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ASSESSING AND ENHANCING PRE-SERVICE PHYSICS TEACHERS' PEDAGOGICAL CONTENT KNOWLEDGE (PCK) THROUGH REFLECTIVE CoRes CONSTRUCTION

Research Article

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Abstract

The purpose of this study was to explore the effect of Content Representations (CoRes) construction, and reflective peer discussions on pre-service physics teachers' pedagogical content knowledge (PCK). Participants consisted of 16 third year pre-service physics teachers; 12 females and 4 males. The results show that the majority of participants made positive improvements to their initial PCK. Participants became more knowledgeable about students' misconceptions, developed improved orientations to teaching, and suggested more responsive instructional strategies and assessment strategies along with more elaborate justifications. Discussion focuses on implications of these results for professional development of pre-service science teachers and research on PCK.

Keywords: pedagogical content knowledge, physics, preservice, science.

1. Introduction

One of the main goals of science education is to help students develop scientifically accurate and personally meaningful mental models of scientific phenomena and application of the learned knowledge into relevant contexts (National Research Council [NRC], 2012). The degree to which these goals get accomplished depends largely on teachers' professional knowledge base. The type of knowledge that is needed for promotion of these goals in an effective and meaningful way goes beyond teachers' subject matter knowledge or pedagogical knowledge alone; it requires a knowledge base that combines and transforms these two types of knowledge (Hume & Berry, 2011). This type of knowledge is called pedagogical content knowledge (PCK) (Shulman, 1986). Shulman (1986) defined PCK as 'the form of knowledge that embodies the aspects of content most germane to its teachability' (p. 9). These include 'the most useful forms of representation of scientific ideas, the most powerful analogies, illustrations, examples, explanations and demonstrations- in a word, the ways of representing and formulating the subject that make it comprehensible to others' (p. 9). Science educators have taken up on this definition, critiqued it, refined it and used it in their unique contexts. While there has been a significant effort in PCK research over the last three decades, educators are still trying to find more effective ways to measure and improve teachers' PCK (Abell, 2008; De Jong & Van Driel, 2004; Hume & Berry, 2011; Loughran, Mulhall & Berry, 2004; Nilsson & Loughran, 2012; Park & Oliver, 2008; Schneider & Plasman, 2011; an Driel, De Jong, & Verloop, 2002). Whether empirical or theoretical, all of these studies highlight the importance of PCK for improving the quality of learning experienced by the students in the classroom. If teachers' PCK is central to the quality of instruction that students receive in the classroom, we need to find effective methods for measuring and improving teacher PCK even before we send them to the classroom. The purpose of this study therefore was to improve pre-service physics teachers' PCK through reflection. The research question that guided our inquiry is:

What impact does critical reflection around CoRes has on pre-service physics' teachers' PCK related to the concepts of heat and temperature?

2. Review of Relevant Literature

Science educators have studied teachers' PCK in multiple contexts ranging from pre-service education, in-service teachers and in college settings. While some of these studies are of exploratory nature (Lee & Luft, 2008; Park, Jang, Chen & Jung, 2011), others look at the growth in teachers' PCK as a result of practice or short interventions (Authors, 2014; Adadan & Oner, 2014; Hume & Berry, 2011). Nevertheless, the results of these studies suggest that most pre-service teachers hold naïve PCK (Authors, 2014; Adadan & Oner, 2014; Hashweh, 2005) and that development of PCK takes time and requires critical reflection upon one's knowledge, experiences and practice (Adadan & Oner, 2014; Brown, Friedrichsen & Abell, 2013; Nilsson & Loughran, 2012; Park & Oliver, 2008; Schneider & Plasman, 2011; Van Driel et al. 2002).

Caillods, Gottelmann-Duret and Lewin (1997) conducted a study with experienced Malaysian teachers. They explored teachers' PCK through interviews. The results of their study showed that teachers were insensitive to the difficulties experienced by their students. More specifically, teachers believed that the difficulties experienced by the students were 'due to students' lack of interest and their poor mathematical competency rather than due to limited conceptual understanding of the topics' under study (as reported in Halim & Meerah, 2002, p. 216). These naïve conceptions may also be the result of teachers own limited content knowledge.

Halim and Meerah (2002) conducted a study with 12 pre-service teachers and report that the lack of sensitivity teachers has in understanding the difficulties experienced by their students and lack of their ability to suggest responsive instructional strategies is correlated with their content knowledge. More interestingly, they found that while two third of the participants were aware of possible misconceptions that students could have, half of the participants did not take into account students' misconceptions in their suggested instructional strategies. This suggests that even experienced teachers may fail to design instruction with students' misconceptions in mind. These observations call for scaffolds to help science teachers to make explicit connections between content, patterns of student thinking, the difficulties that the teachers may have in conceptualizing concepts and pedagogy (Hume & Berry, 2011). In fact, in recent years, science educators have developed scaffolds called CoRes both to explore teachers' PCK and to help teachers establish such connections before instruction. We discuss some of these studies next.

