ABSTRACT

TOPIC-SPECIFIC PEDAGOGICAL CONTENT KNOWLEDGE (PCK) IN CHEMISTRY: CHARACTERIZING ACID-BASE CHEMISTRY AND CHEMICAL BONDING PCK THROUGH A NOVEL DATA COLLECTION METHOD

by R. Thomas Smith

Pedagogical content knowledge (PCK) is a complex concept. Broadly defined, PCK allows teachers to transform subject matter, context, and pedagogical knowledge into instruction so diverse learners can achieve conceptual understanding. Due to its complexity, PCK is difficult to observe and document. The purpose of this study is to optimize the data collection process and characterize high school chemistry teachers’ topic-specific PCK. This study proposes a model of PCK synthesized from the literature, as well as a four-stage data collection method aimed at improving PCK data quality. Results from the pilot study on acid-base chemistry demonstrated that the data collection method allowed researchers to characterize PCK trends across teachers, as well as identify unique PCK characteristics. Results from the main study on bonding uncovered that teachers employ different PCK components to different extents depending on the teaching task. Recommendations for a professional development program and future research were generated.
TOPIC-SPECIFIC PEDAGOGICAL CONTENT KNOWLEDGE (PCK) IN CHEMISTRY: CHARACTERIZING ACID-BASE CHEMISTRY AND CHEMICAL BONDING PCK THROUGH A NOVEL DATA COLLECTION METHOD

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R. Thomas Smith
Miami University
Oxford, Ohio
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Advisor: __________________________
Dr. Ellen J. Yezierski

Reader: __________________________
Dr. Stacey Lowery Bretz

Reader: __________________________
Dr. Richard T. Taylor

Reader: __________________________
Dr. C. Scott Hartley
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Dedication

Dedicated to my parents,

Brad and Janet Smith

Who offered support, guidance, love, and always believed in me.

You have made me into the person I am today.
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Chapter 1: Statement of the Problem

Pedagogical content knowledge (PCK) is a knowledge base unique to teachers. When employed, PCK allows for the transformation of knowledge from other knowledge bases—content knowledge, pedagogical knowledge, and knowledge of context—into instruction, with the goal of having students gain a conceptual understanding of the content being taught. (Shulman 1986, 1987; van Driel, Verloop, & de Vos, 1998; Magnusson, Krajcik, & Borko, 1999; Park & Oliver, 2008; Park et al., 2011; Jüttner et al., 2013; Aydin, et al., 2014). Due to its importance to teaching, PCK is necessary for reformed and exemplary teaching (Abell, 2008; Magnusson, Alonzo, Kobarg, Seidel, 2012; Krajcik, & Borko 1999; Park et al., 2011). Furthermore, PCK is topic specific. This means that PCK will not be transferred from one topic to another (Shulman 1986, 1987; van Driel, Verloop, & de Vos, 1998; Magnusson, Krajcik, & Borko, 1999; Park & Oliver, 2008; Park et al., 2011; Jüttner et al., 2013; Aydin, et al., 2014).

While PCK is essential for effective instruction, it is also complex and difficult to observe and document (Shulman 1986, 1987; van Driel, Verloop, & de Vos, 1998; Magnusson, Krajcik, & Borko, 1999; Park & Oliver, 2008; Park et al., 2011; Jüttner et al., 2013; Aydin, et al., 2014). Differing and sometimes competing models of PCK and definitions of PCK components exist (Magnusson, Krajcik, & Borko 1999; Mavhunga & Rollnick et al., 2008; Rollnick, 2011; Schmelzing et al., 2013; Schmelzing, S., Wuesten, S., Sandman, A., & Neuhaus, B., 2010). On top of the disagreement, PCK also requires multiple data collection methods to elucidate data from multiple facets of teaching. Previous PCK analyses have been conducted through the use and development of paper and pencil tests, PCK rubrics, and interviews. A comprehensive data collection method that includes all facets of PCK-data-collection through planning, enactment, and reflection—has not yet been developed (Jüttner et al., 2013; Loughran, Berry, & Mulhall, 2006; Schmelzing et al., 2013; Rollnick, et al., 2013). Moreover, there is a call in the literature for a focus on topic specific PCK. More specifically, there is a need for the characterization of topic specific PCK across different topics and subjects (Abell, 2008; Aydin, S., Friedrichsen, P. M., Boz, F., & Hanuscin, D. L., 2014; Park et al., 2011).

In the spotlight of this study will be the topics of acid-base chemistry and chemical bonding. The reasoning for chemical bonding is threefold. First, bonding is a complex integral chemical concept that typically gives rise to student alternative conceptions (Gilbert et al., 2002). This characterizes the importance of having high PCK for this topic, to limit and remediate
pedagogical impediments. Second, chemical bonding is a crosscutting and essential standard in the Next Generation Science Standards (Achieve, 2013). Lastly, chemical bonding has been subject to minimal PCK study, and research has characterized what bonding PCK may look like (Nahum et al., 2007). Acid-Base chemistry was chosen for the pilot study due to the previous literature on acid-base PCK (Drechsler & Van Driel, 2007). The purpose of the pilot study was to test the efficacy of a data collection method and PCK model, making this topic a good choice.

To address the difficulty of data collection and characterization of topic specific pedagogical content knowledge, the following research questions guided this study:

1. To what extent does the PEER data collection method elicit and capture novel and complete data to characterize acid-base PCK across a small group of teachers?
2. How does the reflection stage (VIdEOs) of the PEER method generate unique acid-base PCK data as compared to data generated by the explication and enactment stages?
3. What novel findings can the PEER data collection method generate for chemical bonding PCK?
4. How can the PEER data collection method characterize chemical bonding PCK?

To answer these questions a comprehensive model of PCK was synthesized from the literature, then a four-stage data collection method, PEER, was developed to elucidate data from three measurable indicators. The PEER method was tested and revised during the pilot study implementation. In the main study data analysis focused on characterizing novel PCK findings and characterizing bonding PCK. The characterization of topic specific PCK has implications for pre-professional and professional teacher development, and provides tools to characterize other topics across subjects.
Chapter 2: A Review of Literature

I. Pedagogical Content Knowledge: An Overview

Due to its importance in developing critical thinking and meeting the needs of a shifting workforce, effective science education is essential for students and has been at the center of national reforms (NGSS Lead States, 2013; Their, 2001, p. 19). Abell (2008) states that teaching science is not about having a bag of tricks and gimmicks, but the merging of context, subject matter knowledge (at a topic and discipline specific level), and teaching methods to form meaningful instruction. Others have stated a need for reformed science teaching practices. Reformed teaching is described as being student-centered, standards-based, and inquiry-oriented with a philosophical basis in constructivism (Magnusson, Krajcik, & Borko 1999; Park et al., 2011; Sawada, Piburn, & Judson, 2002). Many examples describe exemplary teachers using inquiry-based practices (Haley-Oliphant, 1993; Carlson, Humphrey, & Reinhardt, 2003; National Research Council, 2002, pp. 39-74; Llewellyn, 2005, pp. 14-20). As summarized by Magnusson, Krajcik, and Borko (1999), to be exemplary, teachers must be able to provide learning experiences for diverse students in varied and constraining situations; it is not the ability to give students’ information, but rather the ability to transform the information (content and skills) in a meaningful way. The knowledge base required to transform the various facets of science education has been referred to in a significant literature base as pedagogical content knowledge and frames the basis for this study.

Broadly defined, pedagogical content knowledge (PCK) is a part of teaching knowledge that allows for the metamorphosis of subject matter knowledge, knowledge of teaching methods, and knowledge of context so that diverse learners can achieve conceptual understanding in the classroom. PCK is an elusive and important concept in education (Shulman 1986, 1987; van Driel, Verloop, & de Vos, 1998; Magnusson, Krajcik, & Borko, 1999; Park & Oliver, 2008; Park et al., 2011; Jüttner et al., 2013; Aydin, et al., 2014). PCK was also the topic of a recent conference titled “The PCK Summit.” This summit hosted some of the leaders in PCK with the goal of developing a model and definition of PCK (Gess-Newsome & Carlson, 2013). While PCK is widely researched and necessary for teaching, its tacit nature leads to a lack of consensus on working definitions and difficulty in observing, documenting, and measuring the components that comprise PCK. Previous research has analyzed PCK through the use and development of paper and pencil tests, PCK rubrics, and interviews, but a comprehensive data collection method
that includes all facets of PCK has not yet been developed (Jüttner et al., 2013; Loughran, Berry, & Mulhall, 2006; Schmelzing et al., 2013; Rollnick, et al., 2013).

