct application and execution of the cognitive skills involved.</p> <p>* to make an objective and thoughtful meta-cognitive self-assessment of one's opinions and reasons for holding them.</p> <p>* to judge the extent to which one's thinking is influenced by deficiencies in one's knowledge, or by stereotypes, prejudices, emotions or any other factors which constrain one's objectivity or rationality.</p> <p>* to reflect on one's motivations, values, attitudes and interests with a view toward determining that one has endeavored to be unbiased, fair-minded, thorough, objective, respectful of the truth, reasonable, and rational in coming to one's analyses, interpretations, evaluations, inferences, or expressions.</p>
Description	For example: to examine one's views on a controversial issue with sensitivity to the possible influences of one's personal bias or self-interest; to review one's methodology or calculations with a view to detecting mistaken applications or inadvertent errors; to reread sources to assure that one has not overlooked important information; to identify and review the acceptability of the facts, opinions or assumptions one relied on in coming to a given point of view; to identify and review one's reasons and reasoning processes in coming to a given conclusion.
Code 6B	
Label	Self-Regulation: Self-Correction
Definition	* where self-examination reveals errors or deficiencies, to design reasonable procedures to remedy or correct, if possible, those mistakes and their causes.
Description	For example: given a methodological mistake or factual deficiency in one's work, to revise that work so as to correct the problem and then to determine if the revisions warrant changes in any position, findings, or opinions based thereon.

Table 5. Example of applying codes to the transcription data

Codes with labels	Data from the transcripts
Code 6A. Self-Regulation: Self-Examination	<p>"I want each person to have their own individual web, created the way they see fit."</p> <p>"What is the one thing that you are struggling with right now on your web?"</p> <p>"Well, why did you do this?"</p>
Code 6A. Self-Regulation: Self-Correction	<p>"See if there are any changes, you would make to your web. So move things around, make alterations, redesign your web."</p>

Chapter 4: Results

Quantitative Results

This section will report the findings of the quantitative analyses in an effort to answer research question (a): After participating in the MSP workshops, how has teacher perception of critical thinking skills changed over time based on self-reported Concerns-Confidence-Commitment Questionnaires?

To compare changes in self-reported scores of all teacher participants before and after a single workshop, statistical analyses were run on each set of pre- and post-Triple C-Q during the October 2015, January 2016, and March 2016 workshops. Although not all pre- and post-questionnaire analyses revealed significant paired t-test values, there were significant changes in teachers' self-reported perceptions within each category (concern, confidence, commitment) during at least one of the workshops (Table 6). Figures 5-7 show average self-reported scores for teachers in all workshops. Specifically, significant t-test values were obtained with regard to decreased teacher concerns in March, increased confidence in October and January, and increased commitment in January. It is important to note that teachers' levels of commitment may have plateaued at the top end of the Likert scale in March 2016 with 10 of 17 participants rating their commitment levels at a 9 or 10 out of 10.

Table 6. Significant changes in teacher perceptions during a workshop

Questionnaire component	October 2015	January 2016	March 2016
Concerns			
Develop	N.S.	N.S.	N.S.
Implement	N.S.	N.S.	0.00185
Evaluate	N.S.	N.S.	0.03017
Confidence			
Develop	0.02396	0.00139	N.S.
Implement	0.00194	0.02042	N.S.
Evaluate	0.00921	0.00397	N.S.
Commitment			
Develop	N.S.	0.03362	N.S.
Implement	N.S.	0.02958	N.S.
Evaluate	N.S.	0.01266	N.S.

Note: N.S. = No Significance ($p > 0.05$); Statistically significant p -values ($p < 0.05$) found using one-tailed, paired T -tests comparing pre- and post- Triple C-Q for each workshop

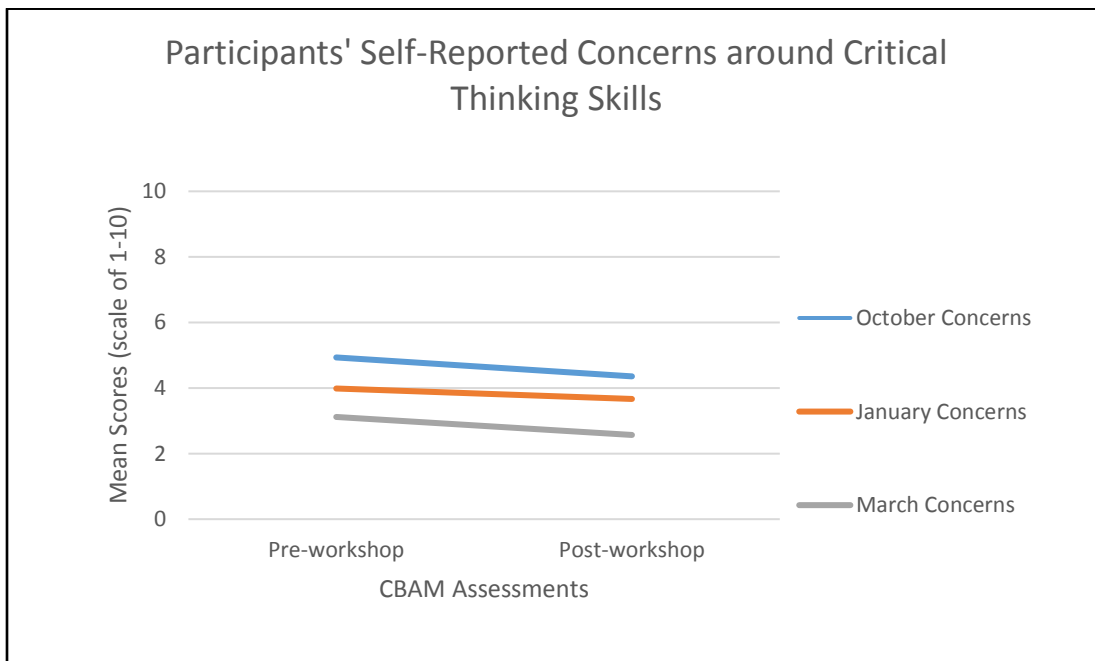


Figure 5: Teachers' average self-reported concerns over three workshops. Concerns decreased significantly in March 2016 ($n=17$; $p=0.0091$). No significant decrease in October 2015 ($n=15$; $p=0.5206$) or January 2016 ($n=23$; $p=0.5278$).

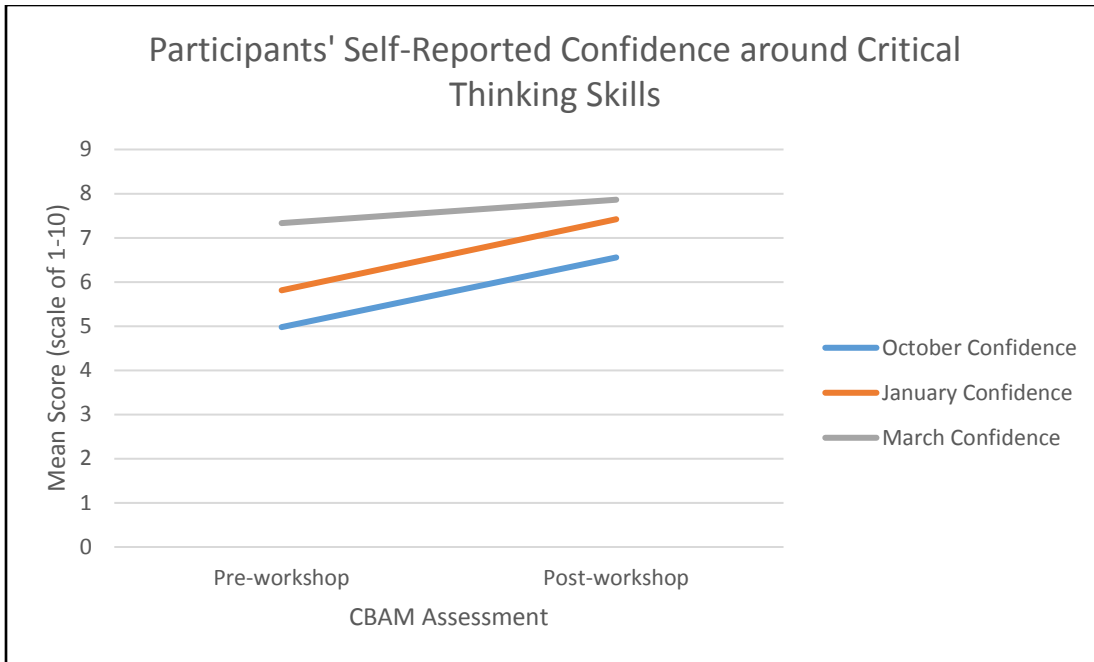


Figure 6: Teachers' average self-reported confidence over three workshops. Confidence increased significantly in October 2015 ($n=15$; $p=0.0093$) and January 2016 ($n=23$; $p=0.0067$). No significant increase in March 2016 ($n=17$; $p=0.2559$).

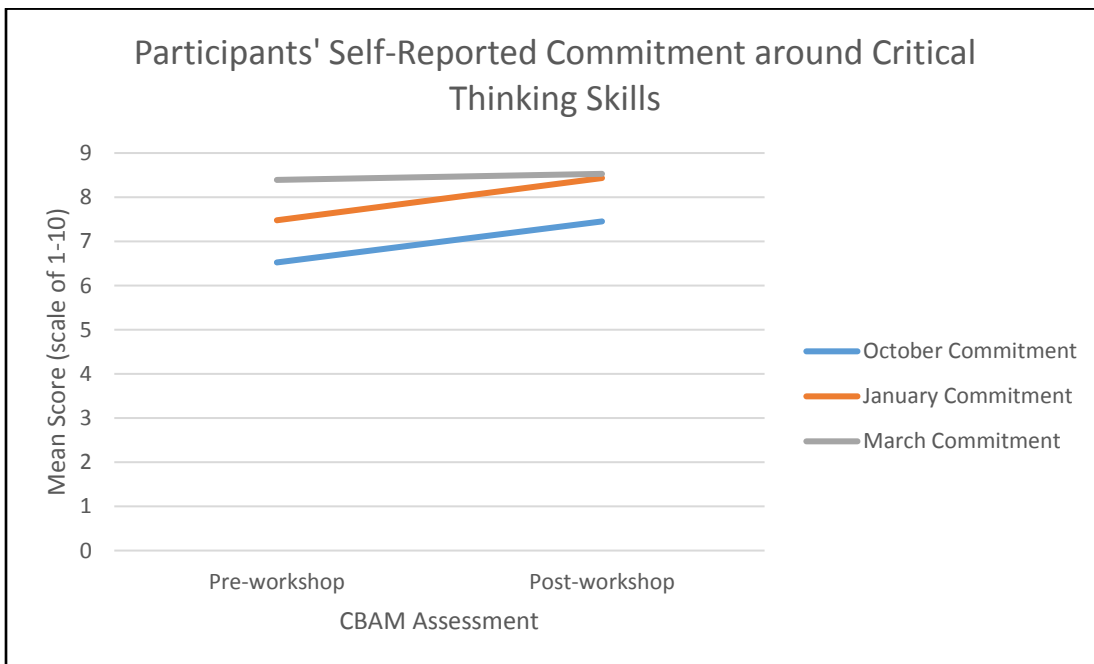


Figure 7: Teachers' average self-reported commitment over three workshops. Commitment increased significantly in January 2016 ($n=23$; $p=0.0406$). No significant increase in October 2015 ($n=15$; $p=0.1565$) or March 2016 ($n=17$; $p=0.5191$).

To look for overall trends over time, statistical analyses were run to compare teachers' initial self-reported perceptions before the October 2015 workshop with their perceptions at the end of the March 2016 workshop. A total of 14 teachers took both the pre-October Triple C-Q and the post-March Triple C-Q; as shown in Table 7, paired, two-tail t-test analyses reveal significant shifts in perception in all components (develop, implement, and evaluate) of all sections (concerns, confidence, and commitment). Examination of teachers' average scores for their concerns, confidence, and commitment reveal significant decreases in concerns ($p = 0.0139$) and significant increases in confidence and commitment ($p = 0.0024$, $p = 0.0395$, respectively) over time.

Table 7. Significance of overall change in teacher perception from October 2015 to March 2016

Questionnaire component	p-values
Concerns	
Develop	0.0167
Implement	0.0064
Evaluate	0.0405
Confidence	
Develop	0.0006
Implement	0.0033
Evaluate	0.0151
Commitment	
Develop	0.0319
Implement	0.0480
Evaluate	0.0451

Note: *p-values are the results of paired, two-tailed T-tests for overall change in teacher self-reported perceptions between the pre-October 2015 Triple C-Q and post-March 2016 Triple C-Q. All values are statistically significant ($p < 0.05$)*

In addition to ranking their concerns on a ten-point Likert scale, teachers provided written comments elaborating on the specific concerns that caused them to score themselves accordingly. All of teachers' open-ended responses were coded and aggregated into Hall's (1973) Stages of Concern; percentages of each stage were calculated and can be found in Table 8. A single-factor ANOVA analysis reveals statistical significance ($p = 0.00005$).