Hume and Berry (2011) conducted a study in New Zeeland, where they engaged nine pre-service chemistry teachers in construction of CoRes in an attempt to improve their PCK. The authors engaged the participants in a sequence of four 3-hour workshops. First, they asked the participants to identify and discuss possible misconceptions and pre-existing conceptions that the students in grade 11 would have about the Atomic structure and bonding by consulting several online resources. Second, participants worked in small groups of three to discuss what grades 11, 12 and 13 students would be expected to learn about the Atomic structure and bonding by analyzing national curriculum and other relevant materials. Each group focused on one grade level and got together at the end to discuss their findings 'to get an overall picture of how the sequence of concepts and skills evolved over 3 years' (p. 347). Then, participants were given an empty CoRes template and were asked to complete the CoRes for the topic of Redox reactions. After completing the Redox CoRes, participants worked in smalls groups to discuss answers to the question: what are the enduring ideas and misconceptions related to the concept of Redox reactions? Finally, they shared their results/answers and discussed them as a class. The authors found that despite lack of classroom experience, these pre-service teachers developed pedagogical capacity that could result in responsive instruction. For instance, as a result of the intervention the participants became aware of common misconceptions that the students bring with them to the classroom and became aware of effective instructional strategies that they could potentially use in their classrooms. Hume and Berry (2011) argue, 'If carefully scaffolded the CoRe design process enables student teachers to begin accessing and accumulating some of the knowledge of experienced science teachers in ways that can help to bolster feelings of confidence and competence' in PCK (p. 354).

Adadan and Oner (2014) traced the development of two pre-service chemistry teachers' PCK over the course of a semester in a science methods course. After having covered the theoretical foundations of several reform-based instructional models, the author, a pre-service science teacher educator, modeled several reform-based instructional strategies in the classroom through hands-on activities targeting students' understanding of a specific chemistry topic (chemical reactions). In addition, the participants were given the opportunity and required to view recorded video modules, featuring best practices on reform-based teaching methods. Following these experiences the instructor engaged the students in class discussions about the content of the videos observed. During these discussions, the pre-service teachers were guided to reflect on their experiences with different teaching methods featured in the videos of best practices. It must be noted that the participants were asked to read and reflect on reform-based instructional and assessment methods on a weekly-basis throughout the semester. The authors measured participants' PCK through CoRes design and interviews. While the authors reported notable improvements in participants' PCK, they did not observe growth in all aspects of the PCK reflected in the CoRes framework. More specifically, while the number and diversity of ideas in participants' initial CoRes were limited, post CoRes reflected more diverse ideas in most PCK dimensions measured. This suggests that participants were able to add new pieces of knowledge to their knowledge base across PCK components.

Collectively, the results of these studies suggest that CoRes are useful in helping pre-service science teachers to start to think about students' misconceptions, framing the purpose of teaching and consider instructional strategies that are responsive to students' learning needs. Therefore, teacher educators should use CoRes to help their pre-service science teachers to develop a strong foundation for PCK that is likely to evolve and become stronger with experience and reflection upon experience (Abell, 2008). However, CoRes based PCK studies are either in Biology or Chemistry. To our knowledge, no one has explored the effects of CoRes construction on physics' teachers' PCK. Inspired by the results of these interventions implemented in chemistry and the need for PCK studies in physics, we designed this study to explore if and how CoRes construction and reflective discussion over their responses to CoRes contribute to pre-service physics teachers' PCK.

3. Theoretical Framework

Science educators have used different frameworks for studying science teachers' PCK. In this study, we used Magnusson, Krajcik and Borko (1999) framework to measure and evaluate the sophistication of pre-service physics teachers' PCK. This framework consists of five dimensions: teachers' knowledge of curriculum, teaching orientation, knowledge of student learning, knowledge of instructional strategies, and knowledge of assessment. The first dimension, knowledge of curriculum refers to teachers' awareness and understanding of goals promoted by the specific curriculum that the teacher is expected to teach. The second dimension, teaching orientation refers to teachers' beliefs about how students learn, what students should be able to learn as a result of her/his instruction, how to teach and what to assess about student learning. Teachers with sophisticated PCK are expected to adopt a constructivist approach to teaching and view the role of teacher as the facilitator of learning rather than being the transmitter of knowledge (Park & Oliver, 2008). The third dimension, knowledge of student learning, students' preconceptions, the difficulties they experience while learning a specific science topic, and the form of reasoning (i.e. causal reasoning, statistical reasoning) called for while learning a specific topic. (Adadan & Oner, 2014; Alonzo, Kobarg & Seidel, 2012; van Driel, Verloop, & Vos, 1998). The fourth dimension, knowledge of instructional strategies refers to teachers' knowledge of instructional strategies and the value the teacher places on use of a specific instructional strategy. This is an important aspect of teachers' PCK because in combinations with knowledge in other domains (e.g. students' preconceptions), guides teacher decision making both during planning and enactment of the lessons (Alonzo et al, 2012; Park & Oliver, 2008; Park et al., 2011). Fifth and final dimension of this framework is teachers' understanding of the purpose of assessment and knowledge of assessment strategies. The assumption is that teachers with sophisticated PCK will use multiple assessment strategies either to elicit students' ideas, to engage them in learning or to assess their knowledge and that these teachers will use assessment both for summative and formative purposes. This theoretical framework guided our thinking in collecting and analyzing our data.