II. Theory and Challenges in Observation and Documentation

A. The Roots of PCK

The notion of being able to transform information to produce a desired learning outcome has its roots in Shulman’s (1986, 1987) work on PCK. While Shulman’s work serves as the baseline for a PCK conceptualization, PCK has also been described as topic-specific, meaning that PCK for one topic may not translate to another topic within the same subject (Shulman 1986, 1987; van Driel, Verloop, & de Vos, 1998; Magnusson, Krajcik, & Borko, 1999; Park & Oliver, 2008; Park et al., 2011; Jüttner et al., 2013; Aydin, et al., 2014). Furthermore, much debate about the components of PCK and teacher knowledge exists (Shulman 1986, 1987; van Driel, Verloop, & de Vos, 1998; Magnusson, Krajcik, & Borko, 1999; Park & Oliver 2008; Schmelzing et al., 2010; Schmelzing et al., 2013). The following discussion compares and contrasts the components of PCK as described in seminal works to extract the agreed upon components that guided this study.

B. Teacher Professional Knowledge Bases

Shulman (1986, 1987) originally defined seven different areas of teacher professional knowledge: Content knowledge, general pedagogical knowledge, curriculum knowledge, knowledge of learners and their characteristics, knowledge of educational contexts, knowledge of educational ends, and pedagogical content knowledge.

These original ideas have changed as a result of research and theoretical development and have been compressed into four knowledge domains: Subject matter knowledge, pedagogical content knowledge, pedagogical knowledge, and knowledge of context (Grossman, 1990; Magnusson, Krajcik, & Borko, 1999; Park & Oliver, 2008). While the definition of subject matter knowledge is explicit, pedagogical knowledge is defined as the knowledge of educational goals and aims, assessments, learners and learning, classroom management, and instructional strategies. The knowledge of context refers to the teacher’s knowledge of the students’ backgrounds, classroom, school, district, community, state, and nation (Grossman, 1990; Magnusson, Krajcik, & Borko, 1999; Park & Oliver, 2008).
C. PCK Components

From these knowledge bases extend the components that specifically comprise PCK. Shulman (1986, 1987) stated that PCK encompasses representations, analogies and illustrations, examples and explanations, demonstrations, and student difficulties stemming from students’ conceptions and preconceptions by grade level. Magnusson, Krajcik, and Borko (1999) presented a model of PCK with five components based on Grossman’s (1990) conception: Knowledge of science curriculum, knowledge of students understanding of science, knowledge of instructional strategies, knowledge of science assessment, and orientation to science teaching. This model is hierarchical, identifying “orientations to science teaching,” as superior to the rest, and acting as a filter between the PCK components and PCK as a broad construct. Park and Oliver (2008) adjusted this model, per the results of their study, and developed a model where the components have an equal influence on PCK. This was then expanded into what Park and Oliver call the “hexagon model,” which includes teacher efficacy as a sixth component. Of these components, only two are fully agreed upon and deemed essential by other scholars: Knowledge of student conceptions and pre-conceptions and representations and illustrations, which falls under the component “knowledge of instructional strategies.” The rest of their components are being debated (van Driel, Verloop, & de Vos, 1998; Park et al., 2011; Alonzo, Kobarg, Seidel, 2012; Jüttner et al., 2013; Schmelzing et al., 2013).

D. Measurable Indicators

Understanding PCK is made more complex by researchers’ efforts to define it, not only in terms of its components, but also in terms of observable and measurable indicators. Three measurable indicators are being employed in this study: Explication, enactment, and reflection. Shulman (1987) originally defined the transformation of knowledge into instruction, as a combination of preparation of classroom materials, representation of content, instructional method selection, adaptation of the represented content to a particular group of students, and tailoring instruction to classroom constraints. Those categories were compressed into what is known as declarative and procedural PCK, or PCK-in-action and PCK-on-action, respectively (Park & Oliver, 2008; Schmelzing et al., 2010; Alonzo, Kobarg, & Seidel, 2012; Jüttner et al., 2013; Schmelzing et al., 2013). Originating from the idea of declarative and procedural knowledge (Alexander, Schallert, & Hare, 1991), declarative PCK is what teachers can state
about their understandings such as student difficulties, limitations to procedures, and instructional strategies. This measurable indicator is called explication in this study.

Procedural PCK describes the actions and reactions that take place throughout the lessons and bring about some of the teachers’ tacit knowledge (Park & Oliver, 2008; Schmelzing et al., 2010; Alonzo, Kobarg, & Seidel, 2012; Jüttner et al., 2013; Schmelzing et al., 2013). Declarative and procedural PCK have been used interchangeably with PCK-on-action and PCK-in-action (Jüttner et al., 2013). Procedural PCK is called enactment in this study.

Another process embodied in PCK is how teachers evaluate their practice and its impact on student learning. Reflection is a critical process for the formation, revision, and observation of PCK (Shulman, 1986, 1987; Magnusson, Krajcik, Borko, 1999; Park & Oliver, 2008; Schmelzing et al., 2010; Jüttner et al., 2013; Schmelzing et al. 2013). Although most scholars have labeled this measurable indicator as reflection (Shulman, 1986, 1987; Magnusson, Krajcik, Borko, 1999; Park & Oliver, 2008; Schmelzing et al., 2010; Schmelzing et al. 2013), Jüttner et al. (2013) has labeled it as conditional PCK. With its roots in Alexander, Schallert, and Hare’s 1991 work (1991), conditional PCK is defined as the meta-knowledge of the PCK construct (Jüttner et al., 2013). In summary, conditional PCK is a process that allows a teacher to evaluate their practices, pedagogy, planning, and assessments to inform future classroom decisions. Synthesizing these works, conditional PCK is not only a measurable indicator, but also the process by which PCK is revised and developed (Park & Oliver, 2008; Aydin, et al., 2014), making it as critical as declarative and procedural PCK.

E. Current Data Collection Methods

To observe and document PCK, multiple data collection methods are needed (Abell, 2008; Gess-Newsome & Carlson, 2013; Park & Oliver, 2008). Current data collection methods focus on developing and employing paper-and-pencil tests, teaching artifacts, interviews, and interview activities to elucidate declarative PCK (explication) (Kleickmann et al., 2012; Jüttner et al., 2013; Schmelzing et al., 2013; Rollnick, et al., 2013). For example, Schmelzing, et al. (2013) developed a paper-and-pencil test focusing on teachers’ knowledge of student understandings and teaching strategies. This test was based on expert opinions and video recordings of classrooms. Rollnick et al. (2008) employed Professional-experience Repertoires (PaP-eRs) and Content Representations (CoRes) (Loughran, J., Berry, A., & Mulhall, P., 2006) in their case study on South African teachers teaching equilibrium and substance amount. CoRes
and PaP-eRs (CoRes will be discussed in detail later) were designed as a tool to help teachers explicate their PCK. CoRes focuses on aspects of PCK surrounding a topic, while PaP-eRs focuses on aspects of teaching in a general sense (Loughran, J., Berry, A., & Mulhall, P., 2006). From there, Mavhunga and Rollnick (2011) developed a paper-and-pencil test. This test asked teachers to respond to written teaching situations, and included a rubric for scoring responses. Aydin et al., (2013) also used CoRes to collect PCK data, but also included a card sorting activity, asking teachers to place various pedagogical options closer or farther away from cards with the topics at the heart of the study.

While much research has focused on explicating teachers’ PCK, some studies include classroom observations as well (enactment) (Park & Oliver, 2008; Park et al., 2011; Aydin, et al., 2014). While some studies used videotapes to inform the development of a paper-and-pencil test (Schmelzing, et al., 2013), others used observation protocols, such as the Reformed Teaching Observation Protocol (Park et al., 2010; Sawada et al., 2002).

There are no studies, however, in which data collection captures declarative, procedural, and conditional PCK, where teachers reflect on their own videotaped classroom instruction. Before building a comprehensive method for encapsulating all three subunits of PCK (declarative, procedural, conditional), we required a coherent model of PCK to guide the data collection method and serve as an analytic framework to represent knowledge generated by all three measurable indicators. This study proposes a chemistry-focused, hexagonal model (Park & Oliver, 2008) of PCK, as well as a four-stage data collection method to close gaps in observation and documentation.

III. Literature on PCK Data Collection

Based upon the gaps in the literature and the complexity of PCK, there is a need for a data collection method that elucidates data from each measurable indicator in our model. To collect data related to each indicator, implementation of a data collection method was necessary before, during, and after instruction. This resulted in the PCK Explication, Enactment, and Reflection data collection method (PEER). PEER is a four-stage data collection method designed to collect data on one lesson, on a particular topic in a high school chemistry classroom. The PEER data collection method employed four research-based tools for uncovering PCK: Content Representations (CoRes), the Reformed Teaching Observation Protocol (RTOP) (Appendix A), Electronic Quality of Inquiry Protocol (EQUIP) (Appendix B), and the Representations in
In seeking a tool to explicate and solicit data on the teacher’s declarative knowledge before the classroom instruction, CoRes was chosen and implemented as a semi-structured interview (Appendix G) (Richards & Morse, 2007). CoRes was designed to elucidate PCK from the practitioners point of view and is the result of extensive research with science teachers. It was designed to uncover the conceptualizations of PCK in experienced teachers through teachers’ written responses to promopts. Since its development it has been used for a wide range of experience.(Loughran, Berry, & Mulhall, 2006; Loughran, Berry, & Mulhall, 2008). The decision to use CoRes was grounded in its research-based development, the predominance of CoRes in PCK studies on developing and documenting PCK, and because the CoRes elicits data on multiple PCK components (Abell, 2008; Rollnick et al., 2008). The structure of CoRes was changed slightly, as we transformed the prompts from a table into a semi-structured interview. This provided the opportunity to probe teachers’ knowledge at a deeper level and solicit follow-up information when needed.