Table 8. Percentage of concern comments by Stages of Concern

	Awareness concerns	Informational Concerns	Self-Concerns	Management Concerns	Consequence Concerns	Collaboration concerns	Refocusing concerns	No concerns
OCTOBER WORKSHOP								
Pre-test	5.88	41.18	17.65	23.53	11.76	0.00	0.00	0.00
Post-test	0.00	20.00	12.00	12.00	28.00	4.00	0.00	24.00
JANUARY WORKSHOP								
Pre-test	3.70	22.22	7.41	11.11	37.04	3.70	0.00	14.81
Post-test	0.00	30.43	4.35	17.39	17.39	4.35	0.00	26.09
MARCH WORKSHOP								
Pre-test	0.00	4.55	0.00	13.64	36.36	4.55	0.00	40.91
Post-test	0.00	0.00	0.00	13.33	20.00	0.00	0.00	66.67

Note: Single-factor ANOVA was statistically significant ($p = 0.00005$).

Qualitative Results

This section reports the findings of the qualitative analyses in an effort to deepen the answer to research question (a): After participating in the MSP workshops, how has teacher perception of critical thinking skills changed over time based on self-reported Concerns-Confidence-Commitment Questionnaires? and to answer research question (b): Based on classroom observations, how do teacher perception and teacher practice compare after

participation in the MSP workshops? Findings come from classroom observations of six secondary science teachers involved in the professional development workshops. Figures 8 – 10 display the teachers’ average concerns, confidence, and commitment scores from the Triple C-Q for each workshop through time. Table 9 summarizes the quantitative and qualitative trends found for each teacher, respectively.

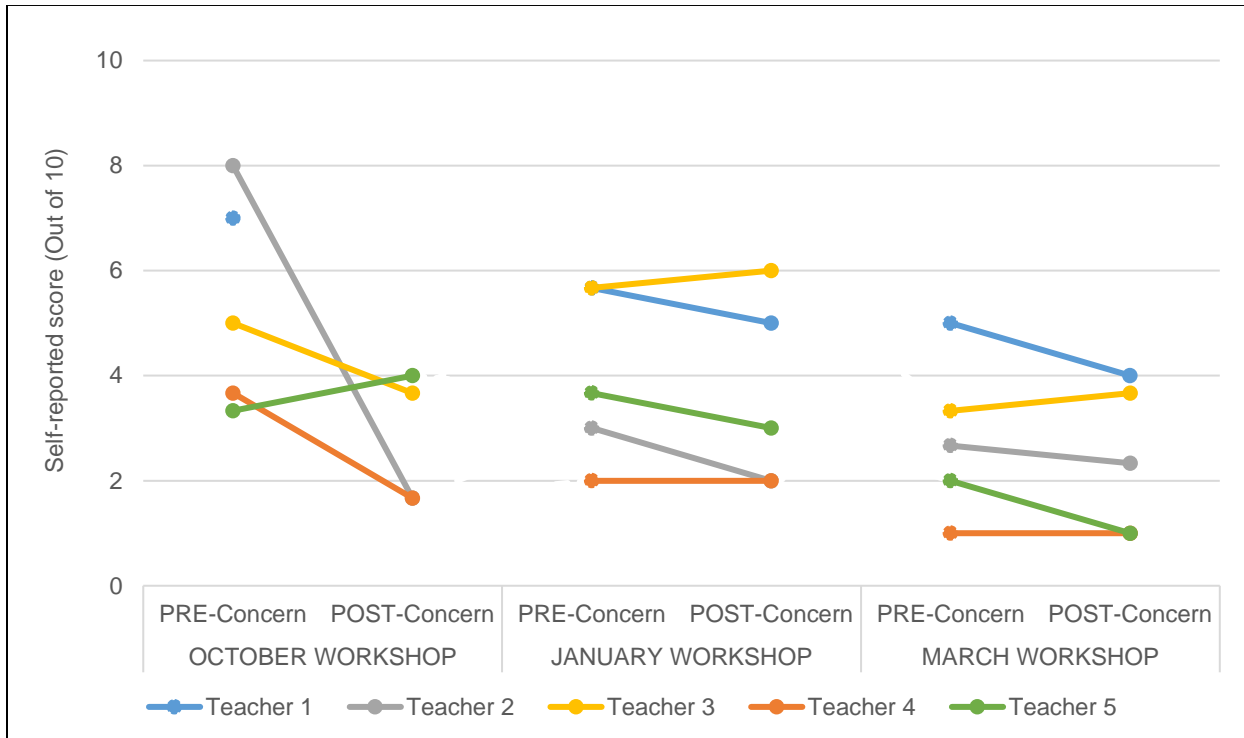


Figure 8: Average self-reported concern scores for observed teachers. Concerns are associated with the development, implementation, and evaluation of critical thinking skills in the classroom..

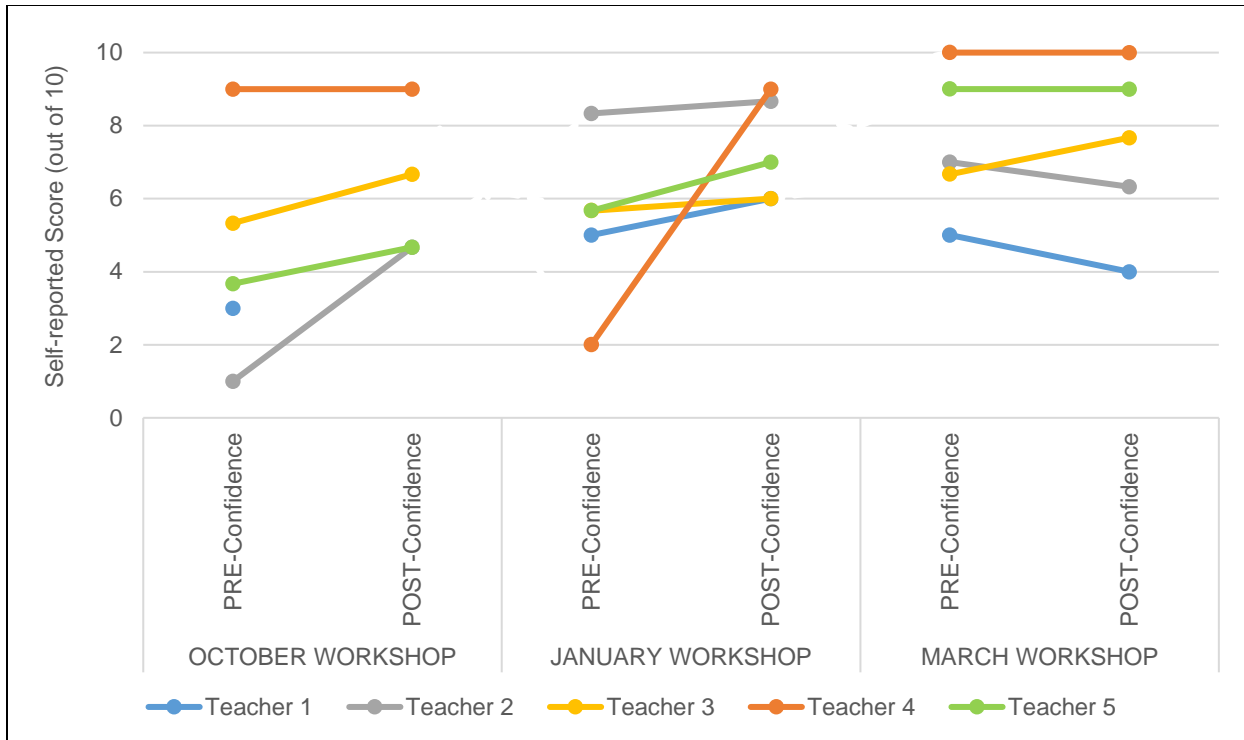


Figure 9. Average self-reported confidence scores for observed teachers.

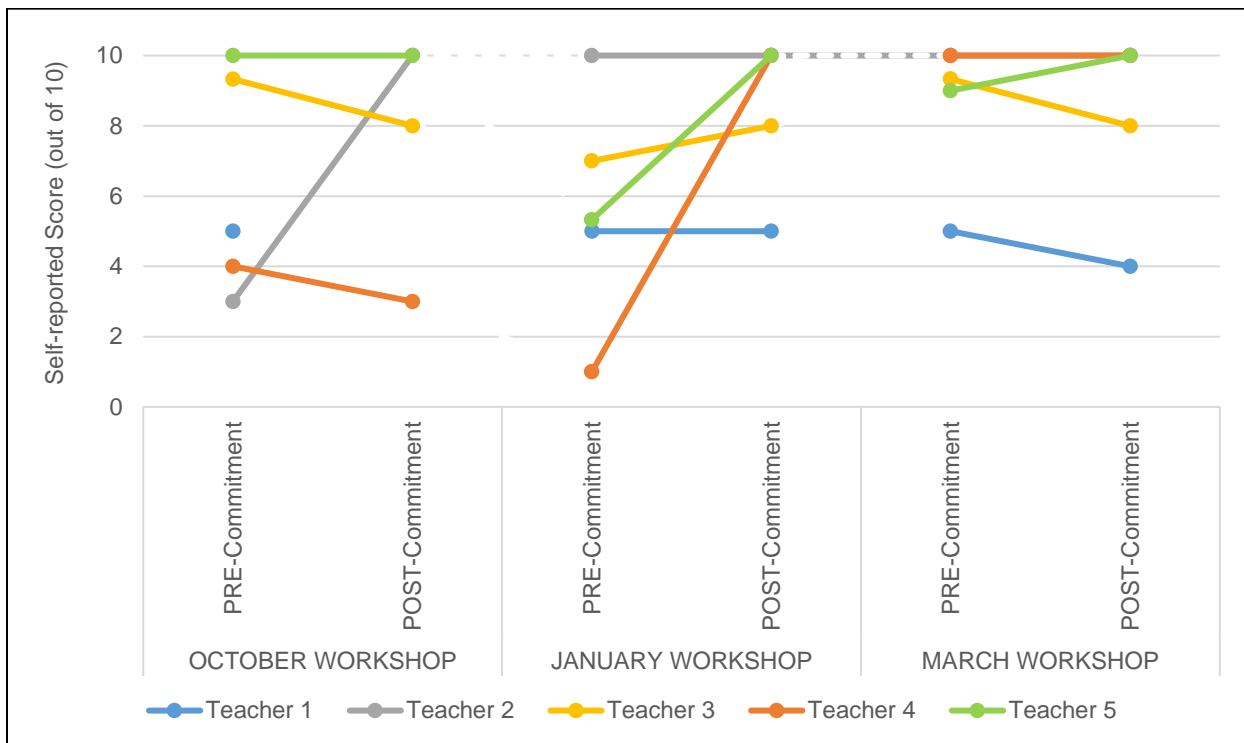


Figure 10. Average self-reported commitment scores for observed teachers.

Teacher 1: Colin

Colin was a third year teacher who was observed teaching in a 7th grade Physical Science class, in which students were tasked with constructing a contraption to keep a raw egg intact after a 15 m drop. Colin self-reported mid-level concerns, confidence, and commitment throughout the year, and stated in email correspondence prior to the observation that his lesson would promote the Delphi critical thinking *Subskill 4B: Conjecturing Alternatives*.

With a class size of 16, he framed the lesson by having students follow along as he read the background for the construction task from a worksheet. Then, he asked students to label one blank piece of paper “Engineering Plan” and another blank piece “Understanding”. They would be using these papers to write down their thought process and answer questions posed by the teacher throughout the lesson. The lesson proceeded with students working individually to construct a contraption that would prevent an egg from cracking when dropped. The teacher circulated around the classroom asking and fielding questions, and paused students throughout to answer a question on their second piece of paper.

Despite Colin’s assertion that he would promote *Subskill 4B: Conjecturing Alternatives*, there was little evidence of the promotion of this skill. Rather, he focused on students’ practice in *Subskill 5B: Justifying Procedures* by frequently asking students individually and as a class why they were doing certain things and reminding them to write down what they were doing in their journals. After asking several questions such as “Why are you folding that?” and “What are you thinking about?”, he clarified his intended connection to the skill of *Justifying Procedures* by framing the written journal exercise as eliciting the “main purpose for what [they’re] doing”. Although this falls under the critical thinking skill of *Justifying Procedures*, he did not justify or explain why students should be keeping a running log of their thoughts and actions, which might

limit student understanding and transference to other activities. Additionally, Colin stopped students and had them answer six questions throughout the lesson that caused them to practice *Drawing Conclusions (Subskill 4C)* with regard to physics concepts related to their engineering challenge. He was never explicit in suggesting that students use these questions to inform their design and engineering thought process, so it was possible that students regarded these pauses as isolated or separate from their challenge.