4. Methodology

This study was designed and conducted through an interpretive lens (Crotty, 1998; Patton, 2002) in that while we collected data on students' PCK, we interpreted the results based on our understanding of PCK, its core components and its importance in teaching and learning. While an interpretive methodological paradigm informed our thinking, this study in essence is a case study (Merriam, 1998). According to Merriam (1988) a case can be a single entity or phenomenon around which there are defined boundaries. Moreover, these boundaries define the context and limit the scope of inquiry. Case study proved useful for this inquiry because we conducted this study with 16 participants enrolled in a specific teacher education program with specific curriculum. Merriam suggests that a case is often selected because it contain situations of concern or interest (Meriam, 1998). Two things are of concern and deserve attention in this case study. First, development of pre-service physics teachers' PCK is of concern to us. Second, science education literature reveal that a significant number of students hold misconceptions about the concepts of heat and temperature and fail to successfully distinguish the difference between the two (Alwan, 2011; Kesidou & Duit, 1993; Sozbilir, 2003). Therefore, we focused on physics pre-service teachers and exploring and enhancing their PCK related to the concepts of heat and temperature.

4.1. Participants

This study took place in a classroom measurement and evaluation course in a physics teacher education program. The participants consist of 16 third year pre-service physics teachers: 12 females and 4 males. Students had taken introduction to educational sciences, developmental psychology, learning teaching theories and approaches, and curriculum development and instruction courses. In addition, the students had taken required physics content courses as well.

4.2. Data and Data Collection

While science educators have developed tools to measure science teachers' PCK, a discussion of which methods or tools can most effectively capture a science teachers' PCK is far from settled (Abell, 2008). While until recently science educators had used observations of classroom teaching to make decisions about sophistication of a teachers' PCK, this method has its own limitations. Alonzo et al. (2012) state because 'Teachers are often unaware of knowledge they use to make instructional decisions, and day-to-day discussions of teaching tend to center around practices, rather than the knowledge and reasoning underlying them.'(p. 5), thus, reliance on observations alone may not provide accurate picture of a teacher's PCK. As a result, science educators have recently become interested in measuring teachers' PCK using such tools as CoRes and PaPers (Hume & Berry, 2011; Loughran, Mulhall & Berry, 2004; Nilsson & Loughran, 2012), paper-and-pencil assessments (e.g., Park, Chen, & Jang, 2008), and interviews (Lee & Luft, 2008; Magnusson et al., 1999). Moreover, some have even used a combination of these methods (Adadan & Oner, 2014; Park et al., 2012) to capture a teacher's PCK. While a combination of multiple methods can provide a clearer picture and an in-depth understanding of teachers' PCK, this may not be a feasible method or method of preference because of the limitations placed on the researchers due to the context of the study or the available resources and time. Therefore, science educators have used diverse methods to capture teachers' PCK.

In this study, we collected and analyzed three types of data: 1) 18 questions constructed and answered by the participants, 2) participants' answers to the prompts on CoRes construction template, 3) participants' reflections on the perceived benefits of the intervention on their pedagogical capacity to teach the topic of heat and temperature in their future classrooms. Participants' content knowledge related to the concepts of heat and temperature was measured by having them to construct and answer 18 assessment items aimed at measuring their students' understanding of the target concepts: heat and temperature. Our evaluation of participant's responses to the conceptual test that they developed on the concepts of heat and temperature shows that on a scale of 1-10, nine participants scored at level 4, three participants scored at level 5, and four scored at level 6. This means that all participants were above a threshold and not significantly different from one another in terms of their conceptual understanding of the concepts of heat and temperature.

Participants' PCK was measured through construction of CoRes (Hume & Berry, 2011; Loughran, Mulhall & Berry, 2004). Loughran, Mulhall & Berry (2008) state CoRes provide information that is 'meaningful, useful, and valuable for teachers, teacher educators, and science education researchers' (p. 373). CoRes template is designed in a way that help teachers to make explicit connections between content and pedagogy. It consists of a set of questions focusing on a specific science topic, asking the participants to 'identify key content ideas', elaborate on the purpose of teaching those ideas, elaborate on possible areas of confusion and report on possible perceived challenges students may experience while learning the concept of interest, suggest instructional strategies and examples to ensure student learning and elaborate on 'ways of testing for understanding' (Loughran et al. 2008, p. 1305).