The development of the RTOP was framed around the question “how can you tell if a lesson is reformed?” At the time of its development, the RTOP was designed using current research on science and math standards and various observation protocols and assessments. Sixteen classes were observed by two raters each in order to assess the inter-rater reliability of the observations. The Cronbach’s alpha for the whole instrument was calculated to be 0.97. Face validity was then assessed through a factor analysis (Sawada et al., 2002).

The RTOP contains three subsections: Lesson design and implementation, content, and classroom culture. Multiple items describing lesson and instructional features comprise each section and are scored on a 5-point scale (0=never occurred to 4=very descriptive). Lesson design and implementation contains five items and measures the extent to which student ideas are taken into account and students are able to make autonomous decisions that determine the direction of an investigation. Content contains ten items, divided in half by chemistry content and its real world and cross-curricular connections and the processes and procedures the students employed in the classroom (making predictions, using manipulatives, reflecting on learning, etc.). The last subsection, classroom culture, also has ten items divided equally. The two subscales in this subsection focus on the extent to which communication is done between
students, the teacher, and the whole class, and the extent to which the teacher played the role of a
guide and a listener, as opposed to a director (Sawada et al., 2002). MacIsacc and Falconer
(2002) linked total RTOP score ranges with various types of lessons relating to high school and
college instruction.

The EQUIP was developed out of a need for a protocol to assess the extent to which a
lesson is inquiry-based on a fine-grained level. After reviewing multiple protocols, the authors
did not find what suited their needs and decided to create a new tool. Through a combination of
reviewing literature and existing protocols an initial EQUIP was developed. The authors then
realized they wanted a descriptive rubric to provide more detailed notes on the level of inquiry
being conducted. After the final version was developed, measures of face validity, internal
consistency and inter-rater reliability were taken in order to ensure the protocol was data and
theory driven (Marshall, Smart, & Horton, 2009).

EQUIP is broken into 8 sections, which include demographics, time use analysis, and the
various sections used to score the level of inquiry observed in a lesson. For the purposes of this
study rubrics associated with sections 4-7 of the EQUIP were used to evaluate the level of
inquiry used in a lesson. Each section includes constructs that comprised a specific part of
inquiry instruction. The constructs are evaluated on a 1-4 scale using a rubric with specific
descriptors of each level. The four levels are: pre-inquiry (level 1), developing inquiry (level 2),
proficient inquiry (level 3), and exemplary inquiry (level 4). One advantage of this instrument is
the ability to assign a plus and minus scale to the various levels. For example, if two lessons
(lesson A and B) receive a 2 for a particular construct, but lesson A was on the verge of being a
3, that lesson can receive a 2+ to represent that it was on the upper end of that level. This is a
distinct advantage because it helps researchers, evaluators, and teachers produce a fine-grained
evaluation of a lesson (Marshall, Smart, & Horton, 2009). The four sections for the EQUIP are:
Instructional factors, discourse factors, assessment factors, and curriculum factors. Instructional
factors assesses the role of the teacher and student and the level of conceptual understanding and
thinking being promoted by the lesson. Discourse factors examines the questioning and
discourse seen in the lesson. That includes the extent to which questions were open-ended, the
purpose for asking questions, and the complexity of questions and discussion. Assessment factors
includes constructs about who is using the assessment, the purpose for the assessment, and the
type of information being assessed. Lastly, curriculum factors assesses the depth of the content,
its integration into an investigation, and the role of the student in that investigation (Marshall, Smart, & Horton, 2009).

RICI was developed to be used along side other observation protocols in order to gain an understanding of how representations were being used. Based on Johnstone’s Triangle (Johnstone, 2000), the researchers noticed that current observation protocols did not account for the use of representations in the chemistry classroom, a crucial part of chemistry learning. Research literature on the effective use of representations in chemistry guided the development of RICI (Phillip, Johnson, and Yezierski, 2014).

RICI assesses the use of representations in the classroom through four indicators: User description, conceptual understanding, quality of discourse around representations, and integration of macroscopic, symbolic, and particulate concepts. Influenced by EQUIP, RICI employs the same scale and levels for each indicator. The user description levels differentiate who is using the representations and the extent of the representations use. Conceptual understanding relied on what types of representations (macroscopic, symbolic, or particulate) were used and how they helped develop conceptual understanding. Quality of discourse around representations evaluates the student-centeredness of the discourse and whether or not limitations to the representations were discussed. Finally, integration of macroscopic, symbolic, and particulate concepts indicates the extent to which the different types of representations were connected in a lesson (Phillip, Johnson, and Yezierski, 2014).

IV. Research Questions

1. To what extent does the PEER data collection method elicit and capture novel and complete data to characterize acid-base PCK across a small group of teachers?
2. How does the reflection stage (VIdEOs) of the PEER method generate unique acid-base PCK data as compared to data generated by the explication and enactment stages?
3. What novel findings can the PEER data collection method generate for chemical bonding PCK?
4. How can the PEER data collection method characterize chemical bonding PCK?
Chapter 3: Methods

I. Recruitment

A. Conduction of Ethical Research

The focal point of this study is on high school chemistry teachers. Due to the involvement of human subjects in research, the researchers participating in any part of the study all received certification to conduct research on human subjects from the Collaborative Institutional Training Initiative (CITI). A research proposal was also written and submitted to the Institutional Review Board (IRB) at Miami University. The IRB serves to ensure all research is being conducted ethically and in a way that minimizes risk to the participants. This study was approved under IRB exempt certification number 00776e, and was titled *Investigating and Characterizing High School Chemistry Teachers’ Pedagogical Content Knowledge of Chemical Bonding*.

To ensure informed consent on multiple levels, both teachers and principals were given consent forms that informed them of the nature of the study, its importance, the parameters of the teachers’ responsibilities, and how to withdraw from the study without risk at any time. The participating teacher consent for (Appendix E) was given to the teacher during the interview stage of data collection. Before any data collection occurred, the teacher was asked to read and sign the consent form as long as they were still willing. The teacher told that they would have complete anonymity and could withdraw from the study at any point in time. If the teacher consented, they were then given the principal consent form (Appendix D), which was then received in the videotaping stage of data collection. Because teachers were the focal point of this study, students were not required to give consent. Videotaping focused on the teachers and what the students were discussing and manipulating in their classrooms. If a student did not wished to be video recorded, the videographer ensured that s/he was not captured on camera.

B. Recruitment

Recruitment took place throughout the duration of the study, as the topics at the center of this study are taught during multiple times of the year. Teachers were contacted via email with an IRB approved recruitment script (Appendix F). This script was designed to inform the perspective participant about PCK, its importance, how much work their participation will require, and that they will be given a Flinn Scientific gift card as a thank you gift for participating. If a teacher was interested in the study or more information, a follow-up email was
sent providing the teacher with said information, and then an interview was scheduled. Flinn Scientific is widely used in high schools as a scientific resource and educational material supplier. Because of the prevalence and practicality, $50.00 Flinn Scientific gift certificates were given to participants who completed every data collection stage.

C. Participants

Participants were recruited from high schools in Southwest Ohio. Three teachers participated in the pilot study - Amy, Michonne, and Sophia – and were all teaching acid-base chemistry at the end of the school year. The five teachers in the main study were Don, Doug, Gavin, Janine, and Linda. This group of teachers taught topics within chemical bonding, which took place across the school year. Doug teaches AP chemistry, but the rest of the teachers instruct various levels of regular high school chemistry.

II. Closing the Gaps in PCK Data Collection

A. Synthesizing a PCK Model

In light of the complexity, difficulty in observation, and multiple models existing in the literature, it was important to synthesize a PCK model rooted in the various conceptualizations and definitions. An initial literature search was conducted using Google Scholar. Terms such as “Pedagogical Content Knowledge,” “PCK,” Chemistry PCK,” “Topic Specific PCK,” etc, were searched to produce an initial pool of literature. From there, the literature initial literature provided articles to search for, as well as new keywords. A comparison was done among PCK articles to determine what prominent citations. This search resulted in PCK literature along with a plethora of PCK models. This prompted the authors to synthesize a model of PCK, as it had become clear that PCK was a complex and multifaceted concept with multiple, competing models.

