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EXPLORING TEACHERS' KNOWLEDGE AND PERCEPTIONS ACROSS MATHEMATICS AND SCIENCE THROUGH CONTENT-RICH LEARNING EXPERIENCES IN A PROFESSIONAL DEVELOPMENT SETTING

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ABSTRACT. This paper examines upper elementary and middle school teachers' learning of mathematics and science content, how their perceptions of their disciplines and learning of that discipline developed through content-rich learning experiences, and the differences and commonalities of the teachers' learning experiences relative to content domain. This work was situated within a larger professional development (PD) program that had multiple, long-term components. Participants' growth occurred in 4 primary areas: knowledge of content, perceptions of the discipline, perceptions about the learning of the discipline, and perceptions regarding how students learn content. Findings suggest that when embedded within an effective professional development context, content can be a critical vehicle through which change can be made in teachers' understandings and perceptions of mathematics and science. When participants in our study were able to move beyond their internal conflicts and misunderstandings, they could expand their knowledge and perceptions of content and finally bridge to re-conceptualize how to teach that content. These findings further indicate that although teachers involved in both mathematics and science can benefit from similar overall PD structures, there are some unique challenges that need to be addressed for each particular discipline group. This study contributes to what we understand about teacher learning and change, as well as commonalities and differences between teachers' learning of mathematics and science.

KEY WORDS: content knowledge, in-service professional development, teacher beliefs, teacher development, teacher knowledge, teacher learning

Within the literature on professional development (PD), there are two critical foci to which we would like to draw attention: the knowledge and perceptions of the teacher and the role that rigorous content plays within teacher development. Teacher quality (e.g. content expertise, pedagogical content knowledge) has a powerful influence on student achievement (Nye, Konstantopoulos & Hedges, 2004), and therefore, many reform efforts center their attention to teacher knowledge and change. Improving teacher quality is a complex task since many factors, including teachers' content knowledge and perceptions, impact their instructional choices in the classroom. Teacher knowledge and perceptions are interrelated (Ambrose, 2004), and therefore, both must be addressed in order to transform teaching practice. Thus, it is often necessary for PD efforts to

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strive to expand teachers' content knowledge, as well as their perceptions about that content. Professional development must intentionally include challenging, content-specific learning experiences complete with opportunities for teachers to reflect on practice within the context of their teaching (Garet, Porter, Desimone, Birman & Yoon, 2001).

In this paper, we explore teacher learning, while simultaneously examining the role that content domain plays in how teachers approach learning. Our findings relate to upper elementary and middle grades teachers' learning of mathematics and science content, how their perceptions of their disciplines and learning of that discipline developed through content-rich learning experiences (Stein, Silver, Smith & Henningsen, 2009), and the differences and commonalities of the teachers' experiences relative to content domain (mathematics or science). The following questions guided our study: (1) In what ways do mathematics and science teachers' content knowledge expand as a result of content-rich learning experiences during a professional development program?, (2) In what ways do these teachers' perceptions expand as a result of content-rich learning experiences during a professional development program?, and (3) What are the commonalities and differences of these teachers' experiences relative to their content domain—mathematics or science?

Theoretical Framework

Research on mathematics and science teachers' knowledge, perceptions, and learning (including change) was used to frame this study. We briefly highlight this body of work below.

Teacher Knowledge and Perceptions

Expectations and ideals endorsed by current reform efforts in mathematics and science education (e.g. NCTM, 2000; NRC, 1996) challenge teachers in their thinking about their discipline, teaching, and learning. Teachers are asked to teach in ways that promote an integrated, connected view of content, rather than a procedural, rule-based view; therefore, their content knowledge must be flexible enough to allow them to make connections and conjectures (Ball, Leubienski & Mewborn, 2001). Ball, Thames & Phelps (2008) support that teachers' mathematical knowledge for teaching should include both specific types of subject matter knowledge and pedagogical content knowledge (Shulman, 1987). These content understandings must incorporate both flexibility with content needed beyond the classroom (*Common Content Knowledge*) and content within the

K – 12 level (*Horizon Content Knowledge, Specialized Content Knowledge*). These aspects of content knowledge, as well as extensions to depth of concepts beyond the K – 12 level, are necessary for teachers to make connections across content, as well as bridge to pedagogical content knowledge. Although this work was situated within mathematical knowledge, the ideas, which were an extension of Shulman's (1987) work, can similarly be applied to science.

Teachers' knowledge of and perceptions about mathematics and science are related in powerful ways (Wilson & Cooney, 2002). For example, Lloyd & Wilson (1998) suggest that flexible and well-organized conceptions (knowledge, perceptions) are necessary to implement mathematics teaching that is aligned with reform ideals. However, teachers do not always possess such content conceptions. In particular, research suggests that elementary certified teachers often lack crucial knowledge and perspectives needed to support this approach to teaching mathematics/science (Guillaume & Kirtman, 2010). Preservice teachers, in particular, have been found to focus on superficial aspects of inquiry (e.g. materials, engage in a *project*) (Marshall, Petrosino & Martin, 2010). The path is not clear as to how to promote teacher learning in ways that challenge both understandings and perceptions of content (Ambrose, 2004).

Teacher Learning

Teachers need opportunities to experience inquiry in a way that becomes part of how they think and plan (Jeanpierre, Oberhauser & Freeman, 2005; Khourey-Bowers & Fenk, 2009). The structure of a successful learning environment for teachers must attempt to address both what they as learners bring to the situation and the new ideas to be learned. Nelson & Harper (2006) explore learning formats that force the learner to experience uncomfortable moments needed to open his or her mind to new knowledge. Their *pedagogy of difficulty* (Nelson & Harper, 2006) echoes the early work of Pajares (1992), which discusses moving learners through a series of *cognitive conflicts* in order to help them confront old beliefs and integrate new ones. Learners' conceptions are rooted in their previous ideas, their ontological categories and epistemological beliefs, and these existing conceptions can shape and constrain new learning, often remaining highly resistant to change. Posner, Strike, Hewson & Gertzog (1982) suggest that an individual's existing conceptions are primarily functional: They persist as long as they are effective at solving problems and predicting future events; learners need to be placed in a setting that encourages them to confront their current thinking.