About an hour into the lesson, Colin sought the class's attention and posed two prompts within seven minutes that provide the potential for students to practice the critical thinking skills of *Examining Ideas, Querying Evidence, and Conjecturing Alternatives*. Although his line of questioning did not specifically ask students to *Conjecture Alternatives*, as he had students turn to a partner and state why they think their contraption will work or not work, he provided a context through which students could formulate alternatives once a peer commented on their design. There were two instances in which Colin more explicitly referenced the skill of *Conjecturing Alternatives*. The first time, he asked an individual student, "So, now you know you're going to need to change it, right?" and the second time, he told the class to write down what changes they made between the first two trials.

In summary, Colin's mid-levels of self-reported concerns, confidence, and commitment corresponded to the inclusion of several critical thinking skills in the observed lesson, most of which were not self-identified as an emphasis. Although he repeatedly emphasized and reminded students to write down the reasoning behind their actions, there were few instances in which the teacher discussed *why* students should be doing this. The teacher did not connect back to the notion of revisiting initial ideas and modifying them based on observation and data collection,

which is a major component in the critical thinking skill of *Conjecturing Alternatives*, his self-identified skill for the lesson.

Teacher 2: Shannon

Shannon is an 8th year teacher who was teaching a 6th grade science lesson exploring the objects outside our solar system. Students had been learning about the solar system for several weeks and were tasked with using their background knowledge and evidence from materials presented by the teacher to answer the question: Which planet is most like Earth? A total of 17 students were present during the observation and the class was arranged such that students were grouped into desks of four. After a brief review of their previous science lesson, Shannon introduced students to the essential question for the day (“Which planet is most like Earth?”), which laid the foundation for incorporating the skills of *Analysis* and *Inference* into the lesson. Throughout the lesson, Shannon emphasized that the goal was for students to “be able to answer even more accurately with more evidence”, and not just initial inclination. In order to build students’ mental models and understanding of applicable content, she had them silently think, independently write, talk to a peer, and participate in a class discussion at various points during the lesson.

In the Triple C-Q, Shannon self-reported low concerns overall with high levels of commitment. Initially, Shannon reported low confidence in her abilities, but this confidence increased throughout the year. In an email correspondence prior to the observation, Shannon stated that the lesson would integrate the Delphi critical thinking *Skill 2: Analysis* and *Skill 4: Inference*. Classroom observation revealed that she exhibited numerous instances of promoting all of the subskills within these two skills, with a prominence of speech pertaining to *Subskill 2a:*

Examining Ideas and all of the *Inference* subskills (*Querying Evidence*, *Conjecturing Alternatives*, and *Drawing Conclusions*). Shannon accomplished this through phrases such as “What features would you study on another planet to find an Earthlike planet?...How are you going to figure that out?”; “So does it make sense that that’s what you would want?”; “So now, rethink it. If it’s natural, is a manmade satellite a celestial object?”

Additionally, although she did not state them as an emphasis in pre-observation correspondence, Shannon posed questions and statements that encouraged the use of *Skill 5: Explanation* and *Subskill 1c: Clarifying Meaning* among students. With as high frequency as *Skill 4: Inference* was present, Shannon effectively modeled and had students practice *Skill 5: Explanation* through the use of her questioning and reminders. In ten instances, Shannon used the word “evidence” as she both questioned/prompted students to use evidence in their explanations (e.g., “You have to be able to defend your claim with evidence.”; “What’s your evidence for claiming that...?”) and modeled that they were going to use evidence to support their claims (e.g., “We’re going to look at the evidence that we have”) to encourage the use of this skill.

Not only did she remind students to use evidence, Shannon also demonstrated that alternative responses might still be correct as long as evidence is used. Twice, students were asked to share out their responses to a posed question where not all students had the same answer. Shannon responded with “Did you at least have reasoning?” This line of questioning targets the critical thinking *Subskill 5b: Justifying Procedures*.

At various points throughout the lesson, Shannon would pause the activity or conversation to query whether students understood a term or concept. Instances occurred when a vocabulary word is introduced that students might not know (e.g. “Does anyone remember what

[*celestial*] is?") and pushing students to elaborate on what they meant by an idea (e.g. "What about the atmosphere do we need to consider?"). These conversations, which promoted *Subskill 1c: Clarifying Meaning*, flowed seamlessly and appeared to be a common practice in her classroom. This might explain why Shannon did not include it as an intended skill to be practiced in her pre-observation email correspondence, as she was less aware of a skill that has become habituated in her practice.

In summary, Shannon's self-reported decreasing concerns, increasing confidence, and high levels of commitment corresponded with many instances of integrating her self-identified Delphi critical thinking skills and several other un-identified skills during her classroom observation. She effectively and consistently integrated the subskills of four of the six Delphi critical thinking skills through the use of questions and statements.

Teacher 3: Lindsey

Lindsey is a 6th year teacher who was teaching a 9th grade biology review of heredity and evolution during the observation. The lesson began with a prompt in which students silently and independently labeled and described a graphical representation of disruptive selection. After reviewing the bell ringer, Lindsey framed the lesson by stating that the biggest challenge in previous classes is that students have struggled initially and that that is "ok". She gave students pieces of paper with key terms and asked students to organize them into a web, "in a way that [their] brain works". Slowly, she provided them with definitions and had them discuss and examine others' webs, all the while prompting them to modify their initial mental model to represent their changing conceptions. To assist in this process, she paused students and had them answer questions that elicited their thought processes associated with their web constructions.

The lesson ended with students creating one large class web of the key terms and then working in pairs to re-write the lyrics of a song to be about evolution or heredity.

Over the course of the year, Lindsey's concerns were low, her commitment was high, and her confidence increased. In email correspondence prior to the observation, she identified integrating the Delphi critical thinking sub-skills of *Self-Examination* and *Self-Correction* under *Skill #6: Self-Regulation*. Despite her worry prior to the observation that she may not be correctly integrating these skills, she exhibited numerous and repeated instances of implicitly promoting *Self-Regulation* throughout the lesson. No more than five minutes passed during the web activity before Lindsey asked a question or made a statement that promoted either *Subskill 6a: Self-Examination* or *Subskill 6b: Self-Correction*. By prompting students with statements such as "...put stuff in a way that your brain works", "explain to me how you organized your web", or "...see if there are any changes you would make to your web...move things around, make alterations, redesign your web", and questions such as "Why'd you do that?", she was able to engage students in examining their own knowledge and thinking and provide opportunities for them to modify their conceptions. With one exception, Lindsey was not explicit with her students that these were the skills she was having them practice; her prompting and activities took the form of implicit practice in *Self-Regulation*.

In summary, Lindsey's self-reported low levels of concern, increasing levels of confidence, and high commitment to the process along with her assertion that she was promoting *Skill #6: Self-Regulation* were supported by classroom observation of her engaging students in the critical thinking skill of *Self-Regulation* throughout the lesson via framing and questioning strategies. There were no other clear instances in which she promoted other critical thinking skills.

Teacher 4: Jonathon

Jonathon has been teaching for 17 years in a variety of settings, which include 6 years teaching abroad and several public schools within the states. Overall, Jonathon self-reported low levels of concern and high levels of confidence and commitment throughout the year. In an email correspondence prior to the classroom observation, the Delphi critical thinking skills that Jonathon was intending to integrate and corresponded with the lesson observed were *Subskill 2a: Examining Ideas* and *Skill 6: Self-Regulation*.

During the classroom observation, Jonathon reviewed each student's procedural write-up for an engineering project, in which students were to choose one variable to test in an attempt to build the best electromagnet and write a procedure outlining how they would manipulate that variable. During this time, he exhibited many instances of practicing *Self-Regulation* pertaining to the critical thinking skill of *Stating Results* with students on an individual basis. Over the course of the class period, Jonathon had 26 interactions with individual students as he reviewed their procedures; in every conversation he asked at least one question and made at least one statement that promoted the critical thinking skill of *Self-Regulation*. These included "It'd be even better if you told me what size those nails were", "...but it doesn't say that", "I want to know what you're thinking", "When you say 'tie it off', what do you mean?", or "How am I going to use that to do the experiment?"

Although there appear to be no instances of Jonathon promoting *Subskill 2A: Examining Ideas*, there were several times in which he prompted students in a way that emphasized *Subskill 2B: Identifying Arguments*, which is under the same general skill of *Analysis*. Additionally, *Subskill 1C: Clarifying Meaning* was heavily used during the first 30 minutes of class as students

orally read and discussed an article on Albert Einstein, even though this skill was not identified by the teacher as being emphasized in the lesson.

In summary, Jonathon's self-reported low concerns and high confidence and commitment to integrating critical thinking skills into his curricula corresponded with the heavy presence of language promoting *Skill 6: Self-Regulation*, *Subskill 5A: Stating Results*, and *Subskill 1C: Clarifying Meaning*. To a lesser extent the encouragement of self-identified *Subskill 2A: Examining Ideas* was present.

Teacher 5: Erin

Erin is 6th grade teacher who has been teaching for 4 years. During the observation, she was teaching an introductory lesson on celestial objects outside of our solar system following a unit on the solar system. The lesson consisted of students being given pictures of celestial objects with no descriptive information and asked to categorize them into groups with an accompanying written explanation describing their categorization. Students worked in groups of two to three to accomplish this task. Overall, Erin spoke very little during the lesson with the exception of the first 13 minutes and the last five minutes of class.

Erin self-reported feeling confident and committed to integrating critical thinking skills into her classroom, in general, and specifically in this lesson. Her self-reported Triple C-Q scores indicate that her confidence greatly increased, her commitment remained high, and her concerns were minimal and decreased over time. In response to a pre-observation email sent by the research observer inquiring as to the critical thinking skills Erin would target in her lesson, she states that her "lesson hits all of them", but most specifically *Skill 1: Interpretation* because students will be required to "look at various images and categorize items based on what they already know."

While introducing the activity, Erin tells her students that she wants them to take the knowledge they gained from the previous unit and “apply it to [looking] beyond the solar system”. The activity itself inherently promoted critical thinking *Skill 1a: Categorization* and *Skill 5a: Stating Results* as students sorting cards with common characteristics and explained their reasons for highlighting those characteristics.

Contrary to her self-reported perceptions, Erin rarely posed questions that promoted the Delphi critical thinking skills in the observed lesson. In total, there were 12 instances over a 55-minute lesson where her speech addressed a skill, four of which were to individual students. Of those, an individual subskill was addressed no more than four times (*Justifying Procedures*) and more often once (*Drawing Conclusions, Categorization*) or twice (*Self-Examination, Querying Evidence, Clarifying Meaning*). While modeling what students were to do, Erin gave an example of how one might *justify their procedure* by stating that a student would “describe how her group categorized her [cards]”. While circulating around the room during the activity, Erin said little to the students. On one occasion she asked a student “What’d you do here?” which pushed the student to practice the skill of *Self-Regulation*. Forty-eight minutes into the period, Erin brought the class back together and prompted them practice the skill of *Self-Examination* by asking if anybody could “tell [her] any surprises that [they] encountered”.

In summary, Erin was a confident and committed teacher with few concerns related to integrating critical thinking into her classroom. Her self-reported perceptions aligned with limited accuracy and repetition when analyzing her speech throughout the lesson, although the activity itself incorporated *Subskill 1a: Categorization* and *Subskill 5a: Stating Results*. Anecdotally, in other lessons observed during the planning stages of the research, Erin displayed many instances of explicit modeling and framing for her students.

Cross-teacher Comparisons

The five teachers who were observed implicitly promoted a variety of the critical thinking skills defined by the Delphi Project. To a far lesser extent were seen instances of teachers explicitly promoting these skills or explaining to students what skills they were practicing. As stated earlier, research indicates that critical thinking skills are needed to transfer knowledge to new situations (Facione, 1998). Additionally, in investigating the influence of explicit versus implicit instruction on 6th graders' views of Nature of Science, Khishfe and Abd-El-Khalick (2002) found that explicit, reflective instruction was more effective at promoting Nature of Science conceptions than implicit strategies. Furthermore, the treatment group that received implicit instruction did not change their views on the Nature of Science. Accordingly, explicit instruction should be used to support students' acquisition of cognitive skills such as critical thinking skills. Thus, explicit as well as implicit instruction is important for gaining accurate conceptions of cognitive skills and understandings.