After the participants were introduced to the purpose of the study we sought their participation. All students agreed to participate in the study. After students' participation was guaranteed, we described the procedures to be followed and the timeline of the study activities. First, we introduced the participants to the national high school physics standards related to the topic of heat and temperature. After the participants became familiar with the relevant standards, we asked them to construct three questions targeting lower level students, three questions targeting mid-level students and three questions targeting high-achieving students for each concept (i.e. heat and temperature). Students spent three hours in class to complete heat related questions and another three hours to complete temperature related questions. So, participants ended up forming nine questions for each concept and answering each question. The participants answered these questions in subsequent weeks. So, the total time spent in construction and answering of the questions was six class periods spread over two weeks.

Second, we gave the participants the empty CoRes template and asked them to complete the CoRes in three hours. Third, we engaged students in reflective peer discussions based on their initial responses to CoRes prompts during one-hour class period. We administered the post-CoRes three weeks after this peer-discussion. The completion of post-CoRes lasted for one hour. Finally, we asked the participants to reflect on the study-related experiences on their perceived pedagogical capacity to teach these topics through an open-ended question.

4.3. Data Analysis

Data analyses took place in several stages. First, we evaluated participants' 18 questions and the answers they had provided to measure their content knowledge of heat and temperature. The students prepared their questions targeting lower level-, mid-level- and high-achieving-students for each concept with respect to the high school physics standards. Then, we scored their questions if their questions appropriate for the targets and for the physics standards. Our evaluation of participant's responses suggested that on a scale of 1-10, nine participants scored at level 4, three participants scored at level 5, and four scored at level 6 suggesting limited variation in participants' content knowledge. Second, we read participants' responses to CoRes to get a sense of the nature of the responses provided by participants to CoRes prompts. Third, we analyzed participants' responses on CoRes prompt by prompt between pre-and post to see if there was any growth in participants' knowledge. We reported participants' growth or lack thereof across all CoRes prompts. In some cases, participants started with already robust knowledge related to one category on CoRes so we noted those as well (see Figure 1 in Findings). Both researchers agreed on the given scores and the fit between the scores of the researchers was high.

After these initial analyses, we analyzed participants' responses across four dimensions of PCK: Teaching Orientation (TO), knowledge of students' understanding (KSU), knowledge of instructional strategies (KIS), and knowledge of assessment (KA). CoRes template is structured in such a way that each prompt or groups of prompts correspond to one of the components of PCK (see Table 1). While this structure helped us to easily look for evidence of students' PCK across these components, we also looked for evidence across all responses that could contribute to our evaluation of participants' PCK and their growth. We identified and used evidence from Q1, Q4, Q5, Q6, and Q7 to measure participants' OT, from Q2, Q3, Q5, and Q6 to measure their KSU, from Q4, Q5 and Q6 to measure their KIS, and from Q7 for KA (Table 1).

Table 1. *PCK components and source of evidence used to measure participant knowledge*

PCK Component	Content Knowledge	Teaching Orientation	Knowledge of Student Understanding	Knowledge of Instructional Strategies	Knowledge of Assessment
Source of Evidence	Written answers to 18 questions	Q1, Q4, Q5, Q6, Q7	Q2, Q3, Q5, Q6	Q4, Q5, Q6	Q7

We read all participants' pre and post CoRes answer sheets one by one, identified evidence that could contribute to each component of PCK model that guided our evaluation. Then, we evaluated participants' knowledge in each category either being at level 1, level 2 or level 3, with level 1 being least sophisticated and level 3 the most sophisticated level (see Appendix A). This method is consistent with the evaluation method suggested by Schneider and Plasman (2011) and used by (Mavhinga & Rollnick, 2016). This method of evaluation helped us to monitor progress the participants had achieved in each PCK category (e.g., knowledge of instructional strategies). Finally, we went through participants' reflection papers and analyzed the content of their answers to see whether participants felt this experience helped with their perceived pedagogical capacity to teach the concepts of heat and temperature and if so what aspect of this experience helped improve their pedagogical capacity.

5. Results

Results are presented in two formats. First, we report the growth we observed in participants' PCK across seven specific questions/prompts on CoRes. Reporting results by focusing on each CoRes category helps us see particular weaknesses and strengths in participants' PCK related knowledge structures. The results show that the degree to which participants made improvements in their PCK varied from question to question. The summary of participants' progress across seven questions is shown in Figure 1.

	Q1	Q2	Q3	Q4	Q5	Q6	Q7
N	7	4	2	3	6	7	4
N*	3	5	3	5	2	2	4
Y	6	7	11	8	8	7	8

N: No improvment observed,

N*: No change observed, because they started strong

Y: Major improvement observed

CoRes Questions and Improvement Frequencies

Figure 1. Participants' progress across seven CoRes questions/prompts.

After providing a summary of the results, we now present and elaborate on exemplary statements to highlight the nature of weaknesses and strengths that we detected in students' responses across CoRes categories.