Conceptual change theory has been used as the basis of several teaching models (Chinn & Brewer, 1993; Cosgrove & Osborn, 1985; Nussbaum & Novick, 1982). Although these models have unique elements, they all involve revealing and evaluating the learner's preconceptions, creating cognitive conflict within the learner, and facilitating the restructuring of new ideas. Broadly defined, this work supports the notion that a mechanism for change is needed in order for teachers to be ready to confront beliefs, enhance content understandings, and make connections between content and pedagogy. Although teachers may not be accustomed to intense learning environments (Redish & Hammer, 2009), content-rich learning experiences are necessary to facilitate learning, including opportunities to practice what they are learning (Garet et al., 2001). As noted above, teachers of mathematics and science can hold narrow, inflexible views of content; situating challenging content within PD can facilitate teachers in recognizing their knowledge limitations, thereby providing an environment in which their knowledge and views toward content can expand. To accomplish such goals for PD, Redish & Hammer (2009) recommend restricting the scope of the content in ways that bridge what knowledge teachers bring to the experience with new knowledge necessary to move to flexible understandings. Additionally, they suggest that learners need continual support as they reframe their understanding of what "knowing" the content entails (e.g. articulating class goals).

Furthermore, teachers often agree with the ideas set forth in the reform documents, yet they do not always feel the results of such reform-based instruction are matched by the time required for implementation (Davis, Petish & Smithey, 2006). Teachers also lack appropriate models, as well as struggle to change practice within the realities of teaching; the culture of schools includes mandated standards, high-stakes achievement test goals that must be achieved, classrooms that should operate in a prescribed fashion, and daily management tasks that can consume teachers' thinking (Marshall, Horton, Igo & Switzer, 2009). Finally, teachers' affect and perceptions of students' needs and teaching environments often influence their comfort level in enacting inquiry methods (Dreon & McDonald, 2010). As Cohen, Raudenbush & Ball (2003) explain, " …teachers and learners must operate in several domains: they must hold and use knowledge, coordinate instruction, mobilize incentives for performance, and manage environments" (p. 124). Although research has attempted to capture this complexity (Cohen et al., 2003), the act of teaching necessitates one to negotiate many roles, all of which include student needs and require both *craft* and *skill* (Grossman & McDonald, 2008).

Role of Content in Professional Development

Within PD, a teacher's content knowledge is critical and must be placed as priority (Benken & Brown 2008b). For example, Hill, Rowan & Ball (2005) found that "teachers' mathematical knowledge was significantly related to student achievement gains" in elementary classrooms (p. 371). However, programs must examine the type of mathematical content that is explored, as well as the explicit links they make to pedagogy. From a programmatic standpoint, this perspective suggests that programs should provide opportunities for teachers to learn mathematics and science around specific content and teaching situations that connect to their previous teaching experiences and/or may arise in future practice (Guskey, 2002). Professional development should be grounded in teachers' realities, sustained over time, and rich with opportunities for teachers to grapple, confront, and negotiate (Benken & Brown, 2010).

There is a significant body of research on PD for teachers of mathematics and a distinct, yet similar, body of research on PD for teachers of science. When PD studies have explored the impact of PD across multiple settings, most recommendations are either not specialized for specific content areas (Garet et al., 2001; Nelson & Harper, 2006; Penuel, Fishman, Yamaguchi & Gallagher, 2007) or mathematics and science are combined into one category (Loucks-Horsley, Love, Stiles, Mundry & Hewson, 2009; Marshal, Horton, Igo & Switzer, 2009), as they are often viewed as similar content areas.

Unique Contribution of and Professional Development Framework for This Study

This study expands this work by contributing to what we understand about teacher learning and change through an investigation of teachers' growth in knowledge and perceptions of their disciplines, learning, students' learning, and future practices within a content-focused PD in mathematics and science. However, what is particularly unique about our work is that it furthers what we understand regarding commonalities and differences of learning between mathematics and science when engaged in PD with a common design. Few studies exist that consider the differences and/or similarities of each content group needs, particularly within PD.

Our approach to learning within the structure of the PD program from this study is built upon existing models of teacher learning (e.g. Cohen et al., 2003; Nelson & Harper, 2006; Shulman, 1987). Within our approach, the focus is on teachers' learning, both of content and ability to teach that content. Cohen et al. (2003) propose a triangular model that includes three elements within the classroom context: teachers, students, and content. Their model highlights the interactive nature between a teacher's thoughts and actions and the manifestation of those thoughts on student learning. Their elaboration of the model speaks to the intricacies involved with teaching through the lens of domains.

Our study explored the interaction between two of their three domains: *teachers* and *content* (see Figure 1). Our explicit intent was to explore the teacher–content relationship to reveal how teachers' content understandings and perceptions expand through PD: knowledge of the content, perceptions about the nature of the discipline, perceptions of what it means to "know" the content, and perceptions of how their knowledge and thinking were developing throughout the PD experience. Additionally, our study developed during analysis to also examine a second layer: participants' perceptions about how their students learn content and the impact their content knowledge had on their students' learning. While the effect of PD on student achievement is an important factor in determining the effectiveness of programs, our conceptualization did not attempt to address this element of the Cohen and colleagues' model. Our goal was to directly impact the teachers' knowledge and perceptions as adult learners of content, yet in the teachers' minds their s*tudents* were always present.