In analyzing the teachers' self-reported Triple C-Q scores, there is a marked drop in confidence and commitment by three and two of the four teachers (Colin did not complete a questionnaire for post-October 2015), respectively, and an increase in concerns by three of the four teachers between the October 2015 and January 2016 questionnaires. The ensuing questionnaires all show an increase or stabilization of confidence and commitment and a decrease or stabilization of concerns. In examining all teacher participants' Triple C-Q scores between October 2015 and January 2016, 47%, 45%, and 47% of teachers who completed the questionnaires exhibited similar changes in concerns, confidence, and commitment, respectively. The fact that almost 50% of teachers lost confidence and commitment and returned with elevated concerns might reinforce the need for iterative, sustained professional development. For the rest

of the year, overall trends with regard to concerns, confidence, and commitment were positive in relation to one of the goals of the grant, namely developing, integrating, and evaluating critical thinking skills. The data appear to show that one or two interactions with workshop facilitators was not sufficient in maintaining positive and productive beliefs about the introduced content. It was not until teachers had attended three or more workshops that their self-reported scores stabilizing or improved.

Table 9. Summary of Concern-Commitment-Confidence score and classroom observation trends of five observed teachers

	Teacher 1 Colin	Teacher 2 Shannon	Teacher 3 Lindsey	Teacher 4 Jonathon	Teacher 5 Erin
<i>Triple C-Q concern scores</i>	Mid-levels	Low levels; decreased	Low levels; decreased	Low levels	Low levels; decreased
<i>Triple C-Q confidence scores</i>	Mid-levels	Low initially; increased	Mid- and increasing levels	High confidence (except January pre-)	Low initially; high in end
<i>Triple C-Q commitment scores</i>	Mid-levels	Very committed	High levels	Low initially; high after January	Remained high
<i>Pre-observation self-reported critical thinking skill emphases</i>	<i>Subskill 4B: Conjecturing Alternatives</i>	<i>Skill 2: Analysis</i> <i>Skill 4: Inference</i>	<i>Subskill 6a: Self-examination</i> <i>Subskill 6b: Self-correction</i>	<i>Subskill 2a: Examining Ideas</i> <i>Skill 6: Self-regulation</i>	All Skills
<i>Were self-reported skills observed?</i>	Rarely	Yes, repeatedly	Yes, repeatedly	Skill 6, repeatedly Skill 2a, no (2b, yes)	No
<i>Primary critical thinking skills observed</i>	Emphasis on <i>Justifying Procedures</i> and <i>Drawing Conclusions</i> ; two instances of self-reported <i>Conjecturing Alternatives</i>	Self-reported <i>Analysis</i> and <i>Inference</i> ; emphasis on <i>Explanation</i> and <i>Clarifying Meaning</i>	Self-reported <i>Self-examination</i> and <i>Self-correction</i>	Self-reported <i>Self-Regulation</i> ; emphasis on <i>Stating Results</i> , and <i>Clarifying Meaning</i>	Activity promoted Skill 1: <i>Interpretation</i>

Chapter 5: Discussion

Introduction

The NGSS were released in 2013 and represent the most recent effort to improve science literacy among citizens. These standards come with a major shift in teaching practice and require in-service teacher support. Given the departure of NGSS from past standards, professional development will be pivotal in supporting teachers as they understand and adjust their teaching practices to promote the standards. Although the literature is replete with suggestions for making science teachers' professional development effective, far less exists specific to supporting teachers in changing their practice to promote the NGSS.

The notion that science requires a specific set of literacy skills and that individuals must necessarily be equipped with those skills to be scientifically literate is supported by educator (Cook & Dinkins, 2015a). Educators must, therefore, identify and promote skills that foster disciplinary literacy – “the knowledge, ability, and tools experts in a particular field use to create and communicate knowledge within their discipline...” (Cook & Dinkins, 2015b, pg. 3). According to the NGSS Lead States (2013b), critical thinking skills are wedded to content and intertwined in NGSS with implicit inclusion emphasized within scientific practices. Given the implicit and integral role that critical thinking plays on the NGSS, it can be argued that these skills represent the skills that foster disciplinary literacy in science, which Cook and Dinkins (2015b) describe. Following their line of reasoning, students must be equipped with these skills to be scientifically literate. As such, teachers must be well-versed in these skills and be able to promote these skills within their classrooms.

The purpose of this study was to explore the effect of professional development on teachers' perceptions of their ability to integrate an innovation such as NGSS (specifically,

critical thinking skills) into the classroom. Specifically, this research combined both quantitative and qualitative methods to address the perceptions of secondary science teachers who participated in a year-long voluntary, district-funded MSP Grant. It analyzed longitudinal data of teacher perceptions on integrating critical thinking skills and classroom observation of one lesson in an attempt to corroborate teachers' self-reported perceptions. The study addressed the following questions:

- a. After participating in the CCSD MSP workshops, how has teacher perception of critical thinking skills changed over time based on self-reported Concerns-Confidence-Commitment Questionnaires?
- b. Based on classroom observations, how do teacher perception and teacher practice compare after participation in the CCSD MSP workshops?

Question (a):

With regard to question (a), an analysis of teachers' ranking on the Triple C-Q indicates that teachers' self-reported confidence and commitment increased early in the year ($p < 0.05$ in October 2015 and January 2016 and January 2016, respectively), while their concerns significantly decreased later in the year ($p < 0.05$ in March 2016). Despite significant decreases in teacher concern present only during the March Triple C-Q, analysis of teacher concern comments reveal a shift along Hall's (1973) Stages of Concern throughout the year. As evidenced by the questionnaire, teachers gained significant levels of confidence during the first two workshops, followed by a statistically significant decrease in concerns in March (Fig. 5). This early increase in confidence and commitment is supportive of many behavioral change theories that consider confidence and commitment, two constructs within the theoretical domains of beliefs about capabilities and motivation and goals, important factors in successfully initiating

and maintaining behavior change (e.g., Bandura's social cognitive theory, goal theory, self-regulation theory) (Michie, et al., 2005). The ensuing decrease in concerns may be indicative of an ongoing process associated with being confronted with an innovation, in which an increase in confidence in one's ability to take on that innovation allows for concerns to subside, leaving room for action and change.

In addition to several statistically significant shifts in teacher perception within individual workshops, statistically significant shifts were observed in teachers' overall perceptions from October 2015 to March 2016 in all components of all sections of the Triple C-Q (Table 7). This suggests that teachers' perceptions of developing, implementing, and evaluating critical thinking skills changed over time as they became less concerned, more confident, and more committed to the process with their participation in the CCSD MSP professional workshop series. By creating science teacher professional development that embodies the strategies of effective professional development and NAP findings, findings indicate that teacher perception can change. Such a relationship is encouraging because it suggests the potential for being able to support teachers in successfully changing their practices through teacher perceptions so as to effectively integrate the NGSS into curricula and instruction.

Teacher participants showed an overall decrease in their concerns with regard to developing lessons with, integrating, and evaluating critical thinking skills into their classroom. As outlined in self-efficacy theory (Bandura, 1977), self-confidence is one of the most influential motivators of behavior and behavior change. Additionally, people who are faced with a change go through sequential stages of concerns that must be resolved in order to embrace and implement the change (Hall, 1979), so a high level of concern might hinder one's ability to feel confident enough to initiate a change of behavior. Therefore, the perceived decrease in individual

concern, as a result of participation in science professional development, may play a large role in the successful implementation of the NGSS.

It is also important to couple this with the fact that the professional development specific to this research had characteristics described in the literature as effective. Specifically, there are three attributes that might have resulted in the observed changes in teacher perception (alignment of the workshops and the literature found in Tables 1 and 2). First, the professional development was sustained and long-term as workshops brought teachers together at six points over an entire school year. Such duration and repetition is a pivotal feature of effective professional development as described by the JEPD model and recommended by the NAP report in Conclusions three and five (NAP, 2015). Second, facilitators were attentive to the learning needs of the teachers by planning and modifying workshops based on teacher feedback. This is also outlined as a recommended practice by the NAP (2015). Lastly, the professional development provided continual opportunities for teachers to actively participate in collaborative environments with sessions that were content-focused. These attributes are key strategies to effective professional development backed by ample examples in the literature as helping enact changes in teacher beliefs and practices, as described in the literature review (e.g., NAP, 2015; Hestness et al., 2014; Houseal & Ellsworth, 2014; Miller et al., 2014; Beaudoin et al., 2013; Nagle, 2013; Reiser, 2013; Wilson, 2013; Loucks-Horsley et al., 2003; Elmore, 2002; Darling-Hammond & Sykes, 1999). The presence of these literature-supported effective attributes in the professional development specific to this research study and the findings that teachers decreased concerns and increased confidence and commitment reinforce the notion that professional development embodying effective strategies can be used to assist teachers in making necessary changes to incorporate new reform efforts, such as the NGSS.

While sustained professional development assists teachers in adopting that which they learn while attending sessions, meeting multiple times over an extended period of time to discuss the same concepts is vital to making any change in teacher belief or practice. Such iterative reunions allow teachers to engage in the process of change and revisit their concerns after they practiced a new skill, which is where Guskey (2002b) asserts the largest struggle in change arises.

Question (b):

In an attempt to validate teacher perception with teacher practice and to answer question (b), this research used classroom observation as a means by which to compare self-reported perceptions with actual instruction. Results from the qualitative data suggest that while perceptions significantly shifted among the teachers, the five classroom observations reveal that not all teachers' practices aligned with self-reported perceptions. In four of five cases, teachers integrated the self-identified skill at least one time along with other critical thinking skills they had not identified. In some instances, skills teachers thought they were promoting were not present (Erin, Colin), and in four out of five cases, skills other than the ones the teachers identified as their focus were being promoted (Shannon, Colin, Jonathon). Except for a few isolated exceptions, teachers did not explicitly promote critical thinking skills; rather, they posed questions or prompted students to practice a skill without explicit explanation to the students of what skill was being practiced.

Analysis of the qualitative data reveal that not all practice aligns with teachers' self-reported perceptions. However, this does not negate the trends observed in the quantitative perception data. To master a skill takes repetition of practice, so the fact that the observed teachers were finding some, albeit not complete, success with a new form of instruction holds

promise for the efficacy of professional development in changing teacher perception *and* practice. Studies indicate that it takes an average of 20 instances of practice or more, depending on complexity of skill, before teachers are able to master an introduced skill (Joyce & Showers, 2002). Given the short timeframe in which teachers were exposed to the Delphi critical thinking model, the limited repetition and use of the model prior to observation, and the implementation of that model into a lesson, teachers showed promise in integrating critical thinking skills in the classroom.

According to Guskey (2002b), the biggest struggle in learning a new skill is not in understanding what the skill entails, but rather in the implementation of that skill. This implementation dip is further complicated by evidence that teachers only change their beliefs after seeing success with students (Guskey, 2002b) and that they tend to abandon the practice of a new skill if they do not see success (e.g., Huberman, 1981; Guskey, 1984). It would be interesting to revisit the observed teachers in the following school year and conduct another classroom observation to see if critical thinking skills are still being promoted, to what extent, and with what intent. Interviews would also be useful for providing insight into the correlation between perceived student success by the teacher and continued implementation of critical thinking skills.

The critical relationship between teacher beliefs and their actions to implement educational reform efforts in the classroom has been documented since the 1990's (e.g., Czerniak, Lumpe, & Haney, 1999; Duschl, 1990). Although the results of this study do not clearly support this relationship, some instances of teacher intention and teacher action align and other potential trends reveal interesting questions. In comparing the self-reported scores with the classroom observations, Lindsey was less confident than others and did not report significant

increases in confidence but repeatedly integrated her intended skill, while Erin was more confident and reported significant increases in confidence but rarely integrated her intended skill. While it is impossible to point to one direct cause for these observations, there are several potential explanations. It is likely that the teachers are at different stages of their teaching practice and in their process of change. This would result in varying levels of perceived success, which plays a large influence on the adoption of an innovation (Guskey, 2002b). A larger sample size is needed to determine whether a correlation in teacher perception and practice is absent, if there is another contributing factor, or if a connection exists but couldn't be shown with the small sample size.

The variance in teacher perception and actual practice might also be due to the fact that teachers had been exposed to the ideas of the grant for varying amounts of time. Teaching students new routines, concepts, or ways of thinking requires a lot of explicit modeling and reminders initially, as students are grappling with their new understanding. However, as students adopt and gain proficiency in these routines and ways of thinking, the expectation becomes a learned behavior and the teacher does not have to provide constant support for students to exhibit said behavior. Given that the 6th grade teachers (Erin and Shannon) have been participating in the MSP grant for three years, it is possible that they have already set expectations around critical thinking and it is becoming more of a learned behavior for the students. This might explain the absence of explicit teacher modeling in some of their observations and the discrepancies with which individuals might respond to a situation. Shannon and Erin manifested their confidence in integrating critical thinking skills in two different ways. For Erin, she did not feel it necessary to prompt students with questions promoting critical thinking because the skills were inherent in the activity and she had already been practicing them with her students. For Shannon, she continued

to prompt students with questions that elicited their critical thinking but was not explicit with the students as to what skills were being practiced.