5.1. Nature of Participants' Responses Related to Establishing the Importance of Teaching the Concepts

While most of participants' answers emphasized the importance of understanding the topic for students to engage in productive and intelligent conversations in their daily lives, only two participants justified the importance of learning the concepts for learning in advanced level of formal education. Participants' responses ranged from naïve conceptions to more informed and articulate conceptions. One response that was categorized to be naïve read, "Students should learn this topic because it is a topic that they encounter in their everyday lives." Another response that was also categorized as being naïve read, "Students should learn it because all of the natural and physical phenomena are governed by heat and temperature". These examples did not provide a justification or elaboration as to why students should learn these topics.

We also observed that some participants were able to provide more informed answers to justify teaching of the concepts of heat and temperature. One such exemplary response read:

Students should learn this topic because these two concepts are fundamentals of physics. As students progress through formal schooling they will encounter more complex topics that involve heat and temperature. If we do not want students to experience difficulty in learning later on, we need to teach them these topics well at this grade level.

While this participant justified the teaching of these concepts by focusing on students' future educational experiences, responses that went beyond the limits of formal education were also present. One such exemplary answer read as follows:

They should learn this topic because it will help them to better understand some of the concepts they encounter everyday. For instance, it can help them to think about saving energy in the winters, how to properly dress in the winters and summers, it will also help them to better understand concepts like phase changes. For instance, they will know not to put a closed cup full of water into their freezers if they understand these concepts well.

As these exemplary responses indicate participants' responses varied in that while some only focused on the importance of students' ability to make connections with real life, others justified importance of the topics of heat and temperature being a foundational knowledge for understanding more complex scientific knowledge that students encountered in higher grades.

5.2. Participants' Knowledge of Students' Misconceptions and Difficulties Experienced While Learning the Concepts

Participants, for the most part were able to spell out the main misconception that the students have in this domain that is the difficulty students have in conceptually differentiating between temperature and heat. One response that reflected a naïve understanding read, "They confuse the concepts of heat and temperature." While this participant is aware of students' confusion, no details of this confusion have been provided.

We also identified exemplary answers that reflected a sophisticated understanding of the misconceptions that the student might have about the concepts of heat and temperature. One such example read:

Students have several misconceptions on this topic. What is heat, what is temperature? Are they the same? Are they different? Is there a difference between the two concepts, if so what is this difference? Is heat the same as temperature or the same as energy? Are both of these concepts form of energy? In what units do we express heat and temperature? Which one, heat or temperature can be transferred? Which one can be measured directly and how? Students may not know answers to these questions.

This participant is considered to have a sophisticated answer because he was able to elaborate on multiple misconceptions that students might have and difficulties they may experience while learning these concepts.

5.3. Nature of Instructional Strategies Proposed by Participants

All participants made reference to the multiple intelligences theory as the primary philosophy for their responses in this domain of CoRes. Participants also considered teaching through examples that students could relate to from their everyday lives as one of the most effective strategies. Similarly, majority of participants emphasized the importance of hands-on experiences in helping their students to overcome their misconceptions and learning the concepts under consideration in this domain. However, majority of their responses initially lacked a justification as to why students-would learn by doing or learn through examples. For instance, one response that we categorized as being relatively naïve said:

Teaching through a lot of examples from real life, using hands-on activities, solving a lot of questions. By showing them a video, through presentation, by playing topic-related songs. By showing them examples like this from real life and targeting multiple intelligences, we can help make learning both meaningful and durable. I can tell from my own experience that when teachers taught me through hands-on activities, I understood the topic better and still remember the concepts.

Because most participants were able to provide a list of instructional strategies that held potential to help students learn, we wanted to explore why they taught the proposed instructional strategies would be an effective method. We elaborate on the nature of justifications provided by the participants next.

5.4. Nature of Justifications Provided by Participants

While most participants were able to spell out methods that had pedagogical value, not all of them were able to provide a solid justification as to why they thought the particular methods that they proposed would be effective. For instance, one answer reflecting a naïve view read: "I know these will work because of what I know from learning theories and experience. I know from my own experience that if you can connect and learn through verbal and visual presentations you can learn better." Another response that reflected a more informed view read:

I know this strategy will work based on my reflections on my own learning experiences. Students need to actively participate in the learning process, they need to be guided but at the same time, need to have the autonomy to pursue their inquiry. Giving guidance and autonomy will empower the student to question his/her knowledge become aware of the weaknesses and encourage them to pursue answers. Teaching through examples triggers students' thinking and helps them make sense of course content in relation to their prior knowledge and real life experiences. This contributes to student understanding and durability of knowledge.

As this exemplary quote indicates while some participants provided limited or naïve justifications for their suggested instructional strategies, others were able to provide justifications that had high pedagogical affordance.