To teach all students in conceptually based ways, teachers need to understand subject matter deeply and flexibly so they can help students create useful cognitive maps, relate one idea to another, and address misconceptions; they need to see how ideas connect within a discipline and to everyday life (Borman et al., 2005; Shulman, 1987). Content examined in the PD was not necessarily *new* for participants, as concepts were often those taught by participants in their grade 4 – 9 classes; rather, it was approached in new ways, looking at the content more sophisticatedly and connected to applications not yet considered by participants. The

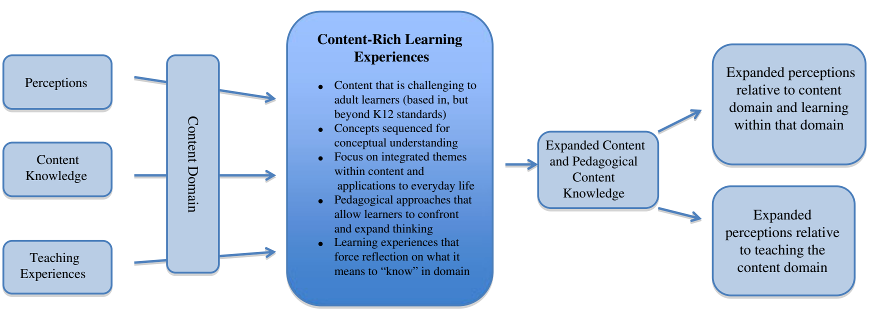

Figure 1. Theoretical framework for study

goal within these content experiences was for teachers to experience learning content as adults; we conjectured these experiences would facilitate teachers bridging being a learner of content with how to teach that content, thereby allowing them to experience content through multiple lenses. As more carefully described in the next section, instructors modeled pedagogical practices and approaches to exploring content that ideally the teachers would translate into their own practice.

Serving as curriculum developers, instructors, and researchers during the PD program, we provided content and pedagogical content expertise as university faculty in content departments (math, science). Our study grew out of our common goals: a focus on teachers' knowledge and perceptions (Farmer, Gerretson & Lassak, 2003), integration of content (appropriate to grade-level) and pedagogy (e.g. Ball, 2000), and alignment of content and approach with state and national standards (e.g. NCTM, 2000). We did not perceive our role as attending to deficits of participants; rather, we held the perspective that they came to the experience with knowledge and something to contribute (Borman et al., 2005). Our overarching goal then moved to providing *coherence* among the participants' existing knowledge and perceptions within the particular content domain goals, their teaching experiences, and our/their goals for their growth in knowledge and future practices (Penuel et al., 2007).

Details of the Professional Development Program

This study took place within a grant-supported PD program in mathematics and science for practicing elementary and secondary teachers (grades 4 – 9). The program was part of a state-wide organization that has been in existence for over 20 years; the organization fosters a systemic, grass-roots approach that is both integral to annual operations for many districts and part of the teaching culture in the primary areas they serve (mathematics/science). The two primary components of this particular program were: (1) week-long institutes during summer, in which math and science were separated into smaller groups (10 – 20) based on either grade-level taught or area of interest, and (2) school-year collaborative meetings (4 – 6) that were held on-site within individual districts (DiRanna, Topps, Cerwin & Gomez Zwiep 2009). A unique feature of the institutes was that teachers often participated more than once; for this reason, each summer the content sessions within the institute had a new theme (e.g. *energy and matter* for science). The goal of both components (content, pedagogy) was to enhance teachers' content and pedagogical content knowledge by addressing teacher practices and beliefs, facilitating pedagogical techniques that are effective for all students, and analyzing student work for conceptual understanding and student growth.

This study focused on data collected during two summer institutes, which were each held for 5 days, 8 h/day, as well as follow-up surveys and interviews done with a subset of participants during the first few months following the institutes. Although each institute serviced different populations of teachers in southern California and occurred at different times within the same summer, the overall PD structure and content/pedagogical foci were identical. During institutes, the focus of instruction was on content expertise (understanding the content addressed in national and state standards, identifying common misconceptions, focusing on sequencing of concepts for better student understanding, analyzing instructional materials) and pedagogical strategies (lesson design, questioning strategies, selecting quality assessments, analyzing student work, utilizing differentiated instruction, encouraging student to student discourse). Content (mathematics and science) sessions constituted one half of each day, and pedagogy sessions the other half; although each one half-day session had a particular focus, the overarching aim was to blend both content and pedagogy in ways that would help support a transition to pedagogical content knowledge. As research suggests (Benken & Brown, 2008b; Shulman, 1987), all types of knowledge (content, general pedagogy, pedagogical content) must be included in effective PD.

Pedagogy-focused sessions focused on math/science best practices, such as developing their own inquiry science/math lessons using Bybee (1997) “5E” lesson design, as well as appropriate techniques for questioning in both whole-group and small-group formats. Instructors of these sessions attempted to prompt reflection on pedagogy within lessons, thereby utilized concepts that were familiar and non-threatening to participants.

Content-focused sessions (see Figure 1) centered on themes (science—*size and scale*, mathematics—*slope*) and were comprised of rigorous, primarily hands-on, open-ended activities that allowed participants to collaboratively explore concepts; some activities also modeled utilization of technology, e.g. graphing calculators (Heid & Blume, 2008). Concepts within themes were grounded in state-level, K – 8 content standards; however, the design of activities and focus of discussion intentionally extended well beyond the knowledge assessed at the classroom level (Ball et al., 2008). These learning experiences were designed to challenge participants’ depth of knowledge and perceptions in ways that are consistent with math and science recommendations (Stein et al., 2009); content was approached in reform-oriented ways that investigated content as an exploration and connection of concepts to everyday situations (NCTM, 2000; NRC, 1996).