The Smith and Yezierski PCK model (Figure 1) is a synthesis of PCK models found in the literature and based on PCK theory (Grossman, 1990; Magnusson, Krajcik, Borko, 1999; Park & Oliver, 2008; Rollnick, et al., 2013). This model places PCK in the center of the other three knowledge domains—subjects matter knowledge, pedagogical knowledge, and knowledge of context—discussed earlier to express the synthesis and influences of all knowledge domains on the transformation of knowledge to instruction. The model employs the five PCK components commonly defined, as well as the sixth (Teacher Efficacy) found in Park and Oliver’s (2008)
work. Due to the debate around PCK components, the authors synthesized and revised the definitions based on PCK theory for the purposes of data analysis in the main study (Grossman, 1990; Magnusson, Krajcik, Borko, 1999; Park & Oliver, 2008) (Table 2).

Figure 1: The Smith and Yezierski PCK Model

In order to synthesize PCK component definitions, we created a spreadsheet containing the definitions for each component from Grossman (1990), Magnusson, Krajcik, Borko, (1999) and Park and Oliver (2008). These articles were chosen based on how often they were cited and their influence to the Smith and Yezierski PCK model. The original definition created by the author was also included. Definitions were revised by looking across each definition and emphasizing the common attributes, while ensuring the components did not overlap too much. For example, chemistry curriculum was expanded to state that this component was about what
was taught and not how it was taught. Without this statement, differentiating between curriculum and instructional strategies would have been difficult.

B. Developing a four stage data collection method

Based upon the gaps in the literature and the complexity of PCK, there is a need for a data collection method that elucidates data from each measurable indicator in our model. With the importance of instruction in PCK and reflection in the expansion and revision of teaching knowledge, it was important to us to collect data from each indicator. Not only does it reveal a more thorough characterization of a teacher’s PCK, but it also allows for the triangulating of themes seen throughout the data collection process. To collect data related to each indicator, implementation of a data collection method was necessary before, during, and after instruction. This resulted in the PCK Explication, Enactment, and Reflection data collection method (PEER).

PEER (Figure 2) is a four-stage data collection method designed to collect data on one lesson, on a particular topic in a high school chemistry classroom. Stage one (explication) is a semi-structured interview that takes place during the planning stages of the lesson. This elucidates information from all three knowledge bases, ultimately to determine what is being taught, how it is being taught, and the explanations for the choice in instructional strategies and content, as well as other pieces of knowledge that are important to the teacher with regards to teaching. Stage two (enactment) is where the lesson discussed in the interview was taped. Stage three (reflection) is where teachers view and assess their own teaching and its alignment with their own views and planning. Stage four (enactment) is the employment of observation protocols couples with the classroom video to create quantitative measures of teachers’ level of inquiry, reformed teaching, and use of representations in the classroom. Each stage will be discussed in depth in the data collection section.
III. Data Collection

A. PEER: Stage One

Stage one focuses on explication and seeks to solicit data on the teacher’s declarative knowledge before the classroom instruction takes place through a semi-structured interview (Richards & Morse, 2007) guided by Content Representations (CoRes) (Loughran, Berry, & Mulhall, 2006). CoRes was designed to uncover topic-specific PCK, employing a table that teachers filled using prompts, and is developed through extensive research with science teachers (Loughran, Berry, & Mulhall, 2006; Loughran, Berry, & Mulhall, 2008). The decision to use CoRes was grounded in its research-based development, the predominance of CoRes in PCK studies on developing and documenting PCK, and because the CoRes elicits data on multiple PCK components (Abell, 2008; Rollnick et al., 2008). The structure of CoRes was changed slightly, as we transformed the prompts from a table into a semi-structured interview. This provided the opportunity to probe teachers’ knowledge at a deeper level and solicit follow-up information when needed.

When implementing this semi-structured interview, the interviewer starts off by gaining informed consent from the participant and asking permission to audio-record the interview. With
the nature of a semi-structured interview, the prompts were not followed in numerical order. The interviewer allowed conversation to develop naturally and used the prompts as a way to spark discussion, although the interviewer ensured that each prompt was thoroughly discussed. The interviews lasted around an hour and were transcribed verbatim by the interviewer (Appendix I).

B. PEER: Stage Two

Stage two of PEER is the classroom observation and captures procedural knowledge. The lesson discussed in the first stage is recorded using a video camera for subsequent analysis and reflection. The videographer remained on the outskirts of the classroom, so as to not interfere or influence student-student or student-teacher interactions. If the teacher is delivering direct instruction, the videographer focuses on him or her. Otherwise the videographer focused on capturing student-student interactions, student-teacher interactions, and captures shots of documents or curricular materials in the process.

C. PEER: Stage Three

The observation leads into stage three, which is aimed at capturing conditional PCK, and is the most novel part of the PEER method. The teacher watches the video of his/her instruction and generates an audio narration of the observation in the form of a reflection. The audio narration, or Virtual Identification of Educational Outcomes (VIdEOs), serves as the measurable indicator for reflection (Appendix H). VIdEOs is a guided reflection based upon the CoRes interview responses. Teachers’ direct responses taken from the CoRes interview are crafted into custom reflection prompts that the teacher is asked to focus on during the narration of their own classroom video. For example, if the teacher stated that her main objective was to elicit misconceptions throughout the lesson, the VIdEOs prompt will ask if she was able to do so and what evidence from the video supports the claim. By offering prompts, but not directing reflection, it allows the teachers to reflect on what is important to them, while keeping the reflections aligned with the teacher-generated content from the CoRes.

In order to prepare teachers for their VIdEOs reflection, three steps were taken. First, a DVD copy of the teacher’s instruction was burned onto a DVD and the VIdEOs prompts are created. Second, the DVD and VIdEOs prompts are mailed to the teacher at an address of their choosing. Lastly, a follow-up email was sent to inform the teacher where to send the reflection. Participants were given the option to type or audio-record their reflections to ensure they did
what they were most comfortable with. Audio recorded interviews were transcribed verbatim (Appendix J).

**D. PEER: Stage Four**

The final data-collection stage is an analysis of instruction using observation protocols. This functions simultaneously as a data collection and analysis method, since the observation protocols create scores across various measures of reformed teaching, student centeredness, and use of representations in the classroom. With the focus on reformed teaching, much like previous PCK studies using observation protocols, three protocols were chosen: The Reformed Teaching Observation Protocol (RTOP) (Sawada et al., 2002), Electronic Quality of Inquiry Instruction (EQUIP) (Marshall, Smart, & Horton, 2009), and Representations in Chemistry Instruction (RICI) (Phillip, Johnson, and Yezierski, 2014). Coupled with the emphasis on reformed teaching, Park et al. (2011) reported a strong correlation between RTOP scores and PCK scores on a PCK rubric assessing instruction, making the RTOP a valuable tool. However, Marshall, Smart, and Horton (2009) point out that the Likert scale used to quantify reformed teaching is effective at producing an overall sense of reformed teaching in the classroom, whereas the fine-grained evaluation of individual aspects is not as strong. This led to the development of the EQUIP, which uses a rubric designed for examining the fine-grained aspects of inquiry based teaching. Finally, one of the major aspects of chemistry content that makes it unique from other disciplines is the use and connections between the symbolic, macroscopic, and particulate domains through the use of representations (Johnstone, 2000). The RICI used the same scale and rubric style as the EQUIP, but focuses on the use of representations in the chemistry classroom. More specifically, it examines who is using the representations, what kinds of representations are being used, and the way in which they are used (Phillip, Johnson, and Yezierski, 2014). Representations are crucial for learning chemistry, and their use in the classroom has been reported as an important part of PCK (Schmelzing et al., 2013).

The RTOP contains three subsections: *Lesson design and implementation, content, and classroom culture*. Multiple items describing lesson and instructional features comprise each section and are scored on a on a 5-point scale (0=never occurred to 4=very descriptive). *Lesson design and implementation* contains five items and measures the extent to which student ideas are taken into account and students are able to make autonomous decisions that determine the direction of an investigation. *Content* contains ten items, divided in half by chemistry content.
and its real world and cross-curricular connections and the processes and procedures the students employed in the classroom (making predictions, using manipulatives, reflecting on learning, etc.). The last subsection, classroom culture, also has ten items divided equally. The two subscales in this subsection focus on the extent to which communication is done between students, the teacher, and the whole class, and the extent to which the teacher played the role of a guide and a listener, as opposed to a director (Sawada et al., 2002). Additionally, Maclsacc and Falconer (2002) linked total RTOP score ranges with various types of lessons relating to high school and college instruction.

To use the RTOP, all scorers were trained and normed by the online RTOP workshop, which provides sample lessons to score and expert scores to compare and norm to (Piburn et al., 2000). All participating researchers scored the observations separately and then negotiated scores on individual items until a consensus was reached. For the RTOP, consensus meant that all subscores and the total score were within three points. This threshold was chosen because the RTOP item scales do not offer specific descriptions for each possible choice; therefore, some variability is retained when negotiating scores.