5.5. Nature of Assessment Strategies Proposed by Participants

As it was the case in other CoRes dimensions, participants provided answers that ranged in their sophistication. One participant who held a naïve view said, "I will ask questions that have one definite scientific answer on my test. Then, I will compare students' answers to the norm to measure their learning." Another participant who was also categorized as holding a naïve conception said, "I will test their understanding through tests, projects, homework and through probing." This particular participant failed to elaborate on how these proposed strategies may serve as effective methods to measure and engage students in deep learning. Yet, some participants were able to provide more elaboration on their proposed assessment strategies. One such participant said:

To understand if my students understand the topic, I will ask them to provide the definition of heat and temperature. Then, to test whether they are able to apply these definitions correctly, I will ask them to use the terms in a real life context by asking them to provide examples from real life. Moreover, I will ask them to justify why they think the example they provide is relevant. In addition, I will construct a matching test in which I will provide examples from real life and ask the students to match which examples are examples of heat and which ones are examples of temperature. I will use posters of examples and ask the students to match the concepts of heat and temperature and ask them to justify their responses.

This example shows that some participants held relatively more sophisticated knowledge both in terms of what they value in student learning and how they go about assessing it.

Up to this point we reported results using CoRes dimensions as our guide. By presenting samples of students' responses, we gave the readers a chance to see the range of answers provided by participants for each CoRes category. While this first method of analyses gave us an in-depth understanding into the range of answers participants provided, we also conducted analyses across four PCK components; namely; orientation to teaching, knowledge of students' understanding, knowledge of instructional strategies and knowledge of knowledge of assessment.

The results reveal interesting trends in observed growth in participants' PCK as a result of the intervention we used. Only twelve out of 16 participants experienced growth in orientation to teaching (TO), ten in knowledge of students' understanding dimension (KSU), nine in knowledge of instructional strategies (KIS) dimension and eight in knowledge of assessment (KA).

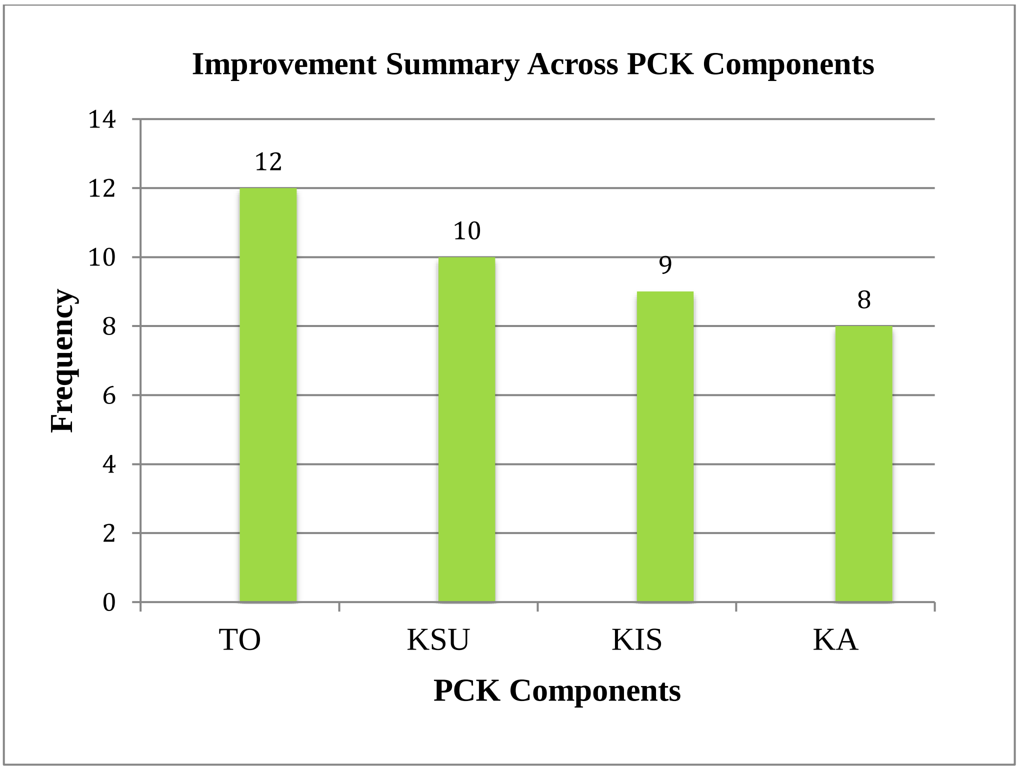

Figure 2. Participants' improvement across PCK components.

The majority of participants developed more sophisticated answers as a result of the intervention. We will show few examples reflecting the growth achieved by participants due to space limitations. The following comparison of the same participant's pre and post answers show the growth achieved in the knowledge of instructional strategies category. While this participant said, "I will teach through multiple intelligences theory and use a lot of examples in my instruction." in his pre-intervention answer, he provided the following elaborate answer in the post-intervention.