For example, one such activity within the mathematics unit on *slope* involved participants assessing accuracy of ramp constructions and adherence to American Disabilities Act guidelines. They measured ramps to see if they met guidelines, as well as problem solved as to how to redesign an imaginary ramp that did not comply. Within the science unit, participants explored how to conceptualize the role that size and scale plays in structure and function within living organisms through activities. For example, one activity involved participants constructing a scaled down model of a human using graph paper; they then examined growth patterns by generating a new model using a given multiplier. Throughout our instruction, we utilized content as the vehicle through which participants could confront and expand their own understandings and perceptions. Instructors posed questions that required participants to analyze, synthesize, and evaluate their thinking, using pedagogical techniques such as collaborative learning, whole-group presentations, and daily reflection journals. Instructors strove to create a learning environment that encouraged on-going participation, as well as the belief that all members could partake in meaning making; contributions did not need to be perfect in order to support group exploration. For example, when small groups shared project solutions, the focus was on their process and thinking, as opposed to their final answer. At the end of each session, participants were asked to reflect on both what they believe they now understood and what was still unclear; these reflections were shared anonymously the following day to promote further discussion.

Methodology

Participants and Data Sources

Participants (n = 103; 52 science, 51 math) were grades 4 – 9 teachers in four large school districts (two suburban and two urban) expanding the metropolitan areas of two large, diverse (socioeconomic and racial) counties. Most of the participants (85 %) held elementary certification; the remaining participants held secondary certification in mathematics or science. It is worth noting that a small number of the elementary certified participants also held subject matter endorsements (16 %). The majority of participants taught middle school mathematics or science. While all participants were practicing teachers during the time of this study, not all were teaching full-time in the content area for which they received instruction; for example, some were participating in a mathematics summer institute, although they taught science or were special education teachers during the year. Although most of our study was embedded within a summer PD context, participation (data analyzed for research purposes) was strictly voluntary and anonymous (except for post-institute e-surveys and interviews).

Data were collected in August, September, and November, 2007. Data included (1) pre- and post-surveys (math and science; August 7), (2) pre- and post-content exams (math and science; August 7), (3) daily institute reflections (August 7), (4) post-institute reflection survey (electronic, September 7), (5) practice-based interviews (November 7), and (6) instructor/research journals (August 7–November 7).

Surveys were completed by all participants; they included five open-ended and 24 Likert-type [1 – 6] questions. Some questions were drawn from existing research (Benken & Wilson, 1996; Cooney & Wilson, 1995); others were generated by instructor–researchers. Scaled questions helped to quantify trends and growth in participants' knowledge of and perceptions about math/science and its teaching and learning (e.g. *Mathematics involves mostly facts and procedures that have to be learned*; *I can improve my math skills, but I can't change my basic math ability*) (Benken & Brown, 2008a). These three areas (perceptions of content, perceptions of learning content, perceptions of teaching content) have been identified within existing research on beliefs as important to understanding learners' experiences (Benken & Brown, 2008a; Wilson & Cooney, 2002). Open-ended questions asked participants about their feelings toward math/science classes, teaching math/science, and institute expectations/experiences (e.g. *Describe someone who is good at teaching science.*; *Specifically, what do you hope to learn and how do you anticipate this experience improving your teaching?*).

Content exams, completed by all participants, included both short answer and multiple-choice questions that addressed representative concepts in content themes (e.g. *slope*). Content exams were generated prior to the institutes by the instructor–researchers; items were based on content to be explored and both math and science exams paralleled in terms of number of questions and quantity within each question type. Exams included four justified multiple-choice questions, five justified true/false questions, and a three-part constructed response question. The science pre–post-exams additionally included an open-response prompt[1]. Exams were scored by instructor–researchers using a rubric that scaled points to 100 to allow for easy calculations in findings. The rubric incorporated points for correctness of choice, as well as sufficiency and accuracy of justification (in words). These rubrics were developed by the instructor–researchers and had been used numerous times by other instructors at similar institutes around California.

Daily reflections were required of each participant in each cohort and discipline. Participants were provided the same prompt at the end of each day that asked for reflection related to what participants had learned and/or believed they did not yet understand well; they were asked to center feedback on specific areas of content and/or approaches to learning and feedback was used to make adjustments for the following day's PD. These reflections were submitted anonymously.

Post-institute reflection questions were emailed to all participants in the weeks following the institute (19 % completion via email). Participants were asked to reflect further on their learning, as well as anticipated implementation of pedagogical approaches and content (e.g. *Currently, are you using anything that you learned at the institute in your practice? Please elaborate, using specific examples.*). A subset of participants (20 %—10 science, 10 math) was randomly selected for interviews. Voluntary interviews were semi-structured (30 – 45 min) and held at participants' regular school sites a few months following institute; they focused on participants' ability to integrate PD content and strategies into practice, as well as reflection on how the institute impacted their knowledge and practices (e.g. *Do you believe that your view of what math teaching entails has changed at all as a result of this experience? Please explain*.).

Analysis

This was a mixed-method study with data sources informing each other through triangulation, both across types of data and multiple researchers (Flick, 2009). Analysis was done at four levels: individual participant, content/discipline cohort, individual institute, and overall group of participants. Data were analyzed using *direct interpretation* (Stake, 1995) to garner overall emergent themes (based on pre–post-comparisons, frequency made in statements, level of importance to participants). Qualitative data were coded (see Table 3). Initial codes were based on goals for the content-rich activities embedded in the PD, as indicated in research questions #1 and 2; they included expansion of teacher content knowledge (applications of content to real life, connections within the discipline) and expansion of teacher perceptions (relative to nature of the discipline, learning the discipline/content, theories about students learning content). Preliminary analyses revealed some overlaps in codes. For example, initially *attitude toward personal learning of content* and c*onfidence in ability to teach content* were coded separately. However, data revealed that participants did not separate their own beliefs about learning from attitudes toward teaching; thus, we integrated these codes into *learning of the discipline*.