EQUIP is broken into 8 sections, which include demographics, time use analysis, and the various sections used to score the level of inquiry observed in a lesson. For the purposes of this study rubrics associated with sections 4-7 of the EQUIP were used to evaluate the level of inquiry used in a lesson. Each section includes constructs that comprised a specific part of inquiry instruction. The constructs are evaluated on a 1-4 scale using a rubric with specific descriptors of each level. The four levels are: pre-inquiry (level 1), developing inquiry (level 2), proficient inquiry (level 3), and exemplary inquiry (level 4). One advantage of this instrument is the ability to assign a plus and minus scale to the various levels. For example, if two lessons (lesson A and B) receive a 2 for a particular construct, but lesson A was on the verge of being a 3, that lesson can receive a 2+ to represent that it was on the upper end of that level. This is a distinct advantage because it helps researchers, evaluators, and teachers produce a fine-grained evaluation of a lesson (Marshall, Smart, & Horton, 2009). The four sections for the EQUIP are: Instructional factors, discourse factors, assessment factors, and curriculum factors. Instructional factors assesses the role of the teacher and student and the level of conceptual understanding and thinking being promoted by the lesson. Discourse factors examines the questioning and discourse seen in the lesson. That includes the extent to which questions were open-ended, the
purpose for asking questions, and the complexity of questions and discussion. *Assessment factors* includes constructs about who is using the assessment, the purpose for the assessment, and the type of information being assessed. Lastly, *curriculum factors* assesses the depth of the content, its integration into an investigation, and the role of the student in that investigation (Marshall, Smart, & Horton, 2009).

Scoring EQUIP used the same process as the RTOP, except all scores are agreed upon after negotiation. Scorers were trained through the online EQUIP training module (Marsh 2015).

The RICI assesses the use of representations in the classroom through four indicators: *User description, conceptual understanding, quality of discourse around representations, and integration of macroscopic, symbolic, and particulate concepts*. Influenced by EQUIP, RICI employs the same scale and levels for each indicator. The *user description* levels differentiate who is using the representations and the extent of the representations use. *Conceptual understanding* relied on what types of representations (macroscopic, symbolic, or particulate) were used and how they helped develop conceptual understanding. *Quality of discourse around representations* evaluates the student-centeredness of the discourse and whether or not limitations to the representations were discussed. Finally, *integration of macroscopic, symbolic, and particulate concepts* indicates the extent to which the different types of representations were connected in a lesson (Phillip, Johnson, and Yezierski, 2014). There is no formal training for the RICI and scoring went through the same process as EQUIP.

**IV. Data Handling, Reduction, and Analysis**

**A. Data Handling and Analysis**

During the pilot study, data were stored and analyzed in NVivo (QSR International, 2014). The aims of the pilot study were to examine the extent to which PEER could elucidate a teacher’s PCK as well as examine the extent to which VIdEOs could improve the completeness of the PCK characterization. The author read through the interviews and reflections multiple times before taking an open coding approach for the analysis. The analysis focused on determining themes for that teacher as well as alignment among the indicators and the CoRes categories (student difficulties, main concepts, misconceptions, etc.). Following the creation of a code, a definition was written and inter-rater agreement between two researchers was assessed.
from a subset of each transcript. Each researcher completed coding individually, and if the code definitions did not produce 75% agreement, revisions were made until agreement was reached. After each teacher’s data sources were individually coded, trends observed across the teachers were coded. This process provided a new coding lens and trends among this group of teachers emerged as a result.

Dedoose (SocioCultural Research Consultants, 2014) served as the data handling software for the main study. The aims of the main study were to characterize chemical bonding PCK. With that, data analysis was completed through the theoretical lens of the PCK components. Transcripts of the interviews and reflections were coded using the synthesized PCK component definitions (Appendix L). For example, if a teacher mentioned an assessment they did or were going to use in their lesson, it would be coded as assessment and instructional strategies. This approach was implemented to help characterize the PCK of each teacher and the overall features of chemical bonding PCK seen in this sample.

Observation protocols were analyzed in the same way during the pilot study and main study. Each instructional video was viewed and scored by the scorers independently. Scorers came together and negotiated the scores until a consensus was reached. For the RTOP, consensus was within three points on each subscale and in the total score, and for the EQUIP and RICI it was complete agreement across scorers. After scoring was completed, items on each protocol were coded based on their content and the coding scheme used (pilot study vs. main study).

B. Data Reduction

With the immense amount of data that needed to be analyzed, an efficient way to enhance and expedite the data analysis process was needed. After the conclusion of the pilot study a data reduction method was developed (Appendix K). This data reduction method took each item across the CoRes interview and the three-observation protocol and sought to place them into a PCK component. For the observation protocols, this allowed for data to immediately be coded and sorted once it was collected. In the case of the interview, the data reduction method provided guidance for the coding, but not a direct coding scheme. This is due to the complexity and richness of interviews and the semi-structured nature of the interview protocol.

This data reduction method was developed through a series of inter-rater reliability meetings. The author and advisor would examine a subset of items and code them by component. The major difficulty in the development of the data reduction method was differentiating among
items, which were explicitly related to a component versus what could be inferred by the item. For example, one item on the EQUIP included the possibility to be a part of multiple components depending on which qualifier most closely described the teaching. It was decided that the mapping should only map onto what was explicitly being measured in relation to the teacher’s own PCK. If an activity had students assessing their own work, for example, that was be considered an instructional strategy and not assessment, because students self-assessing does not provide information about the teacher’s assessment PCK. Two rounds of revision were conducted and agreement was reached during the third IRR session (Table 1).

**Table 1: Inter-Rater Reliability**

<table>
<thead>
<tr>
<th>IRR 1</th>
<th>IRR 2</th>
<th>IRR 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>19/32 (59%)</td>
<td>8/14 (57%)</td>
<td>24/30 (80%)</td>
</tr>
</tbody>
</table>
Chapter Four: Results and Discussion

I. Synthesizing a Model for PCK Analysis

A. Synthesizing the Smith and Yezierski Model

The Smith and Yezierski PCK model (Figure 3) is a synthesis of PCK models found in the literature and based on PCK theory (Grossman, 1990; Magnusson, Krajcik, & Borko, 1999; Park & Oliver, 2008; Rollnick, et al., 2013). This model places PCK in the center of the other three knowledge domains—subject matter knowledge, pedagogical knowledge, and knowledge of context—discussed earlier to express the synthesis and influences of all knowledge domains on the transformation of knowledge to instruction. The model employs the five PCK components commonly defined, as well as the sixth (Teacher Efficacy) found in Park and Oliver’s (2008) work. Due to the debate around PCK components, the authors synthesized and revised the definitions based on PCK theory for the purposes of data analysis in the main study (Grossman, 1990; Magnusson, Krajcik, & Borko, 1999; Park & Oliver, 2008) (Table 2).
Figure 3: The Smith and Yezierski PCK Model

At the center of the Smith and Yezierski model are the measurable indicators, which guide how PCK is observed and documented. For the purposes of simplifying the names of the measurable indicators, the authors shortened each indicator into a single word that best represented each indicator: *explication* for declarative PCK; *enactment* for procedural PCK; and *reflection* for conditional PCK. Enactment is the center of the measurable indicators, where knowledge and reflection overlap. Alexander, Schallert, and Hare (1991) claim that conceptual and metacognitive knowledge are explicitly stated and can only be brought forth after being activated and filtered through social contexts. This leaves a vast majority of knowledge as tacit, or subconsciously understood. If this is the case, capturing the manifestation of this subconscious knowledge could be completed through teachers’ classroom instruction, called enactment in the
model. This places enactment as the center of capturing PCK, while also representing how knowledge and reflection actively influence enactment and vice versa.

B. Synthesizing PCK Components

In order to synthesize PCK component definitions, the author created a spreadsheet containing the definitions for each component from Grossman (1990), Magnusson, Krajcik, and Borko (1999), and Park and Oliver (2008). These articles were chosen due how often they were cited and their influence to the Smith and Yezierski PCK model. The original definition created by the author was also included. Definitions were revised by looking across each definition and emphasizing the common attributes, while ensuring the components did not overlap too much. For example, chemistry curriculum was expanded to state that this component was about what was taught and not how it was taught. Without this statement, differentiating between curriculum and instructional strategies would have been difficult.