Alongside the potential that experience plays in affecting the relationship between perception and practice, observing student input is important to better understand the practices that are present with regard to the students practicing the intended skills. This is in specific reference to Erin's observation, in which the teacher said very little during the lesson. The activity itself promoted skills, but these could not be identified with teacher dialogue alone. Rather, student dialogue would be needed to identify the extent to which students were using critical thinking skills.

Limitations

There were several important limitations to this study including the size of the treatment group, the timeframe for the study, the single observer, and selection of the teachers who were observed. The sample size of the teacher participants was constrained by the number of teachers who voluntarily decided to join the grant. Due to the nature of the research project, data collection was reduced to only a portion of the school year (approximately six months). Given the limited pool of study subjects and the short timeframe in which their perceptions were observed, one must be careful in extrapolating potential correlations to larger population trends.

Although interrater reliability was not an issue, since only one observer was involved in the classroom data collection, inherent in a single observer is a potential bias on the part of that observer.

The selection of the teachers to be observed, although posed to all participants, might have resulted in richer correlations with quantitative questionnaires had researchers specifically targeted teachers ranging a variety of self-reported shifts. By analyzing the Triple C-Q so as to

identify teachers with a variety of self-reported shifts (i.e., no change, increase, and decrease), the potential for noticeable trends might increase.

Despite these limitations, the results of the study can have positive implications for future research on teachers' professional development and provide a foundation for larger studies examining its efficacy.

Recommendations

In terms of the implications that this research study has on the future of K-12 science professional development, findings suggest that organizing professional development around the literature-supported characteristics of effective professional development leads to change in teacher perception. Therefore, facilitators should consider exemplifying similar characteristics in future workshops. Additionally, if schools, districts, and/or states want to see change in teacher practices, they have to provide effective and iterative professional development over longer periods of time. Studies show that 50 to 80 hours of training are required for teachers to master an innovation (Yoon et al., 2007; Banilower, 2002; French, 1997). Additionally, Triple C-Q results show a delay in significantly decreased teacher concerns until the March 2016 workshop (refer back to Table 6). This significant shift occurred six months and three workshops after the data collection period began. These results reinforce the notion that the training should be spread out over multiple sessions across time to allow for teachers' concerns be revealed and addressed and teachers' confidence and commitment remain high.

Because the results of the study indicated that teachers experienced success in changing perception with participation in the MSP professional development workshops, this research and its findings support Guskey's (2002a, 2002b) recommendation that teachers' reactions, learning, and implementation should all be measured and evaluated if professional development is to be

assessed effectively. Accordingly, state and districts should consider monitoring the extent to which professional development has changed teacher practice and improved student achievement. Further research examining similar parameters of teacher perception and actual change is needed to identify the extent to which self-reported perceptions can be used to infer classroom instruction. Along with this research, if the full extent of teacher professional development is to be discovered, it will be important to examine the extent to which it is affecting student achievement, since this is the ultimate measure of educational reform success (Yoon et al., 2007).

With regard to the methodology, the results of the study indicate that self-reported data be coupled with more objective classroom observations. This suggestion arises from the observation that researchers would not have been able to distinguish between implicit and explicit promotion of critical thinking skills with self-reports alone. One might have inferred that teachers were understanding how to integrate critical thinking effectively by just the reports, but the qualitative data allowed for a deeper understanding of the intricacies associated with integrating skills into curriculum, not only in how teachers did so, but also the extent to which they were integrating self-identified and un-identified critical thinking skills.

Conclusion

With the creation and ensuing adoption of the NGSS, the United States is in a unique position to reestablish itself within the realm of science education. In accordance to the warning issued by the National Commission on Excellence in Education's *A Nation at Risk*, the NGSS represent the shift necessary to change how we think about, teach, and learn science. They represent a new vision for science education that is grounded in the notion of science as a set of practices in addition to a body of knowledge. Written by a committee of prominent scientists,

educators, researchers, and state leaders, these standards emphasize a progression-based approach that provides an opportunity for students to develop a complex understanding of science through the integration of core ideas in content (DCI), process (SEP), and overarching themes (CCC).

One challenge in adopting such standards is effectively supporting teachers as they attempt to shift their practice to embody this new vision. Although the NGSS are clear on the student learning outcomes, they say little as to what instructional strategies are needed to realize learning outcomes or what supports are needed for teachers in enacting this vision. Yet as the linchpin to any K-12 science education reform effort, teachers play a crucial role in the success or failure of an innovation (NRC, 2012). Profound changes in teacher professional development will be essential to support educators in acquiring the instructional strategies consistent with the NGSS vision.

By identifying the mechanisms by which professional development can improve teacher practice, professional development can contribute to the design, implementation, and evaluation of future professional development programs (Wayne et al., 2008). With the efforts to implement NGSS across the country, intentional professional development that incorporates effective, literature-supported characteristics of professional development may be the key to assisting teachers in making the affective and instructional shifts necessary for achieving the standards set forth in the NGSS. The professional development workshops used in this study were a direct application of effective strategies defined by the literature. By maintaining sustained sessions that incorporated active learning, modeling, and facilitator responsiveness to teacher needs, teachers increased their perceptions of integrating critical thinking skills into the classroom. And, as evidenced in other studies, teacher instruction aligns with teacher belief (Haney et al., 2002)

and teacher self-efficacy is positively correlated to student achievement (Lumpe et al., 2012; Goddard et al., 2004).

Unless concerted efforts are made to support teachers in changing their instructional strategies and curricula so that they align with the NGSS, the adoption of NGSS will be difficult. Furthermore, without a change in how science teacher professional development is facilitated, the implementation of the NGSS will remain inadequate as the standards represent a new way of teaching science (Bybee, 2013; Pratt, 2013). That said, findings of this research suggest that it is possible to change teacher perception with intentional professional development that embodies effective strategies grounded in the literature. It extends the literature on the effectiveness of teacher professional development by exploring one way in which strategy-grounded professional development can be used to change teacher perception of practice, which is a crucial role and indicator of actual teacher practice (Rosenfeld & Rosenfeld, 2008; Haney et al., 2002; Ford, 1992).

References

- Alexander, P. A. (2014). Thinking critically and analytically about critical-analytic thinking: an introduction. *Educational Psychology Review*, 26(4), 469-476.
- American Philosophical Association (1990). *Critical Thinking: A Statement of Expert Consensus for Purposes of Educational Assessment and Instruction*. "The Delphi Report," Committee on Pre-College Philosophy.
- Anderson, S.E. (1997). Understanding teacher change: Revisiting the concerns based adoption model. *Curriculum Inquiry*, 27(3), 331-367.
- Bandura, A. (1977, March). Self-efficacy: toward a unifying theory of behavioral change. *Psychological Review*, 84(2):191-215.
- Bandura, A. (1982). Self-efficacy mechanism in human agency. *American Psychologist*, 37(2), 122-147.
- Banilower, E. R., Smith, P. S., Weiss, I. R., Malzahn, K. A., Campbell, K. M., & Weis, A. M. (2013). *Report of the 2012 national survey of science and mathematics education*. Chapel Hill, NC: Horizon Research, Inc.
- Bargh, J.A., Gollwitzer, P.M., Oettingen, G. (2010). Motivation. (5th ed.). *Handbook of Social Psychology*, 2, 268-316.
- Beaudoin, C., Johnston, P., Jones, L., & Waggett, R. (2013). University support of secondary stem teachers through professional development. *Education*, 133(3), 330-339.
- Blaxter, L., Hughes, C., & Tight, M. (2006). *How to research*. Berkshire: Open University Press.
- Bloom, B. (1976). *Human characteristics and school learning*. New York: McGraw-Hill.
- Borko, H. (2004). Professional development and teacher learning: Mapping the terrain. *Educational Researcher*, 33(8), 3-15.
- Brown, J. D. (2001). *Using surveys in language programs*. Cambridge: CUP
- Brunsell, E., Kneser, D., & Niemi, K. (2014). *Introducing Teachers and Administrators to the NGSS: A professional development facilitator's guide*. Arlington, VA: NSTA Press.
- Bybee, R. (2013). *Translating the NGSS for classroom instruction*. Arlington, VA: NSTA Press.
- Bybee, R. (2014). NGSS and the Next Generation of Science Teachers. *Journal for Science Teacher Education*. 25(2), 211-221.
- Cook, K. & Dinkins, E. (2015a). Building disciplinary literacy through popular fiction. *Electronic Journal of Science Education*, 19(3), 1-24.
- Cook, K. & Dinkins, E. (2015b). Using popular text to develop inquiry projects: Supporting preservice teachers' knowledge of disciplinary literacy. *Journal of College Science Teaching*, 44(6), 44-50.
- Crabtree, B., & Miller, W. (1999). A template approach to text analysis: Developing and using codebooks. In B. Crabtree & W. Miller (Eds.), *Doing qualitative research* (pp. 163-177), Newbury Park, CA: Sage.
- Czerniak, C.M., Lumpe, A.T., & Haney, J.J. (1999). Science teachers' beliefs and intentions to implement thematic units. *Journal of Science Teacher Education*, 10(2), 123-145.
- Darling-Hammond, L., & Ball, D. L. (2004). *Teaching for high standards: What policymakers need to know and be able to do*. Philadelphia, Consortium for Policy Research in Education and Washington, DC: The National Commission on Teaching and America's Future

- Darling-Hammond, L., Chung Wei, R., Andree, A., Richardson, N., & Orphanos, S. (2009). *Professional learning in the learning profession: A status report on teacher development in the United States and abroad*. Oxford, OH: National Staff Development Council.
- Darling-Hammond, L., & Sykes, G. (1999). *Teaching as the learning profession: Handbook of policy and practice*. San Francisco, CA: Jossey-Bass.
- Desimone, L. M. (2009). Improving impact studies of teachers' professional development: Toward better conceptualizations and measures. *Educational Researcher*, 38(3), 181–199.
- DiClemente, C.C., Schlundt, D., & Gemmell, L. (2004, Mar-Apr). Readiness and stages of change in addiction treatment. *American Journal of Addiction*, 13(2), 103-119.
- Duschl, R.A. (1990). *Restructuring science education*. New York: Teachers College Press.
- Elmore, R. (2002). *Bridging the gap between standards and achievement: The imperative for professional development in education*. Washington, DC: Albert Shanker Institute.
- Estacion, A., McMahan, T., Quint, J., Melamud, B., & Stephens, L. (2004). Conducting classroom observations in First Things First schools. *MDRC Working Papers on Research Methodology*.
- Facione, P. A. (1990). Critical Thinking: A statement of expert consensus for purposes of educational assessment and instruction. Research findings and recommendations. *American Philosophical Association*. Newark, DE.
- Ford, M.E. (1992). *Motivating humans: Goals, emotions, and personal agency beliefs*. Newbury Park, CA: Sage.
- Fraenkel, J. R. & Wallen, N. E. (2003). *How to design and evaluate research in education*. (5th ed.). New York: McGraw-Hill.
- Fullan, M. (2003). *Change forces with a vengeance*. London: RoutledgeFalmer.
- Fullan, M., Hill, P., & Crevola, C. (2006). *Breakthrough*. Thousand Oaks, CA: Corwin Press.
- Garet, M., Porter, A., Desimone, L., Birman, B., & Suk Yoon, K. (2001). What makes professional development effective? Results from a national sample of teachers. *American Educational Research Journal*, 38(4), 915-945.
- Goddard, R. D., Hoy, W. K., & Hoy, A. W. (2004). Collective efficacy beliefs: Theoretical developments, empirical evidence, and future directions. *Educational Researcher*, 33(3), 3–13.
- Good, T. L., and Brophy, J. E. (1974). Changing Teacher and Student Behavior: An Empirical Investigation. *Journal of Educational Psychology*, 66, 390-405.
- Guskey, T. R. (2002a). Does it make a difference? Evaluating professional development. *Educational Leadership*, 59(6), 45–51.
- Guskey, T. R. (2002b). Professional development and teacher change. *Teachers and Teaching: Theory and Practice*, 8(3/4), 381–391.
- Hall, G. (1979). The concerns-based approach to facilitating change. *Educational Horizons*, 57(4), 202-208.
- Hall, G. & Hord, S.M. (1987). *Change in schools: Facilitating the process*. Albany, New York: State University of New York Press.
- Hall, G. & George, A. A. (1979). *Stages of concern about innovation: The concept, initial verification and some implications*. Texas University, Austin, TX: Research and Development Center for Teacher Education/National Institute of Education.