Quantitative analyses on pre–post-content exams included exam means, amount of increase for individuals and cohort (math/science), standard deviations relative to mean individual scores, and median scores for content exams (see Table 1). On pre–post-surveys, Likert-type questions were tabulated and analyzed for growth and average response (see Table 2). Paired *T* tests were utilized to determine the significance of growth on both quantitative measures within discipline cohorts.

Issues of Reliability and Validity

Validity issues were addressed by triangulation of data sources, comparison of researcher journals, coding independently by two researchers (allowing for cross-validation of results), *interviewer corroboration*, and externally validating through *member checking* (Lincoln & Guba, 1985). Additionally, most survey questions were validated in previous studies, and content exams were designed to align to PD goals/instruction and were generated by multiple researchers and checked by experts beyond research team for internal and external validity. Reliability was addressed through similarly designed pre–post-exams and survey, as well as through inquiring regarding dimensions through multiple data sources.

Findings

We organize findings around our three research questions, which investigated teachers' content knowledge, perceptions, and the commonalities and differences of their experiences relative to their content domain—mathematics or science. For each research question (see Table 3), we explore

TABLE 1

Content exam quantitative data

Discipline	*Pre mean (SD)*	*Post mean (SD)*	*Delta (mean)*	*p value*	*Median (post) (%)*
Math	63 % (25 %)	75 % (20 %)	12 points	0.0012	85
Science	43 % (8 %)	70 % (16 %)	26 points	0.0001	68

TABLE 2

Pre–post-survey quantitative data (1 = strongly disagree, 6 = strongly agree)

Item	*Domain*	*Pre mean*	*SD*	*Post mean*	*SD*	Δ	*p value*
1. Scientific/math ability is something that remains relatively fixed throughout a person's life.	Science	2.27	1.53	1.73	1.19	−0.54	0.420
	Math	3.20	1.71	2.55	1.76	−0.65	0.218
2. Science/math involves mostly facts and procedures that have to be learned.	Science	3.03	1.53	2.00	1.02	−1.03	0.007*
	Math	3.44	1.47	2.85	1.42	−0.59	0.182
3. Students who really understand science/math will have an explanation quickly.	Science	3.13	1.38	2.35	1.47	−0.78	0.044*
	Math	2.92	1.29	2.90	1.55	−0.02	0.962
4. I feel confident that I understand the science/math material I may teach.	Science	4.32	0.95	5.00	0.82	0.68	0.007*
	Math	5.52	0.65	4.90	1.21	−0.62	0.033*
5. When my answer to a problem doesn't match someone else's, I usually assume that my answer is wrong.	Science	2.27	1.14	2.23	1.27	−0.04	0.912
	Math	2.44	1.16	3.16	1.12	0.72	0.045*
6. I think of myself as being good in science/math.	Science	3.93	1.14	4.23	1.21	0.30	0.349
	Math	5.04	1.08	4.26	1.45	−0.78	0.050*

*significance is at or less than .05

themes that emerged within participants' responses. For the ease of reading, a subset of the data sources are referred to by the following abbreviations: pre-survey (*ps*), post-survey (*pos*), daily reflections (*dr*), and post-institute reflection survey (*pirs*).

Teachers' Content Knowledge

Participants' content knowledge expanded as a result of the institute (see Table 1). For science, content exam scores rose from an average of 43 to 70 % (p = 0.0001); mathematics score means increased from 63 to 75 % (p = 0.0012). While scores increased significantly for both disciplines, the impact of the increase differed at the participant level. For example, within mathematics although as a cohort the increase was only 12 points, the median increase was approximately 15 points.

This finding had two primary causes: some participants scoring quite low on pre-exam and many increasing significantly (well beyond the 12 points) between pre- and post-exams; for example, one individual increased her score by 30 points. The median scores support this

TABLE 3

Coded examples for qualitative data

Research questions	*Codes*	*Examples from data*
In what ways do mathematics and science teachers' content knowledge expand?	Application of concepts to real life and/or connections of content within the discipline	"The greater the surface area to volume ratio, the more efficiently a cell can exchange materials and nutrients." "I never thought of slope before in terms of steepness and other ways such as the ratio of two numbers." "I see now how early grades concepts lead into algebraic ideas, like linear relationships and slope."
In what ways to mathematics and science teachers' perceptions expand?	The nature of the discipline	"When I began teaching science I was focused solely on content. The scientific process is much more important to me [now]."
	Learning of the discipline	"The more understanding of content I have, the better able I am to teach it to my students."
	How students learn content	"I check for understanding more often and use the result to guide lessons instead of trudging through the book like a foot soldier."
What are the commonalities and differences of these teachers' experiences relative to their content domain?	Gain/deepen content knowledge	"I hope to learn a new theme in life science and tie it together with the big picture."
	Improve affect toward the learning the discipline	"I hope to get over my math phobia."
	Learn new pedagogy relative to content strategies/activities	"[Want to learn] new ways of approaching a concept."
	Learn new pedagogy relative to motivating/ engaging students	"I need to learn new ways to better support student learning." "I hope to have fun new lessons related to what I teach." "I need to learn more strategies to get the kids excited about learning math."

observation. Within science, the mean cohort increase was a better indicator of increase at the individual level, as suggested by both the median and standard deviations. These findings suggest that prior to the PD, participants in the math cohort had greater variance in their understanding of the content (pre-test mean = 68 %, standard deviation = 25 %); most science participants understood little about the phenomena under study (pre-test mean = 43 %, standard deviation = 8 %).