Table 2: PCK Component Definitions

<table>
<thead>
<tr>
<th>PCK Component</th>
<th>Working Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Assessment of Chemistry Learning</td>
<td>The ways a teacher captures and documents student learning throughout a lesson or unit. This involves knowledge of what is important to assess, methods by which assessment can be done, advantages and disadvantages to the assessment being used, and the appropriate time to assess.</td>
</tr>
<tr>
<td>Chemistry Curriculum</td>
<td>The coarse-grained knowledge of curricular programs and materials, vertical alignment, and horizontal alignment. Curriculum includes the tension between breadth and depth of content, the ability to modify activities, what counts as a core idea, skill, or concept needing treatment in the classroom, and what is peripheral to the core concepts. Horizontal</td>
</tr>
<tr>
<td><strong>Alignment</strong></td>
<td>alignment is the knowledge of what is taught in a specific topic at a grade level, while vertical alignment is the knowledge of what has been taught and will be taught in the future. Assessment and instructional strategies are excluded from this component; this is what is taught, not how it is taught.</td>
</tr>
<tr>
<td><strong>Instructional Strategies in Chemistry</strong></td>
<td>Knowledge of general strategies for teaching as well as topic-specific strategies and when/what strategies will be most effective for student learning. General strategies include: learning cycles, eliciting pre-conceptions, debate, inquiry based activities, discussion, etc. Topic-specific strategies include: labs, demonstrations, simulations, representations, and activities. Representations include: illustrations, examples, models, and analogies. While instructional decisions are made based on a teacher’s orientation, instructional strategies are what we see happening in the classroom, not the purposes behind it. Assessment should be included in this component as well.</td>
</tr>
<tr>
<td><strong>Orientations to Teaching Chemistry</strong></td>
<td>The interaction of teachers’ theories and beliefs about learning that influence their instructional decisions. A teacher’s orientation serves as the concept map for making decisions; it is the reason why a teacher makes instructional decisions and the purpose behind them. This component also includes the role of the student and teacher, the nature of science,</td>
</tr>
</tbody>
</table>
and what counts as understanding. Orientation can be organized as process, academic rigor didactic, conceptual change, activity-driven, discovery, project-based, inquiry, and guided inquiry (see table 2 in Magnusson et al.) based on the purpose of an instructional activity, not structure of the activity itself. Although Orientation influences instructional strategies and assessment, they are excluded from this component.

| Students’ Understanding of Chemistry | The teacher’s knowledge of their students’ needs, learning styles, motivations, abilities, prior knowledge (conceptions and schemas), misconceptions, and areas of difficulty. Fine-grained curricular knowledge is embedded in what students should know prior to developing an understanding of the material at hand. When prior knowledge is elicited, student understandings overlap assessment. |
| Teacher’s Chemistry Efficacy | The extent to which a teacher believes their teaching can affect student outcomes (outcome expectancy), and the teacher’s confidence in his or her teaching (self-efficacy beliefs). This plays a major role in a teacher’s orientation and deciding what instructional strategies to use in the classroom. |

C. The PEER Data Collection Method

As discussed in the methods, the PCK Explication, Enactment, Reflection Data Collection method was developed in alignment with the Smith and Yezierski PCK model synthesized from the literature. This was developed to ascertain data in order to triangulate themes, and collect
data using each measurable indicator; it was designed to produce a more complete picture of a teacher’s PCK.

![Diagram of PEER Data Collection Method]

**Figure 4: The PEER Data Collection Method**

The PEER data collection methods (Figure 4) collects data on teacher explication in stage one, through a semi-structured interview guided by Content Representations (CoRes) (Loughran, Berry, & Mulhall, 2006; Richards & Morse, 2007). Stage two and four provide data through the enactment measurable indicator. This is done through videotaping classroom instruction and analyzing it using three observational protocols: The Reformed Teaching Observation Protocol (RTOP) (Sawada et al., 2002), Electronic Quality of Inquiry Instruction (EQUIP) (Marshall, Smart, & Horton, 2009), and Representations in Chemistry Instruction (RICI) (Phillip, Johnson, and Yezierski, 2014). The third measurable indicator was elucidated through teachers’ guided narrations of their own classroom video.

**II. Pilot Study**

*Similarities Across Three High School Chemistry Teachers in a pilot study*

The purpose of the pilot study was to answer the following research questions:
1. To what extent does the PEER data collection method elicit and capture novel and complete data to characterize acid-base PCK across a small group of teachers?

2. How does the reflection stage (VIDEOS) of the PEER method generate unique acid-base PCK data as compared to data generated by the explication and enactment stages?

Data analysis of the pilot study revealed several crosscutting themes, and an overall description of each teacher’s lesson. The two themes at the center of this manuscript were chosen because they include a wide range of PCK components. The similarities among the teachers emerged from data generated by the explication and enactment stages of the PEER method and addresses research question 1: To what extent does the PEER data collection method elicit and capture novel and complete data to characterize acid-base PCK across a small group of teachers? The reflection stage yielded some data that supported the data from the other stages while also generating unique features of individual teachers’ PCK. As such, findings from the reflection stage will be discussed in the second results and discussion section addressing research question 2. The following two themes emerged across all three teachers: (1) School structure produces learning limitations and (2) Student motivation and intelligence guide instruction. These themes highlight how the PEER method elucidated PCK features common across teachers. These themes are aligned with the Smith & Yezierski model synthesized from the literature, particularly “Knowledge of Context.” Although the PEER model elicited a large number of PCK components, common components observed across teachers were students’ understanding of chemistry and instructional strategies. The observation protocols provided a comprehensive view of their enactment and clarified instructional strategies discussed during the interview. The similarity in scores highlights the challenge in obtaining valid PCK descriptions based solely on teacher reports. From those scores, we can determine the extent to which lessons are student-centered, inquiry-based, and use chemical representations.

The theme school structure produces learning limitations, describes varying aspects of school, such as class length, time of the year, and available resources, and how they limit student learning outcomes. The most prevalent and emphasized limitation was time. Time relates not only to the time of the year data was collected at the end of the school year, but also how much time was allocated for each class and for the school year in general. When discussing how a new curriculum is affecting her teaching, Amy cites that the biggest problem is not the amount of material, but rather the amount of time she has to teach it.
It’s a year-long course, but our classes are only 48 minutes, so I don’t even have a full fifty minutes… We used to be on blocks where we had an hour and a half where I could spend thirty minutes, like, ‘ok here’s the introduction material you need to know here’s you know kind of what you’re going to be doing lets go to it,’ and have like a full hour to do the lab. Or you know do it the day before and have a full hour and a half to do a lab. I don’t have that time that we used to, but the class would only be a semester if we were on blocks so… I feel like it’s a little more choppy with only having forty eight minutes… Sometimes it works and sometimes it doesn’t.

In this excerpt, Amy discusses the switch from a block schedule, which was more conducive for facilitating labs. She feels that moving to a schedule with 48 minutes makes teaching the content too choppy, and goes on to say that it does not always encourage learning and she will sometimes have to go over content again. In regards to time, Sophia makes the following remark, “bottom line is I don’t have time to get [the content] in. This is my last week of instruction.” Sophia was on a time crunch; she was teaching acids and bases during the last week of school and simply did not leave enough time left to meet her goals. Michonne is in a similar situation, but the reason the time crunch is a learning impediment is slightly different.

...the time of year because it’s the last day of instruction, is going to be an issue. I’ve tried to put a lot of material in a very short period of time because of the time constraints of the end of the year... they haven’t had as much time to process, like for stoich (stoichiometry)... it’s just a constant, really nice even pace. Everyday something new, where this I have been hitting them with a lot pretty fast. So they may not have what I call, “time to digest,” mull it around and actually get it in a place in their head where they’re comfortable with it so there’s gonna be a more a little bit more uncomfortable feeling about the concepts...

Michonne specifies that her students will not have enough time to work with and make sense of the material, which makes her time crunch a limitation to learning. Amy has a similar statement in her interview, claiming that her students also will not have enough time to “dedicate to follow up with their knowledge.”

Along with the time, there were other structural factors, such as equipment availability, that lead to learning limitations. Amy states that she will not be able to teach her students how to
do a titration because she does not have the equipment to do so. She decided that she would show them a simulation on the projector instead, which she would have to work because she only had one computer that could run simulations. Michonne also discusses not having the equipment to do a titration:

*Labs for this are short because, again, number one, lack of time; number two, equipment. Mr. C, who is our AP teacher, he’s got burettes for everybody and he’s got a bunch of them and he wouldn’t let me have them for my kids to run a titration... I’ve got what, twenty-eight kids in the first period and about twenty-four in the second period, so that would be, by pairs, twenty four burettes if you’re going to do a titration against a known standard and he would cringe you know? I think they’re like 75 dollars a piece or something... so there’s no hands on for them; that’s why I’m doing the demo.*

In this quote, Michonne discusses how Mr. C. does not want her students handling the expensive burettes, so she has to do a demo to teach her students about titrations. Overall, these quotes suggest that one major influence on instructional decisions and learning impediments is the structure of the school day/year as well as the available resources. Limited time and resources forces teachers to make bounded decisions on what to teach and how to teach it. A teacher could decide to allocate less time and resources to a topic based on how important they perceive it to be. Their choices indicate what a teacher thinks is valuable for the students to know, and what the teacher knows about instructional strategies. For this example, Michonne thinks that a demo will teach her students what they need to know about titrations, at this level in their education; they simply need an introduction so they are prepared for an in-depth look if they continue with their chemistry education. Her choice of a demo does provide this brief introduction.