First of all, we need to do our homework and learn the target concepts and develop an in-depth understanding of these concepts. An in-depth understanding allows you to come up with a range of relevant examples from real life. You cannot teach effectively if you do not have an in-depth understanding. Before teaching, I will explore my students' prior understanding of concepts and identify their misconceptions. To teach it effectively, we need to use a range of visuals and examples from real life and if possible engage them in inquiry-based activities in the lab. Then, have them construct sentences and explanations using both concepts to see if they understand the difference between heat and temperature and how they might be related. For instance, we need to check to see if they can construct such sentences as “to increase the temperature of water by 10 C, we need 50 cal. of heat.”

The following is an example of growth achieved by another participant in the knowledge of assessment category. The first answer is from pre-CoRes and the second one from post-CoRes.

I will measure my students’ understanding through a concept map to explore their misconceptions at the beginning of the course. Then, I will measure their learning at the end of the unit through a multiple choice test. (pre-CoRes answer).

I will ask my students to construct a concept map at the beginning of my teaching to explore their prior conceptions and misconceptions. I will build on my knowledge of where my students are and teach the target concepts through examples and questioning to make sure that my students acquire the academic language and establish the connection between the scientific concepts and real life examples. After introducing these concepts to my students, I will use collaborative learning activities to create opportunities for my students to critique each other’s’ understanding and question their own understandings. Finally, I will use three-tiered assessments to measure the impact of my instruction on students’ learning. (post-CoRes answer).

Comparison of this participant’s pre and post answers show that the participant moves from exploring and testing students’ knowledge to, using knowledge of his students’ prior understanding to plan and implement instruction. Similarly, while the participant first offers to use a multiple-choice test to measure his students’ learning, after the intervention he suggests use of three-tiered assessments. As these exemplary statements comparing participants’ pre and post answers indicate, participants made progress in their pedagogical capacity for teaching the concepts of heat and temperature and assess student learning.

5.6. Perceived Impact of the Intervention and Cause of Improvement

We also wanted to understand if the participants thought that the intervention made an impact on their learning through an open-ended question. Participants’ responses to question confirmed the results of our analyses. All but one participant said that the intervention helped them to become aware of their own misconceptions or deficiencies in their knowledge of heat and temperature, the majority (n=11) explicitly stated that the intervention changed their beliefs about teaching and learning (i.e. orientation to teaching), expanded their repertoire of instructional strategies (n=15), helped them to experience conceptual change in their approach to assessment (n=14), increased their confidence in writing diverse forms of questions (n=16), increased their knowledge of writing assessments to measure knowledge of students’ of different ability levels (n=13), started to think about finding ways to explore students’ misconceptions before instruction (n=12), started to plan to consider providing a context before jumping into presentation of concepts (n=7) and started to think of assessment beyond summative tests (n=13).

6. Discussion

Teacher professional development is a central piece of systemic reform initiatives in all contexts but particularly in education (Borko, Jacobs, & Koellner, 2010; Penuel & Gallagher, 2009; Van Driel, Beijaard, & Verloop, 2001). Teachers are presented with professional opportunities both in their pre-service education and during their in-service years. In this study, we focused on professional development of pre-service physics teachers. More specifically, we designed an intervention (i.e., construction of assessments, critical peer discussion &

reflection) for the purpose of improving their PCK for teaching the concepts of heat and temperature. The results of our study show that the majority of participants were able to make progress across all CoRes dimensions and PCK components. The improvement was observed in two ways; 1) addition of new knowledge about students' misconceptions, the difficulties students might experience in learning the concepts of heat and temperature, instructional and assessment strategies and 2) reframing of the purpose of teaching and assessment in ways that are more promising in terms of making contributions to the quality of student learning.

These results are promising in that they suggest that through short-term interventions we maybe able to help pre-service science teachers to develop a repertoire of promising instructional and assessment strategies to address students' learning needs. Moreover, the intervention was partly effective at helping most participants to provide sound justifications for the use of proposed reform-based instructional and assessment strategies. While these results are promising, we caution our readers to consider the limitations of pre-service science teachers' PCK in that PCK is a context dependent construct (Grossman, 1990). Moreover, as much as PCK is a cognitive construct, its enactment requires metacognitive awareness, knowledge of content, pedagogy and students (Park & Oliver, 2008). More precisely, it is about how and what teachers notice in student thinking, their knowledge and participation and how they respond to these observations to address students' learning needs.

Abell (2008) in referring to the work of Ertmer & Newby (1996) acknowledges this complexity associated with teachers' PCK and argues that growth in a teacher's PCK, in part, is about adding new knowledge to one's repertoire of existing strategies about how to teach, and 'partly about figuring out ways to integrate and use that knowledge that are strategic, self-regulated, and reflective, as experts do' (p. 1411). While with CoRes we can effectively measure how much new knowledge pre-service science teachers have added to the repertoire of relevant instructional and assessment strategies, we will not know if, why, how and in what contexts teachers may be able to enact these strategies unless we can effectively observe teacher behavior in action and explore their reasoning through in-depth interviews following the teaching episode of interest.