While teacher content knowledge was primarily measured with traditional exams, their representations and relationships within content were also investigated through responses on qualitative data sources (e.g. daily reflections, pre–post-surveys, interviews). Participants reported many “Aha!” moments following content lessons on daily reflections and post-surveys. Participants’ comments from both the mathematics and science cohorts suggested learning of content as applied to real-life phenomena, as well as connected within the discipline. Originally, we had coded these two areas separately (i.e. “application to real life” and “connections within the discipline”): However, many of the participants’ own words revealed that these two ways of thinking about content are often intertwined, and therefore, it did not seem relevant to keep them separate. Examples included “The greater the surface area to volume ratio, the more efficient a cell/organism will exchange nutrients and materials” (*dr*), “I never thought of slope before in terms of steepness and other ways such as ratio of two numbers” (*dr*), and “I understand how size and scale matters in organ functions; I wish we would have had more time to compare animal differences” (*pos*). These comments reveal that participants were beginning to understand how abstract principles in either mathematics or science related to everyday observations.

Participants’ understanding of the content was not only deepened in terms of facts and concepts but also in terms of the relationship between facts and concepts within the discipline as a whole. Examples included “[Slope] requires lot of sub-skills that we need to know like fractions, pattern, and so on” (*pos*), “I am now very sensitive to roles of fractions, ratios, odds, etc., as they work in a problem and their structural differences. I am more careful with my use of vocabulary” (*pos*), and “It is difficult to grasp such small or great scales because we do not naturally think about such things” (*dr*). At the beginning of the PD, participants knew many isolated parts of concepts; following the institutes, they were then able to connect these parts within overarching themes embedded in the content. For example, within science, participants experienced for the first time how ratios of surface area and volume can be important descriptors for the functioning of living organisms; while they knew how to procedurally find these measurements, they had not yet explored how these measurements can be used to explain real-life phenomenon in science. All of these comments indicate that participants' growth in content understandings for both mathematics and science facilitated a move away from procedural approaches to content toward meaning making.

The content selected for the science cohort revolved around foundational ideas in science: scale, constancy and change, and the requirements for life. However, many participants initially questioned the necessary mathematics components to the sessions. For example, after the first 2 days participants had discussed the range of scale involved in scientific concepts (±10°) and surface to volume ratios. Forty percent of the daily reflections included a comment about the amount of math involved in the sessions. For example, one participant noted: "I thought we were supposed to be learning about science? So far there has been a lot of math." Another participant wrote, "I chose science because I am not very good at math. I need more time to digest and understand the math." These responses and the frequency at which they occurred suggest that science participants did not initially understand the relationship between science and mathematics prior to the institute. However, by the end of the week, the majority of participants (83 %) responded that they were happy with the overarching idea of size and scale and many commented that this was "a great concept in understanding the world," yet "students never consider its implications" (*pos*). While this does not imply that participants gained an awareness of the math/science relationship, it does suggest that they gained an appreciation of the necessity of utilizing mathematics within this science concept.

Teachers' Perceptions

Three themes emerged relative to participants' perceptions: (1) nature of the discipline, (2) learning of the discipline, and (3) how students learn content.

Nature of the Discipline. Participants showed growth, and in some areas growth that was statistically significant, in their perceptions about the nature of each discipline. For example, when comparing the pre-/post-survey data, participants were far less likely to agree with statements such as "Science/Math involves mostly facts and procedures that have to be learned" and "Scientific/mathematical ability is something that remains relatively fixed throughout a person's life."

This change was mirrored in participants' survey and interview comments. For example, as one participant noted following institute, "I think that when I began teaching science 3 years ago I was focused solely on content. Now my thinking has shifted. The *scientific process* is much more important to me. How students arrive at their understanding is much more interesting than their actual conclusions" (*pirs*). This comment is illustrative of some participants' change in focus from *what* content they will teach to *how* to best portray scientific thinking relative to content. Additionally, growth in participants' pre–post-content exam scores paralleled comments that revealed this slight change in ways of thinking about the content. This finding (confirmed across multiple data sources—interviews, surveys, daily reflections) supports the idea that participants' perceptions and content understandings were intimately related; for some, as they learned more content, their perceptions of what that content was also expanded. Additionally, this comment illustrates that originally this participant did not view *scientific process* as part of *content*; recent research and recommendations suggest that these two aspects of science cannot and should not be separated (Schneider, Krajcik, Marx & Soloway, 2002; Treagust, 2007).

This reflection on pedagogy through learning of content helped this participant (and others) to bridge being a learner of content with how to teach that content. As adult learners (students of content), they were confident enough at moments within content explorations to be cognizant of the pedagogical choices modeled by instructors. While reflecting on the mode of instruction and how it impacted their own learning, some participants linked these learning experiences with future pedagogical choices they may make in their own K – 12 classrooms.

Learning of the Discipline. Analysis of data also revealed growth in participants' perceptions and attitudes toward learning content, both their own and their students'. What is interesting to note is that this theme was not overtly attended to in the PD design but emerged during analysis as an important theme. For example, science participants' confidence in their own scientific knowledge grew relative to specific concepts discussed in the program. As seen in Table 2, most participants entered their science content sessions relatively neutral in the view of themselves as learners of science (3.93 out of 6 on Likert scale) and in their ability to teach the institute content (4.32 out of 6 on Likert scale). Thus, it was not surprising that most participants grew in both their perceptions of their understanding of the content and subsequent confidence in their ability to teach that content as a result of their learning experiences. As one participant stated, "I feel very confident once the content is explained through this institute" (*pirs*). This sentiment was echoed during post-institute interviews, with the majority (79 %) of the science cohort confirming that the institute experience enhanced their confidence and in some cases made them more eager to teach science in their present settings.