- Hall, G. & Loucks, S. (1977). A developmental model for determining whether the treatment is actually implemented. *American Educational Research Journal*, 14(3), 263-276.
- Hall, G. & Loucks, S. (1978). Teacher concerns as a basis for facilitating and personalizing staff development. *Teachers College Record*, 80 (1), 46–58.
- Hall, G., Wallace, R., & Dossett, W. (1973). *A developmental conceptualization of the adoption process within educational institutions*. Austin, TX: University of Texas Press.
- Haney, J. J., Lumpe, A. T., Czerniak, C. M., & Egan, V. (2002). From beliefs to actions: The beliefs and actions of teachers implementing change. *Journal of Science Teacher Education*, 13(3), 287–313.
- Hestness, E., McDonald, R. C., Breslyn, W., McGinnis, J. R., & Mouza, C. (2014). Science teacher professional development in climate change education informed by the Next Generation Science Standards. *Journal of Geoscience Education*, 62(3), 319-329.
- Hord, S.M. & Hall, G.E. (2000). *Implementing change: Patterns, principles, and potholes*. (4th ed.) New York: Allyn and Bacon.
- Houseal, A. (2015). A visual representation of three-dimensional learning: A tool for evaluating curriculum. *Science Scope*, 39(1).
- Houseal, A. & Ellsworth, P. (2014). What's the big idea? Three big ideas from the research behind the Next Generation Science Standards. *Methods & Strategies: Ideas and techniques to enhance your science teacher*. *Science and Children* 52(4), 65-69.
- Huberman, A.M. & Miles, M.B. (1984). *Innovation up close: How school improvement works*. New York: Plenum Press.
- James, R.K. & Hall, G.H. (1981). A study of the concerns of science teachers regarding an implementation of ISCS. *Journal of Research in Science Teaching*, 18(6), 479–487.
- Kaasbøll, J. J. (1998). Teaching critical thinking and problem defining skills. *Education and Information Technologies*, 3(2), 101-117.
- Keeley, P. (2016). *Science formative assessment: 75 practical strategies for linking assessment, instruction, and learning* (2nd ed.) Thousand Oaks, CA: Corwin.
- Khishfe, R. & Abd-El-Khalick, F. (2002). Influence of explicit and reflective versus implicit inquiry-oriented instruction on sixth graders' views of nature of science. *Journal of Research in Science Teaching*. 39(7), 551–578.
- Loucks-Horsley, S., Love, N., Stiles, K., Mundry, S., & Hewson, P. (2003). *Designing professional development for teachers of science and mathematics*. Thousand Oaks, CA: Corwin Press, Inc.
- Lumpe, A., Czerniak, C., Haney, J., & Beltyukova, S. (2012). Beliefs about teaching science: The relationship between elementary teachers' participation in professional development and student achievement. *International Journal of Science Education*, 34(2), 153-166.
- Marsh, D. (1987). Implementation of a social studies curriculum in an Australian elementary school. *Elementary School Journal*, 87(4), 476–486.
- Marsh, D. & Penn, D. (1988). Engaging students in innovative instruction: An application of the stages of concern framework to studying student engagement. *Journal of Classroom Interaction*, 23(1), 8–14.
- Martin, M. O., Mullis, I. V., Foy, P., & Stanco, G. M. (2012). *TIMSS 2011 International Results in Science*. International Association for the Evaluation of Educational Achievement. Herengracht 487, Amsterdam, 1017 BT, The Netherlands.
- Merriam, S. B. (1998). *Qualitative research and case study applications in education*. San Francisco: Jossey-Bass.

- Michie, S., Johnston, M., Abraham, C., Lawton, R., Parker, D., & Walker, A. (2005). Making psychological theory useful for implementing evidence based practice: a consensus approach. *Quality and Safety in Health Care, 14*, 26–33.
- Miller, R. G., Curwen, M. S., White-Smith, K. A., & Calfee, R. C. (2014). Cultivating primary students' scientific thinking through sustained teacher professional development. *Early Childhood Education Journal 43*, 317-326.
- Nagle, B. (2013). Preparing high school students for the interdisciplinary nature of modern biology. *CBE-Life Sciences Education, 12*(2), 144-147.
- National Academy of Sciences. (2007). *Rising above the gathering storm: Energizing and employing America for a brighter economic future. Committee on Prospering in the Global Economy of the 21st Century: An Agenda for American Science and Technology. Committee on Science, Engineering, and Public Policy, and Policy and Global Affairs.* Washington, DC: The National Academies Press.
- National Academy of Science. (2015). *Science teachers' learning: Enhancing opportunities, creating supportive contexts.* Washington, DC: The National Academies Press.
- National Association of State Boards of Education (2016). *Next Generation Science Standards.* Retrieved from <http://www.nasbe.org/project/next-generation-science-standards/>
- National Commission on Excellence in Education. (1983). *A nation at risk: The imperative for educational reform. A report to the Nation and the Secretary of Education, U.S. Department of Education.* Washington, DC: U.S. Government Printing Office.
- National Research Council. (1996). *National science education standards.* Washington, DC: National Academy Press.
- National Research Council. (2007). *Taking science to school: Learning and teaching science in grades K-8.* Washington, DC: The National Academies Press.
- National Research Council. (2008). *Ready, set, science!: Putting research to work in K-8 science classrooms.* Washington, DC: The National Academies Press.
- National Research Council. (2012). *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas.* Washington, DC: National Academies Press.
- National Research Council. (2015). *Guide to Implementing the Next Generation Science Standards.* Washington, DC: National Academies Press.
- National Science Teachers Association. (2013). *NSTA Position Statement: The next generation science standards.* Washington, DC. Retrieved from <http://www.nsta.org/about/positions/ngss.aspx>
- NSTA. (2014). *Classroom Resources.* Washington, DC. Retrieved from <http://ngss.nsta.org/Classroom-Resources.aspx>
- NGSS Lead States. (2013a). *Next Generation Science Standards: For states, by states.* Washington, DC: The National Academies Press.
- NGSS Lead States. (2013b). *Next Generation Science Standards: For States, By States, FAQs.* Washington, DC: The National Academies Press. Retrieved from <http://www.nextgenscience.org/faqs##Contents1>
- Nunan, D. (1999). *Research methods in language learning.* Eighth printing. Cambridge: CUP
- Oğuz, A. and Sariçam, H. (2016, February). The relationship between critical thinking disposition and locus of control in pre-service teachers. *Journal of Education and Training Studies, 4*(2):182-192.
- Pajares, M. F. (1992). Teachers' beliefs and educational research: Cleaning up a messy construct. *Review of Educational Research, 62*(3), 307–332.

- Palak, D. & Walls, R. (2009). Teachers' beliefs and technology practices: A mixed-methods approach. *Journal of Research and Technology in Education*, 41(4): 417-441.
- Patton, M. Q. (2002). *Qualitative research & evaluation methods* (3rd ed.). Thousand Oaks, CA: Sage Publications.
- Pellegrino, J., Wilson, M., Koenig, J., & Beatty, A. (2014). *Developing assessments for the Next Generation Science Standards*. Washington, DC: National Academies Press.
- Pratt, H. (2013). *The NSTA reader's guide to the Next Generation Science Standards*. Arlington, VA: NSTA Press.
- Prochaska, J.O., DiClemente, C.C., & Norcross, J.C. (1992, September). In search of how people change. Applications to addictive behaviors. *American Psychologist* 47(9): 1102-1114.
- Reiser, B. J. (2013, September). What professional development strategies are needed for successful implementation of the Next Generation Science Standards. In *Paper written for the Invitational Research Symposium on Science Assessment, September* (Vol. 24, p. 25).
- Rosenfeld, M., & Rosenfeld, S. (2008). Developing effective teacher beliefs about learners: The role of sensitizing teachers to individual learning differences. *Educational Psychology*, 28(3), 245–272.
- Sandholtz, J. H., Ringstaff, C., & Dwyer, D. C. (1997). *Teaching with technology: Creating student-centered classrooms*. New York: Teachers College Press.
- Seliger, H. W. & Shohamy, E. (1989). *Second language research methods*. Oxford: OUP.
- Tashakkori, A., & Teddlie, C. (Eds.) (2003). *Handbook of mixed methods in social and behavior research*. Thousand Oaks, CA: Sage.
- Thompson, C. (2011). Critical thinking across the curriculum: Process over output. *International Journal of Humanities and Social Science*, 1(9), 1-7.
- Thompson, Charles, L., and Zeuli, J. (1999). The frame and tapestry: Standards-based reform and professional development. In *Teaching as the learning profession: Handbook of policy and practice*. San Francisco: Jossey-Bass Publishers.
- U.S. Department of Education. (2015). *Programs: Math and Science Partnerships: Purpose*. Retrieved from <http://www2.ed.gov/programs/mathsci/index.html>
- van den Berg, R. (1993). The concerns-based adoption model in the Netherlands, Flanders, and the United Kingdom: State of the art and perspective. *Studies in Educational Evaluation*, 19, 51–63.
- van den Berg, R. & Ros, A. (1999). The permanent importance of the subjective reality of teachers during educational innovation: A concerns-based approach. *American Educational Research Journal*, 36(4), 879–906.
- Wayne, A. J., Yoon, K. S., Zhu, P., Cronen, S., & Garet, M. S. (2008). Experimenting with teacher professional development: Motives and methods. *Educational Researcher*, 37(8), 479–479.
- Wilson, S. M. (2013). Professional development for science teachers. *Science*, 340(6130), 310-313.
- Yoon, K. S., Duncan, T., Lee, S. W.-Y., Scarloss, B., & Shapley, K. (2007). *Reviewing the evidence on how teacher professional development affects student achievement (Issues & Answers Report, REL 2007-No. 033)*. Washington, DC: U.S. Department of Education, Institute of Education Sciences, National Center for Education Evaluation and Regional Assistance, Regional Educational Laboratory Southwest.

Zohrabi, M. (2013). Mixed methods research: Instruments, validity, reliability and reporting findings. *Theory and Practice in Language Studies*, 3(2): 254-262.

Appendices

Appendix A. Critical Thinking Skills from “The Delphi Project”

Appendix B. Outlines for Workshops

Appendix C. CCSD-MSP Teacher Consent Form

Appendix D. Concerns-Confidence-Commitment questionnaire

Appendix E. NAP Report Committee Conclusions and workshop alignment

Appendix A. Critical Thinking Skills from “The Delphi Project”

*Excerpt from “The Delphi Report” (pg. 6-10)

TABLE 1
CONSENSUS LIST OF CT COGNITIVE SKILLS AND SUB-SKILLS

SKILL	SUB-SKILLS
1. Interpretation	Categorization Decoding Significance Clarifying Meaning
2. Analysis	Examining Ideas Identifying Arguments Analyzing Arguments
3. Evaluation	Assessing Claims Assessing Arguments
4. Inference	Querying Evidence Conjecturing Alternatives Drawing Conclusions
5. Explanation	Stating Results Justifying Procedures Presenting Arguments
6. Self-Regulation	Self-examination Self-correction

The Delphi experts find remarkable consensus on the descriptions of each of the skills and sub-skills. (See Table 4.) The examples associated with each sub-skill are intended as clarifications. Some readers might see in them suggestions of possible instructional or assessment strategies. Others might see in them the tools to initiate staff development conversations about the curricular implications. However, the panel's consensus has to do with the skill and sub-skill descriptions, and does not necessarily extend to the examples.

TABLE 4.
CONSENSUS DESCRIPTIONS
CORE CT SKILLS AND SUB-SKILLS

1. INTERPRETATION: To comprehend and express the meaning or significance of a wide variety of experiences, situations, data, events, judgments, conventions, beliefs, rules, procedures or criteria.

1.1 CATEGORIZATION:

* to apprehend or appropriately formulate categories, distinctions, or frameworks for understanding, describing or characterizing information.

* to describe experiences, situations, beliefs, events, etc. so that they take on comprehensible meanings in terms of appropriate categorizations, distinctions, or frameworks.

For example: to recognize a problem and define its character without prejudice to inquiry; to determine a useful way of sorting and sub-classifying information; to make an understandable report of what one experienced in a given situation; to classify data, findings or opinions using a given classification schema.

1.2 DECODING SIGNIFICANCE:

* to detect, attend to, and describe the informational content, affective purport, directive functions, intentions, motives, purposes, social significance, values, views, rules, procedures,

criteria, or inferential relationships expressed in convention-based communication systems, such as in language, social behaviors, drawings, numbers, graphs, tables, charts, signs and symbols.

For example: to detect and describe a person's purposes in asking a given question; to appreciate the significance of a particular facial expression or gesture used in a given social situation; to discern the use of irony or rhetorical questions in debate; to interpret the data displayed or presented using a particular form of instrumentation.

1.3 CLARIFYING MEANING:

* to paraphrase or make explicit, through stipulation, description, analogy or figurative expression, the contextual, conventional or intended meanings of words, ideas, concepts, statements, behaviors, drawings, numbers, signs, charts, graphs, symbols, rules, events or ceremonies.