PCK scholars recognize that PCK is context-dependent (e.g., Grossman, Wilson, & Shulman, 1989) in that different student profiles and curricular demands may impact the nature of PCK enacted by the teacher. For instance, a teachers' PCK observed in an advanced placement course may be different than the type of PCK observed of the same teacher in a regular high school science course. Similarly, a teacher's espoused PCK (Authors, 2014) may be challenged when the student population served deviates from the norm (e.g., majority of students do not fit the mainstream student population). Unless tested against practice in different contexts, we cannot make reliable claims about the robustness of a teachers' PCK (Hill, Ball & Schilling, 2008). We encourage PCK scholars who have access to contexts and resources to study the projections of teachers' PCK growth over a sustained period of time and in different contexts.

While conducting a review of literature, we also became aware of the urgent need to study the relationship between teacher PCK and student achievement. While scholars have elaborated on the rationale for the connection between sophisticated teacher PCK and the quality of learning that maybe experienced by the students (Abell, 2008; Alonzo et al., 2012; De Jong & Van Driel, 2004; Loughran, Milroy, Berry, Gunstone, & Mulhall, 2001; Park & Oliver, 2008), to date no studies that we are aware of have tested this relationship empirically (Abell, 2008; Alonzo, et al., 2012). The only study of such nature that we are aware is a study conducted by Roth et al. (2011) in the U.S and a study conducted by Alonzo et al. (2012) with two teachers in Germany. Roth and colleagues used video analyses method to capture evidence of teachers'

PCK. Participants were asked to analyze video cases of teaching and comment on what they observed in the video using guiding prompts. They rated teachers' PCK through analyses of teachers' 'analytical comments about the science content, the teaching, and… student thinking' (p.126). Then, explored the relationship between teachers' PCK and their students' achievement.

Alonzo et al (2012) conducted a study in Germany to establish a correlation between teacher PCK and student achievement. The authors measured 'content-based interactions' between the students and the teacher to measure teachers' PCK. The authors found that students who were in Peter's (teacher with high PCK) classroom made larger gains between a pre and post test that was administered to the students on the topic of optics. In justifying the reported gains, the authors attributed gains achieved by the students to the teacher's ability to monitor and notice students difficulties, ability to use content-based scaffolding, making connections to real life, effective use of content-based questioning and making instructional decision based on an informed understanding of how students develop knowledge. It follows that a sophisticated pedagogical content knowledge base involves knowing how to organize, sequence, and present the scientific content to the students in a meaningful and effective fashion (Gess-Newsome & Lederman, 1999). While this case study provides an in-depth understanding and evidence of how a teacher's PCK may contribute to students' learning gains, these judgments are based solely on two teachers' 90 minute of instruction. We join Abell's (2008) call and urge our colleagues to conduct more systematic empirical studies that explore the causal relationship between teachers' PCK and student achievement.

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Appendix A: PCK Sophistication Levels and Descriptors.

	Level 1	Level 2	Level 3
Orientation to Teaching (TO)	Provides a content-based perspective. Focuses on preparing students for the next level of schooling (i.e. taking advanced physics courses). Provides a statement that emphasizes real life application but fails to provide justification or elaboration.	Emphasizes real life applications of the content taught and attempts to justify and elaborate on the objective of learning. Recommends student-centered approaches in teaching. Fails to effectively justify the effectiveness of the proposed methods.	Emphasizes students' understanding of real life application of the content and effectively justifies its importance by connecting content to real life through examples. Emphasize developing an understanding and appreciation for the complexity of the nature. Recommends student-centered approaches in teaching. Able to justify the effectiveness of the proposed instructional methods.
Knowledge of Student Understanding (KSU)	Ignores students' prior conceptions or just states one misconception. Fails to report a sound difficulty that the students might be experiencing in learning the target concepts.	Provides all possible misconceptions and makes an attempt to elaborate on the causes of the reported misconceptions. Starts to think about why students might be experiencing difficulty in learning the target concepts.	Provides multiple misconceptions students may have. Justifies the causes of misconception or the difficulties students may have. Considers these misconceptions as important resources for planning to teach. Provides several difficulties that the students may have.
Knowledge of Instructional Strategies (KIS)	Instructional strategies are teacher-centered includes presentation of content. When student-centered activities are offered, learning mostly involves focuses on the activity rather than building on activities to provide a meaningful learning experience.	Instructional strategies are student-centered but the participant fails to effectively elaborate on the theoretical bases of the theory.	Instructional strategies are student-centered, the participant effectively elaborates on the theoretical bases of the theory. Focuses on collaborative learning, opportunities for questioning the content, engaging in inquiry-based learning and analyses of experimental or observational data.

Knowledge of Assessment Strategies (KA)	Suggests use of traditional one-shot summative tests and the primary means of assessing student learning.	Suggests use of multiple tests but still primarily focuses on the summative function of assessment.	Acknowledges the presence of misconceptions and talks about ways to assess & address them. Suggests use of multiple assessments. Emphasizes both formative and summative purposes of assessment. Assessment focuses on the application of knowledge gained through instruction.