The previous examples highlight how the knowledge base, “knowledge of context,” interacts with several components. While all deal with curriculum to an extent, the component *Instructional Strategies in Chemistry* was highlighted through the limitations to their methods, due to time constraints, and choice in teaching methods based on the available resources. *Orientations to Teaching Chemistry* also surfaced in Michonne’s example, when she discussed the idea that students needed more time to “mull [the information] around.”
The second theme, student motivation and intelligence guide instruction, describes how the teachers perceive their students’ abilities and approaches to chemistry, and how that affects learning and teaching. After discussing what content was difficult for students, Amy says this:

*Another thing is they aren’t very good at like graphing. So setting up the titration curve, they’re like whoa, wait. You know? Like its hard for them, they don’t understand what’s going on because they have a hard time graphing and that’s like one of the biggest things I’ve noticed with all the classes... more and more of them [go] through, they’re getting worse and worse and worse at graphing; they can’t read them or create them. So, that definitely does not help.*

Amy feels as though her students’ difficulty in creating and interpreting graphs hinders their understanding of titrations. In fact, her perception of her students’ abilities leads her to change her classroom instruction from what she has done in the past.

*Normally would have them teach this lesson... I’d break them into groups and have them each teach like a section of the chapter; they’d have to come up with notes you know follow up with a worksheet follow up with a lab you know do all the assessment and everything, but these guys aren't honestly at that point they can’t do that yet... For the past three years I’ve been able to have the kids teach it and this year there’s no way... they just can’t explain it very well, I mean, they could put something together, but it would be very awkward and have several gaps in it that I would be filling in with and they I don’t know that they would necessarily walk away with the same experience that my previous chemistry classes did because they just they really just aren’t as sharp... not as chemistry inclined as I’ve had in the past.*

While Amy is changing her instruction based on how she perceives her students, she also feels as though this group of students, overall, is not as good at chemistry as in past years. This quote highlights that this is a major concern of hers and that she has to alter her teaching because of her students’ abilities. Amy wasn’t the only one who cited student abilities as a factor in learning and lesson planning; Michonne has identified what class she feels has more motivation and a higher ability to succeed. “…my second period class is the one that’s better. They’re younger, there are a lot of freshmen in this class and they’re just smart and they’re good kids and they work hard and that’s the ones I wanted you to come to see, because they will actually try
tomorrow. First period, there’s juniors in there and they [don’t care] they’re just done.”

Michonne discusses the relationship she has noticed between year in school and motivation to learn; the older you get in high school, the less motivated you become. She continues on to say this:

_And the older ones, like my sophomores and especially my juniors, they... they don’t care... They just don’t have the drive that these younger smarter kids have. So the first period class I have sophomore/junior in my second period class I have freshmen/sophomores more freshmen laden and there’s also you know they kind of know each other because they came from three different little feeder schools coming in so they kind of know each other and there’s a little edge of competitiveness, but yet camaraderie between them that they lose as they get older. It’s like its more of a societal thing... they come in, they’re young, they still can be touchy feely you... then they get to be like a junior and it’s like don’t touch me, don’t talk to me, you know what I mean?_

Michonne further describes her students’ motivation towards learning. She thinks as though her students are enculturated into an apathetic mentality, which leads to lower learning gains because students are not motivated to learn and do not want to help each other through the learning process. Sophia also discusses her students’ abilities and simply claims “they’re just not thinkers,” when discussing her students’ difficulties in differentiating hydronium and hydroxide. This theme suggests that these teachers not only consider what their students can do, but also adjust their own practice and expectations based on how they perceive their students. These examples again focus on the relationship between “Knowledge of Context” and multiple PCK components. _Instructional Strategies in Chemistry and Students’ Understanding of Chemistry_ are explicit throughout the quotes. This exemplifies how teachers’ perceptions of their students’ abilities and motivations drives their pedagogical choices. This is also an important influence on the teachers’ outcome expectancy (part of _Self-Efficacy_).

In summary, common themes emerged from the pre-instruction interviews; the themes _school structure produces learning limitations_ and _student motivation and intelligence guide instruction_ describe the participants’ perceptions of their students’ motivation and ability as well as how time and equipment affect teaching, learning, and outcome expectancies.

B. Describing Classroom Instruction
The previous themes came from the *explication* measurable indicator. Enactment provided comprehensive PCK descriptions that were independent of the teachers’ explications. Table 3 presents the results from each subsection of the three observation protocols.

**Table 3: Observation Protocol Scores by Teacher**

<table>
<thead>
<tr>
<th>Protocol</th>
<th>Subscale (Max score)</th>
<th>Amy</th>
<th>Michonne</th>
<th>Sophia</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>RTOP</strong></td>
<td>Lesson Design and Implementation (20)</td>
<td>14</td>
<td>6</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Content (40)</td>
<td>23</td>
<td>16</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>Classroom Culture (40)</td>
<td>20</td>
<td>11</td>
<td>6</td>
</tr>
<tr>
<td><strong>EQUIP</strong></td>
<td>Instructional Factors (4)</td>
<td>2</td>
<td>1+</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Discourse Factors (4)</td>
<td>2</td>
<td>1+</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Assessment Factors (4)</td>
<td>1+</td>
<td>1+</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Curriculum Factors (4)</td>
<td>1+</td>
<td>1+</td>
<td>1</td>
</tr>
<tr>
<td><strong>RICI</strong></td>
<td>User Description (4)</td>
<td>2</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Conceptual Understanding (4)</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Quality Around Discourse (4)</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Integration of Macroscopic, Symbolic, and Particulate Concepts (4)</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>

The RTOP scores can tell us information about design, content, and the classroom environment. Additionally, the total scores are indicative of particular types of lessons relating to high school and college instruction (Table 4) (MacIsacc & Falconer, 2002). The table in MacIsacc and Falconer (2002) can be seen below.
### Table 4: Total RTOP Score and Type of Classroom Instruction

<table>
<thead>
<tr>
<th>Type of Classroom Pedagogy</th>
<th>RTOP Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traditional university lecture (Passive)</td>
<td>&lt; 20</td>
</tr>
<tr>
<td>University lecture with demonstrations (some student participation)</td>
<td>&lt; 30</td>
</tr>
<tr>
<td>Traditional high school physics lecture (with student questions)</td>
<td>&lt; 45</td>
</tr>
<tr>
<td>Partial high school reform (some group work; most discourse still with teacher)</td>
<td>&lt; 55</td>
</tr>
<tr>
<td>Medium sized (100 &gt; n &gt; 50) university lectures with Mazur-like group work (ConcepTests) and a student personal response system</td>
<td>65–75</td>
</tr>
<tr>
<td>The author’s modified (whiteboards, etc.) large (170 &gt; n &gt; 75) lectures</td>
<td>70–75</td>
</tr>
<tr>
<td>Modeling curriculum (varies with amount and quality of discourse)</td>
<td>65–99</td>
</tr>
</tbody>
</table>

Amy had a total score of 57, which, according to MacIsacc and Falconer’s (2002) scale, is a classroom with some reform and group work. This is in agreement with what was seen in the classroom observation. Students conducted a short lab, where they made predictions and used pH test paper to find the pH of household items. While this is not as reformed as other lessons with the same score, the predictions and use of manipulatives and household items markedly increased the score on the content section of the RTOP. Michonne’s RTOP of 33 came from a lesson on which she reviewed homework, conducted a titration demo with a student’s help, facilitated a few practice problems on determining the molarity of an unknown solution, and assigned homework. According to MacIsacc & Falconer (2002), a score of 33 was between a college lecture with a demo and a high school lecture including student questions. While Michonne and Sophia had similar scores on lesson design and content, the extra interactivity that Michonne included when facilitating practice problems as a class resulted in her higher score.
Sophia had a lecture about the differences between acids and bases using the Bronsted-Lowry acid-base theory. She received a 23, which was about the same as a typical, passive university lecture (MacIsacc & Falconer, 2002).

While the RTOP helps us differentiate and describe the overall lessons and the level of reform, the EQUIP and RICI provide a fine-grained description of the amount of inquiry present and the use of representations. Overall, all three teachers ranged from pre-inquiry (level 1) to developing inquiry (level 2), which is about half of the magnitude of the EQUIP and RICI scales. However, a three is consistent with “proficient inquiry” which means that three out of four is an acceptable target for quality lessons. While the RTOP score for Amy was elevated due to the use of manipulatives and everyday materials, she only received a 2 for instructional design and discourse, which means the lesson and communications were still teacher driven, but the students did have a stronger role than in a lecture. This also tells us that Amy did act somewhat as a facilitator, as opposed to being at the center of the activity. A score of one represents a teacher-centered lesson where the teacher delivers information, as well as teacher-directed and initiated interaction between the students. While students in Michonne and Sophia’s class did go beyond a mastery of facts, their classrooms were still teacher-centered and focused mostly on facts and process skills. Pre-assessments and reflections are two of the constructs listed in the assessment section. Sophia’s instruction included a pre-assessment that did not influence her subsequent teaching and a reflective assignment asking students to rate what they knew about acids and bases. This gave her a score of 2, while Amy and Michonne remained at a 1 due to a lack of classroom assessments executed during the lesson. Lastly, all three teachers scored in the 1 range for curriculum factors. The lessons either were exclusively content focused or lacked integration into an activity and did not contain conceptual content. Sophia and Michonne’s lessons also lacked investigation. This could be a result of the lack of time mentioned in the crosscutting themes above. Carrying out investigations in the classroom require teacher preparation as well as ample class time.