* to use stipulation, description, analogy or figurative expression to remove confusing, unintended vagueness or ambiguity, or to design a reasonable procedure for so doing.

For example: to restate what a person said using different words or expressions while preserving that person's intended meanings; to find an example which helps explain something to someone; to develop a distinction which makes clear a conceptual difference or removes a troublesome ambiguity.

2. ANALYSIS: To identify the intended and actual inferential relationships among statements, questions, concepts, descriptions or other forms of representation intended to express beliefs, judgments, experiences, reasons, information, or opinions.

2.1 EXAMINING IDEAS:

* to determine the role various expressions play or are intended to play in the context of argument, reasoning or persuasion.

* to define terms.

* to compare or contrast ideas, concepts, or statements.

* to identify issues or problems and determine their component parts, and also to identify the conceptual relationships of those parts to each other and to the whole.

For example: to identify a phrase intended to trigger a sympathetic emotional response which might induce an audience to agree with an opinion; to examine closely related proposals regarding a given problem and to determine their points of similarity and divergence; given a complicated assignment, to determine how it might be broken up into smaller, more manageable tasks; to define an abstract concept.

2.2 DETECTING ARGUMENTS:

* given a set of statements, descriptions, questions or graphic representations, to determine whether or not the set expresses, or is intended to express, a reason or reasons in support of or contesting some claim, opinion or point of view.

For example, given a paragraph, determine whether a standard reading of that paragraph in the context of how and where it is published, would suggest that it presents a claim as well as a reason or reasons in support of that claim; given a passage from a newspaper editorial, determine if the author of that passage intended it as an expression of reasons for or against a given claim or opinion; given a commercial announcement, identify any claims being advanced along with the reasons presented in their support.

2.3 ANALYZING ARGUMENTS:

* given the expression of a reason or reasons intended to support or contest some claim, opinion or point of view, to identify and differentiate: (a) the intended main conclusion, (b) the premises and reasons advanced in support of the main conclusion, (c) further premises and reasons advanced as backup or support for those premises and reasons intended as supporting the main conclusion, (d) additional unexpressed elements of that reasoning, such as intermediary conclusions, unstated assumptions or presuppositions, (e) the overall structure of the argument or intended chain of reasoning, and (f) any items contained in the body of expressions being

examined which are not intended to be taken as part of the reasoning being expressed or its intended background.

For example: given a brief argument, paragraph-sized argument, or a position paper on a controversial social issue, to identify the author's chief claim, the reasons and premises the author advances on behalf of that claim, the background information used to support those reasons or premises, and crucial assumptions implicit in the author's reasoning; given several reasons or chains of reasons in support of a particular claim, to develop a graphic representation which usefully characterizes the inferential flow of that reasoning.

3. EVALUATION: To assess the credibility of statements or other representations which are accounts or descriptions of a person's perception, experience, situation, judgment, belief, or opinion; and to assess the logical strength of the actual or intended inferential relationships among statements, descriptions, questions or other forms of representation.

3.1 ASSESSING CLAIMS:

* to recognize the factors relevant to assessing the degree of credibility to ascribe to a source of information or opinion.

* to assess the contextual relevance of questions, information, principles, rules or procedural directions.

* to assess the acceptability, the level of confidence to place in the probability or truth of any given representation of an experience, situation, judgment, belief or opinion.

For example: to recognize the factors which make a person a credible witness regarding a given event or credible authority on a given topic; to determine if a given principle of conduct is applicable to deciding what to do in a given situation; to determine if a given claim is likely to be true or false based on what one knows or can reasonably find out.

3.2 ASSESSING ARGUMENTS:

* to judge whether the assumed acceptability of the premises of a given argument justify one's accepting as true (deductively certain), or very probably true (inductively justified), the expressed conclusion of that argument.

* to anticipate or to raise questions or objections, and to assess whether these point to significant weakness in the argument being evaluated.

* to determine whether an argument relies on false or doubtful assumptions or presuppositions and then to determine how crucially these affect its strength.

* to judge between reasonable and fallacious inferences;

* to judge the probative strength of an argument's premises and assumptions with a view toward determining the acceptability of the argument.

* to determine and judge the probative strength of an argument's intended or unintended consequences with a view toward judging the acceptability of the argument;

* to determine the extent to which possible additional information might strengthen or weaken an argument.

For example: given an argument to judge if its conclusion follows either with certainty or with a high level of confidence from its premises; to check for identifiable formal and informal fallacies; given an objection to an argument to evaluate the logical force of that objection; to evaluate the quality and applicability of analogical arguments; to judge the logical strength of arguments based on hypothetical situations or causal reasoning; to judge if a given argument is relevant or applicable or has implications for the situation at hand; to determine how possible new data might lead logically to the further confirmation or disconfirmation of a given opinion.

4. INFERENCE: To identify and secure elements needed to draw reasonable conclusions; to form conjectures and hypotheses; to consider relevant information and to deduce the consequences flowing from data, statements, principles, evidence, judgments, beliefs, opinions, concepts, descriptions, questions, or other forms of representation.

4.1 QUERYING EVIDENCE:

- * in particular, to recognize premises which require support and to formulate a strategy for seeking and gathering information which might supply that support.
- * in general, to judge that information relevant to deciding the acceptability, plausibility or relative merits of a given alternative, question, issue, theory, hypothesis, or statement is required, and to determine plausible investigatory strategies for acquiring that information.

For example: when attempting to develop a persuasive argument in support of one's opinion, to judge what background information it would be useful to have and to develop a plan which will yield a clear answer as to whether or not such information is available; after judging that certain missing information would be germane in determining if a given opinion is more or less reasonable than a competing opinion, to plan a search which will reveal if that information is available.

4.2 CONJECTURING ALTERNATIVES:

- * to formulate multiple alternatives for resolving a problem, to postulate a series of suppositions regarding a question, to project alternative hypotheses regarding an event, to develop a variety of different plans to achieve some goal.
- * to draw out presuppositions and project the range of possible consequences of decisions, positions, policies, theories, or beliefs.

For example: given a problem with technical, ethical or budgetary ramifications, to develop a set of options for addressing and resolving that problem; given a set of priorities with which one may or may not agree, to project the difficulties and the benefits which are likely to result if those priorities are adopted in decision making.

4.3 DRAWING CONCLUSIONS:

- * to apply appropriate modes of inference in determining what position, opinion or point of view one should take on a given matter or issue.
- * given a set of statements, descriptions, questions or other forms of representation, to educe, with the proper level of logical strength, their inferential relationships and the consequences or the presuppositions which they support, warrant, imply or entail.
- * to employ successfully various sub-species of reasoning, as for example to reason analogically, arithmetically, dialectically, scientifically, etc.
- * to determine which of several possible conclusions is most strongly warranted or supported by the evidence at hand, or which should be rejected or regarded as less plausible by the information given.

For example: to carry out experiments and to apply appropriate statistical inference techniques in order to confirm or disconfirm an empirical hypothesis; given a controversial issue to examine informed opinions, consider various opposing views and the reasons advanced for them, gather relevant information, and formulate one's own considered opinion regarding that issue; to deduce a theorem from axioms using prescribed rules of inference.

5. EXPLANATION: To state the results of one's reasoning; to justify that reasoning in terms of the evidential, conceptual, methodological, criteriological and contextual considerations upon which one's results were based; and to present one's reasoning in the form of cogent arguments.

5.1 STATING RESULTS:

- * to produce accurate statements, descriptions or representations of the results of one's reasoning activities so as to analyze, evaluate, infer from, or monitor those results.

For example: to state one's reasons for holding a given view; to write down for one's own future use one's current thinking about an important or complex matter; to state one's research findings; to convey one's analysis and judgment regarding a work of art; to state one's considered opinion on a matter of practical urgency.

5.2 JUSTIFYING PROCEDURES:

* to present the evidential, conceptual, methodological, criteriological and contextual considerations which one used in forming one's interpretations, analyses, evaluation or inferences, so that one might accurately record, evaluate, describe or justify those processes to one's self or to others, or so as to remedy perceived deficiencies in the general way one executes those processes.

For example: to keep a log of the steps followed in working through a long or difficult problem or scientific procedure; to explain one's choice of a particular statistical test for purposes of data analysis; to state the standards one used in evaluating a piece of literature; to explain how one understands a key concept when conceptual clarity is crucial for further progress on a given problem; to show that the prerequisites for the use of a given technical methodology have been satisfied; to report the strategy used in attempting to make a decision in a reasonable way; to design a graphic display which represents the quantitative or spatial information used as evidence.

5.3 PRESENTING ARGUMENTS:

* to give reasons for accepting some claim.

* to meet objections to the method, conceptualizations, evidence, criteria or contextual appropriateness of inferential, analytical or evaluative judgments.

For example: to write a paper in which one argues for a given position or policy; to anticipate and to respond to reasonable criticisms one might expect to be raised against one's political views; to identify and express evidence and counter-evidence intended as a dialectical contribution to one's own or another person's thinking on a matter of deep personal concern.

6: SELF-REGULATION: Self-consciously to monitor one's cognitive activities, the elements used in those activities, and the results educed, particularly by applying skills in analysis and evaluation to one's own inferential judgments with a view toward questioning, confirming, validating, or correcting either one's reasoning or one's results.

6.1 SELF-EXAMINATION:

* to reflect on one's own reasoning and verify both the results produced and the correct application and execution of the cognitive skills involved.

* to make an objective and thoughtful meta-cognitive self-assessment of one's opinions and reasons for holding them.

* to judge the extent to which one's thinking is influenced by deficiencies in one's knowledge, or by stereotypes, prejudices, emotions or any other factors which constrain one's objectivity or rationality.

* to reflect on one's motivations, values, attitudes and interests with a view toward determining that one has endeavored to be unbiased, fair-minded, thorough, objective, respectful of the truth, reasonable, and rational in coming to one's analyses, interpretations, evaluations, inferences, or expressions.

For example: to examine one's views on a controversial issue with sensitivity to the possible influences of one's personal bias or self-interest; to review one's methodology or calculations with a view to detecting mistaken applications or inadvertent errors; to reread sources to assure that one has not overlooked important information; to identify and review the acceptability of the facts, opinions or assumptions one relied on in coming to a given point of view; to identify and review one's reasons and reasoning processes in coming to a given conclusion.

6.2 SELF-CORRECTION:

* where self-examination reveals errors or deficiencies, to design reasonable procedures to remedy or correct, if possible, those mistakes and their causes.

For example: given a methodological mistake or factual deficiency in one's work, to revise that work so as to correct the problem and then to determine if the revisions warrant changes in any position, findings, or opinions based thereon.

Appendix B.

Secondary STEM Agenda March 17 and 18, 2016

March 17, 2016:

- CBAM
- Pre-observation meetings for classroom observations
- Classroom observations
- Debrief of classroom observations

March 18, 2016: Work at LLC

- 7:00-7:30: Breakfast and Coffee
- 7:30-8:00: Check-in and Housekeeping
- 8:00-9:00: Critical Thinking Skills and Integration (District coordinator)
- 9:00-12:00: How do we know what students know? (University staff)
- 12:00-1:00: Lunch (on your own)
- 1:15-3:00: Integrating Practice (District coordinator)
- 3:00-3:30: CBAM and plan for year-end activities

Appendix C.

CCSD-MSP Teacher Consent Form

You are invited to participate in a research study looking into the efficacy of teacher professional development (PD). This is a research project that I, Martha Inouye, will complete to aid in effective future PD as Next Generation Science Standards (NGSS) and critical thinking skills are integrated into the curriculum. As the Responsible Project Investigator (RPI) I will be studying the ways in which the Math Science Partnership and its collaboration with University of Wyoming have effectively assisted in your growth as an educator. I hope that you will participate in this study. Your participation will provide information that could help inform other teachers, school administrators, and professionals in the field of education interested in developing curriculum based on the NGSS or conducting professional development regarding the NGSS.

Participation in this study entails completion of online surveys and participation in interviews, as well as an agreement to allow the RPI and Co-Investigators to use previously collected data as part of the Math Science Partnership Grant. The in person interviews will take place during the 2015-16 UW-CCSD STEM Math Science Partnership Professional Development workshops at the Lakeway Learning Center, or any Professional Development that takes place in schools in the district. Online surveys will be submitted using Google Forms. Previously collected data will include responses on the Survey of Enacted Curriculum (SEC), Concerns-Based Adoption Model (CBAM) survey, and/or the California Critical Thinking Skills Test (CCTST). Additionally, copies of selected student and teacher work will be collected and analyzed. Examples of the type of work that will be collected include lesson plans that you have written and student journal entries, pre/posttests, and pictures of other student work and/or projects.