Within mathematics, findings revealed greater complexity in participants' attitudes. As can be seen in Table 2, most participants entered the institute with very high confidence in their view of themselves as being good at math and understanding the math they teach (average of 5+ out of 6 on Likert scale on items 4 and 6). Some of the participants holding elementary teaching credentials expressed less confidence in their overall mathematical abilities; however, they were still confident in their understanding of the lower-level content they teach in their classrooms. By the end of the program, the majority of those with high confidence decreased in confidence by over half of a point on both measures ($\Delta = -0.62$, $p = 0.033$ and $\Delta = -0.78$, $p = 0.05$), suggesting that the depth of content exploration facilitated their recognition of gaps in their understanding of institute concepts. As one participant noted (*pos*), "I have taken many math classes and classes on teaching math concepts; however there is a lot more to learn. The institute shows me that I do not know as much as I thought and I need to learn more." Interestingly, most of these same participants still expressed that they liked doing and teaching mathematics and still had greater than neutral confidence (4.9 out of 6 on Likert scale) in their ability to teach content at or below the level they were currently teaching.

Learning content deepened many teachers' understanding of how to teach that content. As one participant so succinctly noted in her statements following the institute (*pirs*), "Content learning (was the most helpful). The more understanding I have of content, the better able I am to teach it to my students." As elaborated earlier, by the end of the PD, over 85 % of participants in both domains came to recognize their own growth in content and the impact it may have on their future practice.

In addition to the focus on underlying concepts and connections to real-life phenomena, both mathematics and science participants noted particular pedagogical approaches they experienced within the institute as helping to facilitate their own learning of content. For example, "In the content aspect, the hands on activities, the field trips, and group activities were very beneficial in terms of understanding the concepts we learned about. The small group discussions are great as I learn a lot from peers who have a science background" (*pirs*). This participant speaks to the hands-on activities and collaboration with colleagues as being most helpful; other participants echoed similar structures. For example, "The training activities that were the most useful were those designed for participants to actively engage in group activities to conceptualize science content" (*pirs*). This participant identified the explicit attempt to use cooperative learning to help become investigators of science, noting a meta-cognitive experience with the institute.

Reflection survey (*pirs*) responses suggest that experiences as learners of content caused many participants to reexamine their perceptions of what it means to do and learn math/science. Some (~48 %) noted that at times they were "frustrated," as the content was sometimes challenging, but that the experience helped them to better understand the concepts. Content became the mechanism for change. This trend was common for both mathematics and science.

How Students Learn Content. Within the data, there is also evidence of a trend regarding how participants thought about what "understanding" looks like in their students as their own understandings of the discipline deepened. This shift was related to changes in what type of thinking was necessary for students to fully understand mathematics and science. Although participants often spoke of this implication for their own teaching and students, they often claimed that the impetus was the change in their own understanding of the discipline. Within participants' comments were references to a focus on conceptual learning of students, as well as pedagogies that support a conceptual approach to learning mathematics/science. For example, comparing pre- and post-surveys, science participants became significantly less likely to agree with the statement "Students who understand content will have an explanation quickly" by the end of the PD experience (Table 2, item 3, $\Delta = -0.078$, $p = 0.044$). These findings are echoed in statements made by participants during the post-institute survey and during interviews. As one participant stated (*pirs*), "The institute shifts my focus …For example, I check for understanding more often and use the result to guide lessons instead of trudging through the book like a foot soldier." This participant, like many others, recognized that her pedagogical choices and methods by which she evidenced student learning changed as she herself grew in her content understandings and perceptions of the discipline.

Although the focus of our sessions was content and not pedagogy, teachers often made connections between their new content understandings and renewed enthusiasm for teaching students (expressed by approximately 40 % of participants using pre–post-surveys and post-institute email reflection surveys). "It energizes me for the coming year. Teaching to standards is brutal at times. This brings us back to thinking and learning for the sake of thinking and learning," "I have been teaching 17 years. I wouldn't say I am more 'excited.' I would say that I am more interested in learning ways to engage my students more. I think the institute has kept me connected to teaching 'big ideas' and not focusing on rote skills" (*pirs*). In the PD component that focused on teachers' content learning, teacher perceptions related to how students learn were equally affected, which was an explicit goal for the institute experiences.

Differences Relative to Teachers' Content Domain

Content Growth. The overall PD structure was the same for both the mathematics and science cohorts even though they were held as distinct sessions and focused on different content themes. Additionally, while participants chose to be in different content groups, the majority taught both subject areas and represented similar grade ranges. What is interesting to note are the similarities and differences that occurred between and across groups. Across all participants, there was evidence of deepened understanding of the nature of the discipline and content knowledge rose as a result of participating in the rich learning experiences. However, the science cohort as a whole entered with little understanding of the science content addressed at the institute and the mean change in pre–post-exams accurately represented the growth of the cohort as a whole (see Table 1). The participants in the mathematics cohort had a much wider range of initial mathematical understanding, and although each participant demonstrated growth in content knowledge, he/she did not enter or exit with the same uniformity of measured knowledge as the science cohort.

Perceptions. Participants from both disciplines also demonstrated significant shifts in their confidence and attitudes about teaching mathematics or science (see Table 2). Science participants entered with relatively neutral views about their understanding of the science they teach; by the end of the institute, science participants had a significant increase in their confidence related to these understandings (item 4; $\Delta = 0.68$, $p = 0.007$). To the contrary, as measured on the pre-survey, some mathematics participants entered the PD experience with rather high levels of confidence in their teaching abilities and this confidence decreased by the end of the institute after PD learning experiences challenged their thinking and revealed gaps in their knowledge. This finding was corroborated across multiple survey items related to confidence (item

4; $\Delta = -0.62$, $p = 0.033$; item 5; $\Delta = 0.72$, $p = 0.45$; item 6, $\Delta = -0.78$, $p = 0.05$). This suggests that teachers are perhaps less aware of the limitations of their content knowledge in mathematics.