You will be asked to devote no more than 2 hours to participating in the interviews and no more than another 2 hours in completing the online surveys. The total amount of time you will be asked to be involved in this study will be between no more than 2-4 hours.

There are minimal risks to participants involved in this research study. Potential minimal risks may include feeling some level of embarrassment or self-consciousness in online surveys and/or interview responses, as well as the potential risk that information obtained through the surveys or interviews could adversely affect participants if disclosed outside the research setting. The potential risk of disclosure of the information outside of the research would be related to possible embarrassment and will not impact the reputation or employability of the participants. To minimize these potential risks participants will be identifiable only to the RPI and Co-Investigators. No identifying features will be associated with the final written report. Surveys will be conducted electronically to reduce personal identifiers and the privacy of participants. The audio and/or video recording from the interviews will be transcribed with pseudonyms for each participant and personal identifiers will be removed and therefore, the risk in this study is minimal, not more than ordinarily encountered in daily life.

You may choose to withdraw from the study at any point in time by indicating that you would like to opt out of the study for any reason. Participants may withdraw during any of the online surveys or interviews. You will be able to opt out by indicating your preference to the RPI or any other Co-Investigator.

Indirect benefits include having opportunities to reflect on your teaching practices and share your experiences in learning about the NGSS and creating new curricular units using the NGSS. This research may provide a case study and resource to other teachers, school administrators, and professionals in the field of education interested professional development regarding the NGSS and curriculum development using the NGSS.

The audio and/or video files of the interviews and the electronically submitted surveys will be stored on a password-protected computer and only the RPI and the Co-Investigators will have access to any of the raw data. When the raw data is transcribed you will be given a pseudonym and all personal identifiers will be removed. This will help protect your privacy and confidentiality. If you wish to have copies of the subsequent reports on the research project, you will be able to submit this desire through the use of a Google Form. The data will not be used for any research purposes other than those stated above. The data will be stored up to 3 years and then be destroyed.

Freedom of consent:

My participation is voluntary and my refusal to participate will not involve penalty or loss of benefits to which I am otherwise entitled, and I may discontinue participation at any time without penalty or loss of benefits to which I am otherwise entitled. To terminate participation in the study, I will indicate my preference to the Responsible Project Investigator or any other Co-Investigator.

If you have any questions about the research or participation in the research please contact:

Martha Inouye - (208) 540-1680 - minouye@uwyo.edu

If you have questions about your rights as a research subject, please contact the University of Wyoming IRB Administrator at 307-766-5320.

Consent to use photographs and/or audio and video recordings (check yes or no for each):

<u>Yes</u>	<u>No</u>	
_____	_____	You may use my previously collected data (Content tests, SEC, CBAM, CCTST, Reflections, & Curriculum work) If there are any of these you would like to eliminate, you may cross them out on the list and they will not be used in the data analysis.
_____	_____	You may use photographs in which I am identifiable
_____	_____	You may use audio recordings in which I speak
_____	_____	You may use video recordings in which I am present

Consent to participate:

Printed name of participant

Participant signature

Date

Appendix D.

Concerns-Confidence-Commitment Questionnaire

Using a scale of 1 to 10 described below, enter your level of **concern** for each item in the table.

1 ←-----
 A **LOW** level of concern, i.e. comfortable
 proceeding with implementation or more learning

-----> 10
 A **HIGH** level of concern, i.e. many worries and
 doubts make proceeding with implementation or
 more learning overwhelming

		Rating
1	When it comes to developing science lessons that incorporate the skills of INTERPRETATION, ANALYSIS, EVALUATION, INFERENCE, EXPLANATION, AND SELF-REGULATION , my level of concern is ...	
2	When it comes to implementing science lessons that incorporate the skills of INTERPRETATION, ANALYSIS, EVALUATION, INFERENCE, EXPLANATION, AND SELF-REGULATION , my level of concern is ...	
3	When it comes to evaluating science lessons that incorporate the skills of INTERPRETATION, ANALYSIS, EVALUATION, INFERENCE, EXPLANATION, AND SELF-REGULATION , my level of concern is ...	

Comment section: Briefly describe any concerns that influenced your rating above

My concerns are... _____

Using a scale of 1 to 10 described below, enter your level of **confidence** for each item in the table.

1 ←-----
 A **LOW** level of confidence, i.e. need much more
 guidance and/or learning before implementing

-----> 10
 A **HIGH** level of confidence, i.e. comfortable
 proceeding with implementation

		Rating
1	When it comes to developing science lessons that incorporate the skills of INTERPRETATION, ANALYSIS, EVALUATION, INFERENCE, EXPLANATION, AND SELF-REGULATION , my level of confidence is ...	
2	When it comes to implementing science lessons that incorporate the skills of INTERPRETATION, ANALYSIS, EVALUATION, INFERENCE, EXPLANATION, AND SELF-REGULATION , my level of confidence is ...	
3	When it comes to evaluating science lessons that incorporate the skills of INTERPRETATION, ANALYSIS, EVALUATION, INFERENCE, EXPLANATION, AND SELF-REGULATION , my level of confidence is ...	

Comment section: Briefly describe any concerns that influenced your rating above

My concerns are... _____

Using a scale of 1 to 10 described below, enter your level of **commitment** for each item in the table.

1 ←-----
 A **LOW** level of commitment, i.e. I'm not sure I'll
 really make it happen, even if I think it's a good idea

-----> 10
 A **HIGH** level of commitment, i.e. I'll try to
 make it happen no matter what

		Rating
1	When it comes to developing science lessons that incorporate the skills of INTERPRETATION, ANALYSIS, EVALUATION, INFERENCE, EXPLANATION, AND SELF-REGULATION , my level of commitment is ...	
2	When it comes to implementing science lessons that incorporate the skills of INTERPRETATION, ANALYSIS, EVALUATION, INFERENCE, EXPLANATION, AND SELF-REGULATION , my level of commitment is ...	
3	When it comes to evaluating science lessons that incorporate the skills of INTERPRETATION, ANALYSIS, EVALUATION, INFERENCE, EXPLANATION, AND SELF-REGULATION , my level of commitment is ...	

Comment section: Briefly describe any concerns that influenced your rating above

My concerns are... _____

Appendix E.

Table E1. Conclusions from a comprehensive study on supporting K-12 science teachers (NAP, 2015).

The overlap between the committee's conclusions and the research study's professional development workshops.

<u>Committee's Conclusions</u>	<u>Professional Development Connections</u>
<p>Conclusion 1: An evolving understanding of how best to teach science, including the NGSS, represents a significant transition in the way science is currently taught in most classrooms and will require most science teachers to alter the way they teach.</p> <p>Conclusion 2: The available evidence suggests that many science teachers have not had sufficiently rich experiences with the content relevant to the science courses they currently teach, let alone a substantially redesigned science curriculum. Very few teachers have experience with the science and engineering practices described in the NGSS. This situation is especially pronounced both for elementary school teachers and in schools that serve high percentages of low-income students, where teachers are often newer and less qualified.</p> <p>Conclusion 3: Typically, the selection of and participation in professional learning opportunities is up to individual teachers. There is often little attention to developing collective capacity for science teaching at the building and district levels or to offering teachers learning opportunities tailored to their specific needs and offered in ways that support cumulative learning over time.</p> <p>Conclusion 4: Science teachers' learning needs are shaped by their preparation, the grades and content areas they teach, and the contexts in which they work. Three important areas in which science teachers need to develop expertise are</p> <ul style="list-style-type: none">• the knowledge, capacity, and skill required to support a diverse range of students;• content knowledge, including understanding of disciplinary core ideas, crosscutting concepts, and scientific and engineering practices; and	<ul style="list-style-type: none">➤ Professional development sessions included those in which teachers were pushed to expose their beliefs and practices, experience cognitive conflict, and observe/talk about/consider/try other techniques than they might normally use.➤ Facilitators introduced the 3D-model (Houseal, 2015) to assist in the integration of all three dimensions of learning within a unit/lesson.➤ Facilitators organize opportunities for teachers to observe their peers to get other techniques.➤ Explicit sessions on NGSS, breaking apart standards, the 3D-model (Houseal, 201-), and troubleshooting.➤ Facilitators model lessons that incorporate all three dimensions of NGSS followed by breaking down the lesson to identify what components are present and how they are promoted.➤ Since secondary teachers in the state are required to possess coursework in their area of expertise, content knowledge was not the emphasis of the sessions.➤ This grant is a district-wide initiative. Workshop sessions are planned in response to previous workshops and teacher surveys.➤ The teachers involved committed to a year-long experience with professional development sessions scheduled throughout the academic year.➤ Facilitators explicitly teach the 3D-model (Houseal, 2015), model teaching techniques applicable to NGSS, organize and aid in teacher discussions on what content is entailed in NGSS, and organize opportunities for teachers to observe their peers to get other techniques.➤ There is less emphasis on content knowledge as all secondary teachers in the state are required to have content expertise via university courses.

- pedagogical content knowledge for teaching science, including a repertoire of teaching practices that support students in rigorous and consequential science learning.

Conclusion 5: The best available evidence based on science professional development programs suggests that the following features of such programs are most effective:

- active participation of teachers who engage in the analysis of examples of effective instruction and the analysis of student work,
- a content focus,
- alignment with district policies and practices, and
- sufficient duration to allow repeated practice and/or reflection on classroom experiences.

Conclusion 6: Professional learning in online environments and through social networking holds promise, although evidence on these modes from both research and practice is limited.

Conclusion 7: Science teachers' professional learning occurs in a range of settings both within and outside of schools through a variety of structures (professional development programs, professional learning communities, coaching, and the like). There is limited evidence about the relative effectiveness of this broad array of learning opportunities and how they are best designed to support teacher learning.

Conclusion 8: Schools need to be structured to encourage and support ongoing learning for science teachers, especially given the number of new teachers entering the profession.

Conclusion 9: Science teachers' development is best understood as long term and contextualized. The schools and classrooms in which teachers work shape what and how they learn. These contexts include, but are not limited to school, district, and state policies and practices concerning professional capacity (e.g., professional networks, coaching, partnerships), coherent instructional guidance (e.g., state and district curriculum and assessment/ accountability policies), and leadership (e.g., principals and teacher leaders).

- Teachers are active participants in workshops as they observe and are observed in classroom settings and participate in debriefs and reflections of observed lessons.
- Teachers take on the role of students during modeling simulations, and create/modify curriculum to be used in their classroom.
- Teacher discussion and activities often revolve around their curriculum and content
- The professional development sessions are facilitated by the District Secondary Science Coordinator; district policies and practices are considered in planning sessions
- The workshops run from August 2015 – June 2016 and the grant was renewed for another year (sustained)

N/A

- Teachers travel to schools in the district to observe their peers as well as meet in a district venue housing central administrative offices.
- The grant provides a stipend to teacher participants.
- The district schedules subs for teachers during the workshop weeks, so teachers can attend.
- The grant is through the school district, focused specifically on their county, and facilitated by University partners and district administrators

Conclusion 10: School and district administrators are central to building the capacity of the science teacher workforce.

Conclusion 11: Teacher leaders may be an important resource for building a system that can support ambitious science instruction. There is increasing attention to creating opportunities for teachers to take on leadership roles to both improve science instruction and strengthen the science teacher workforce. These include roles as instructional coaches, mentors, and teacher leaders.

Conclusion 12: Closing the gap between the new way of teaching science and current instruction in many schools will require attending to individual teachers' learning needs, as well as to the larger system of practices and policies (such as allocation of resources, use of time, and provision of opportunities for collaboration) that shape how science is taught.

Conclusion 13: The U.S. educational system lacks a coherent and well-articulated system of learning opportunities for teachers to continue developing expertise while in the classroom. Opportunities are unevenly distributed across schools, districts, and regions, with little attention to sequencing or how to support science teachers' learning systematically. Moreover, schools and districts often lack systems that can provide a comprehensive view of teacher learning; identify specific teacher needs; or track investments—in time, money, and resources—in science teachers' professional learning.

- Outreach has been attempted with principals, but with limited success
- The District Secondary Science Coordinator is the primary facilitator
- Trying to foster teacher leaders by having teachers do peer classroom observations and (de)brief before and after
- Teachers are asked for exemplar lessons to be used in the professional development sessions. They are also encouraged to describe successes and challenges and to ask questions of others as would a coach or teacher leader.
- Individual teachers' learning needs are attended to by modifying workshops based on teacher feedback and concern (ex. Triple C-Q, teacher logs, prior workshops, informal interviews).
- Some sessions are centered on discussion of what these changes mean for teachers and how they can move forward accordingly.
- Systematic learning is promoted by empowering teachers to embrace and successfully execute the new way of teaching science that NGSS requires and instills.
- Specific teacher needs are identified using Google Forms, and in-person check-ins; Facilitators plan sessions accordingly
- Teacher investment is tracked through the use of teacher logs via a Google Form.