This trend was echoed in the differences in mathematics and science teachers' goals for participating in the institutes. Most of the mathematics participants had similar learning expectations entering the PD experience; when asked what they hoped to learn at institute (*ps*), almost 75 % referred to pedagogical approaches/teaching strategies and/or specific classroom activities. Only 25 % of math participants mentioned content knowledge as a learning goal, which further suggests that participants were quite confident in their understanding of the mathematical content to be explored. Many mathematics participants seemed genuinely surprised by how much content they learned; in post-institute surveys, interviews, and during content activities, they often highlighted that they explored the content in new ways and to greater depth. As one participant stated at the end of the institute, "The things I am finding useful is the content. I am surprised that I say that because teachers really just want a quick fix and a better way to teach 'fractions.' Overall I think the content has made me more confident in teaching math" (*pirs*). To the contrary, over 60 % of science participants noted gaining content knowledge as their primary learning goal entering institute. They recognized their own deficiencies relative to the content; this view is perhaps encouraged by the compartmentalized nature and abundance of topics within the overarching discipline of *science*.

Participants in both cohorts also expanded their perceptions of their relative disciplines and how students learn within those disciplines (see Table 2, items 1 – 3). However, these shifts were only statistically significant for science participants. This enhanced shift suggests two possible conclusions: (1) These participants' initial lower confidence (relative to math participants) allowed them to be more open as learners, and/or (2) these participants' initial lack of science content knowledge (43 % pre-exam mean) propagated a narrow view of the discipline. This second conclusion is further supported by participants' comments made at the end of the institute; as noted in the quote on page 19, some participants' view of what science content constituted expanded to include scientific process.

Discussion and Implications

Throughout the institute, participating teachers' existing content understandings were challenged, causing them to experience uncomfortable moments that led to change and growth. As Nelson & Harper (2006) note, intentional situations must be created that cause learners to confront previous understandings before new ones can arise. Within PD that places teachers as adult learners, “Teachers need to become confident with the content and processes they are to facilitate with their students. The importance of professional development providing teachers with rich content and numerous opportunities to experience the learning that they are expected to facilitate with students may serve to assist them in translating inquiry practices to their own classrooms” (Jeanpierre et al., 2005, p. 686). This work suggests that when embedded within an effective PD context, content can be a critical vehicle through which change can be made in teachers' understanding and perceptions of mathematics and science. Professional development must provide challenging learning experiences that inspire conflict and allow teachers to move beyond tightly held notions relative to content and discipline. When participants in our study were able to move beyond their internal conflicts and misunderstandings, they could expand their knowledge and perceptions of content and finally bridge to reconceptualize how to teach that content.

However, finding an appropriate balance between challenge and success can be difficult. Difficulty should arise for the purpose of confronting previous notions of content, rather than for its own sake (Redish & Hammer, 2009). Science participants accurately assessed their limited knowledge entering the PD and as a result increased their level of confidence relative to the content they teach. On the other hand, mathematics participants perceived that they were good at math and were quite confident in their ability to teach it. As a result of activities that facilitated the recognition of limitations in their understandings, participants learned content, yet also became less confident in that knowledge. This led some participants to question their mathematical problem solving abilities. This significant decrease in confidence was also likely due to the large grade span (4 – 9) within the mathematics cohort; as noted earlier and in Table 1, participants' content knowledge entering institute varied greatly (standard deviation = 25 %). While it is our desire for PD to help teachers expand the quantity and flexibility of their content understandings, we must not allow learners to become so fragile in their affect that they avoid teaching that content in the future.

Findings from this study suggest that there is a direct relationship between teachers' developing understandings within content-rich learning experiences and their perceptions and affect relative to content and learning (see Figure 1). A major contribution of this work is that it additionally provides insight regarding commonalities and differences of learning between mathematics and science when engaged in PD with a common design. Few studies exist that consider the differences and/or similarities of each content group needs, particularly within PD, and across multiple data sources. Our findings indicate that although teachers involved in both mathematics and science can benefit from similar overall PD structures (e.g. collaborative learning, content-rich activities), there are some unique challenges that need to be addressed for each particular discipline group. Teachers participating in mathematics and science PD have different needs related to their perceptions (e.g. confidence) and knowledge of content. While we did not intentionally address these domain-specific needs in our original PD design, we now recommend that other programs incorporate mechanisms that acknowledge distinctions such as those identified in our study. These distinctions should apply to both how designers approach learning of content and the emphasis that is placed on providing participants opportunities to honestly assess the depth of their own content understandings.

Limitations

It is worth mentioning that although there were two distinct cohorts (math and science), the themes addressed with the science specific cohorts (size and scale in living organisms) focused heavily on mathematical applications of science concepts. It is quite possible that participants may not have found as many new dimensions within the discipline had the PD focused on perhaps more traditional science content (e.g. photosynthesis). For example, in their study of K – 12 teachers' beliefs in mathematics and science, Marshall et al. (2009) found that science teachers were less likely than mathematics teachers to perceive inquiry teaching methods to be necessary for effective practice, particularly in higher grades; they note that perhaps the compartmentalized nature of standardized student assessments in science at the secondary level contributes to this difference. More research that intentionally explores differences between teachers learning mathematics and science within PD contexts is needed.

Note

[1] Consider a grasshopper and an elephant. The two organisms exist in very different scales of size, one being very large and the other being quite small. Describe how the difference in their scale relates to differences in the way each organism behaves and

functions. Specifically address how a biological system's surface area to volume ratio is related to modifications that come with large changes in scale.

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