Aside from a score of one that Sophia received for user description, all three teachers received a score of 2 on all of the RICI indicators. This indicates that representations used in the classroom were controlled, directed, and explained by the teacher, but there was some student usage of the representations. For example, Michonne provides her students with chemical formulas (symbolic) and explains what is occurring during her titration demonstration.
(macroscopic) and has the students use provided formulas to solve problems. Representations included the symbolic and macroscopic domains, but those domains were not explicitly connected in the lesson.

In summary, the observation protocols show that even with seemingly different instructional plans, as described by teachers in the explication phase, the enactment across teachers was similar and was teacher-centered for all three.

**C. Reflection: Highlighting Distinctive in Sophia’s PCK**

Even when contrasting Amy and Sophia’s classroom (pH lab versus lecture), there was no major difference in the level of inquiry used or how representations were being used in the classroom. The explication phase data supports the enactment phase data. When the teachers were discussing their teaching and what was going to happen during the lesson, all three teachers tended to focus on what they would be doing, as opposed to what the students would be doing. Here is a quote from Sophia:

> I’ll talk to them and I’ll say remember a salt is anything that is a metal and a non-metal... I’ll give them a couple visuals which they have access to, I’ll give them a couple visuals of other reactions umm one is sodium acetate... which is a salt. A couple examples I give... just to remind them, you’re always going to get water and always going to get a salt, and I’ll have to remind them [what] a salt is and I’ll have them write it down.

Like Sophia’s classroom described in her words above, most of the representations and content were explained and directed by the teacher. The novel acid-base PCK descriptions generated from the explication and enactment stages of the PEER method demonstrate how common PCK elements across teachers can be identified and characterized. Furthermore, PCK characterizations benefit from the teachers’ voices (explication) and the inputs of the observer (enactment; observation protocols), as having both yields a more complete description.

While these results paint a picture of homogeneity, one measurable indicator has not yet been discussed – reflection. Although many observable features of the teachers’ classrooms were similar, data from the reflections demonstrate unique aspects of the teachers’ PCK, thus addressing research question 2: How does the reflection stage (VIdEoS) of the PEER method generate unique acid-base PCK data as compared to data generated by the elicitation and enactment stages? For brevity, Sophia will be the focus of the following data analysis that shows
how the reflection produces novel PCK aspects as compared to the other measurable indicators. What follows are unique aspects of Sophia’s PCK using all three measurable indicators.

While reflection does contribute information to overall themes, it was more useful for triangulating the unique within each individual teacher. The following two quotes from Sophia and Michonne highlight some similarities between the two teachers, but also what makes part of their PCK unique.

Michonne: *I like the way I moved out of the way, finally, and let the students come up and start participating in this. Like I said last day of class last day of the year a little harder to do. Typically, this is what I do a little bit more of.*

Sophia: *I want to give kids real life examples to tie it in to help with this explanation… my idea was that this would lead into a discussion of concentration and pH but I also think I got off my learning target, and sometimes I’m just not very concise when I speak, as you are experiencing now.*

In the previous two examples, each teacher provided a critique of themselves, and how they could have improved. Michonne states that she is glad she finally moved out from in front of the board so her students could practice problems. She then states that her students being more active in the learning is the norm for her class. Sophia focuses on how she wanted her classroom instruction to end: a discussion of concentration and pH. She states that she did not reach that point because she was not concise when speaking. While both of these teachers focus on what they were doing as opposed to what their students were doing, perhaps because of their teacher centered instruction, Michonne wishes she would have made it more student-centered, while Sophia wanted to deliver content in a more concise way. This is representative of their reflections and interviews, and provides data to triangulate their goals and approaches to teaching. Without the reflection, one could conclude that the teachers spoke about student-centered instruction and taught in a teacher-centered way. As the previous example demonstrated, when the reflection is added, fine-grained details are revealed that differentiate the teachers from one another. The following text focuses on Sophia’s reflection and how that measureable indicator and how it highlights the distinctive features between teachers.
Sophia was chosen to highlight because her reflection clearly demonstrates how we can triangulate themes that only arise in the interview, instruction, or both. Table 5 includes quotations from Sophia, organized by categories, as well as from the measurable indicator from which they originated. The data presented exemplifies four categories: two are related to content errors this teacher holds (fixed pH and dissolve vs. dissociate), one criterion the teachers uses to measure student achievement (student assessment), and an approach to teaching that is specific for (fears about acids and bases).

The fixed pH category first appeared during instruction, when the teacher told the students that a strong and weak acid were defined by their pH. The teacher extends this to bases as well, stating that bases with a pH of 11-14 are considered strong bases. This is reinforced in the teacher’s reflection, where she states why the discussion occurred, and that “pH doesn’t change, but concentration does,” resulting in the name of this category, “fixed pH.” The other notable misconception this teacher held was that the words dissolve and dissociate have the same meaning. The teacher explicitly says this in both the pre-instruction interview and during classroom instruction. In the teacher’s reflection, she notes that a student had a hard time saying dissociate and she had to help them. This is important because the observation was made at immediately after she had finished explaining that dissociation and dissolution were the same. This reinforces the content error, because she explicitly chose to describe that instance and did not mention the content being incorrect after having some time to reflect. Fixed pH and dissolve vs. dissociate also highlight how the PEER method can elicit knowledge from the “Subject Matter Knowledge,” knowledge base, and subsequently, the component Chemistry Curriculum.

The two other categories relate to assessment in the classroom and a topic-specific goal this teacher has for acid-base chemistry. A major aspect of assessment for this teacher, aside from test scores, is student self-assessments. These assessments involve students rating themselves on a 0-5 scale on how much they know about a chemistry topic before instruction and after the summative assessment. The teacher mentions this assessment method in the pre-instruction interview, has the students self-assess during the classroom observation, and then discusses the self-assessments again during the reflection. Because the self-assessments were the only measure of student content gains discussed, the importance of the self-assessments to the teacher is emphasized in the reflection. Although the quality of data generated by this assessment is questionable, we are at least able to learn that it is valued by the teacher. The last category
highlights an inconsistency in planning, teaching, and reflection. In her planning, the teacher states that a major goal for acid-base instruction is to make sure her students are not afraid of acids and bases. However, this goal is brought into question when she tells a story of a professor who pours a sodium hydroxide solution into a hydrochloric acid solution, then drinks the new solution, thinking he has neutralized the acid. She tells the students the enamel was stripped off of the professor’s teeth, and then expands this by telling her students that acid-base reactions “produce a lot of bubbles… splashing… heat… and blindness.” The quote from her reflection is in reference to the story of the professor drinking the solution, as well as the reasons for telling the story and emphasizing the dangers of acids and bases. These two categories relate to the components *Assessment of Chemistry Learning* and *Orientation to teaching Chemistry*, respectively. While assessment is more explicit, Sophia’s reasons for teaching chemistry (orientation), although inconsistent, are revealed through the three measureable indicators. In her case, she states that she wants students to not be afraid of acids and bases, but then, as the reflection shows, also wants them to be safe with acids and bases.

In the previous examples, the major categories for Sophia would have been incomplete or missing if all three measurable indicators, including a reflection while viewing her own classroom instruction, would not have been present. The content error, *fixed pH*, would not have been detected with just the interview; this content error was revealed during instruction and reinforced by the reflection. This content error would have been left unsupported had the reflection was not present. Without reflection, making a strong argument that a content error existed would have been lackluster, as the classroom statement could be explained as misspeak. The content error “dissolve vs. dissociate,” demonstrates that the reflection indicator can act as a support for a claim about PCK or PCK gaps, while *student assessment*, highlights how the reflection can capture what teachers value the most, so that researchers can weight PCK components appropriately. In the case of *student assessment*, Sophia stated she was going to have the students complete a self-assessment and then having them do it in class does not highlight the significance of this act to the teacher. Instead, the importance is made explicit in the reflection when the teacher uses the data from the self-assessment, over summative test scores, to make conclusions about student learning. Finally, *fears about acids and bases* revealed a discrepancy in findings between explication and enactment. While these competing data points
do not allow us to draw a conclusion about her goals in addressing acids and bases in instruction, the reflection does provide a rationale for emphasizing the dangers, grounded in lab safety.

Table 5: Sophia's Categories and Quotes

<table>
<thead>
<tr>
<th>Measurable Indicator</th>
<th>Fixed pH</th>
<th>Dissolve vs. Dissociate</th>
<th>Student Assessment</th>
<th>Fears about Acids and Bases</th>
</tr>
</thead>
<tbody>
<tr>
<td>Explication</td>
<td></td>
<td>“…basically, when an acid dissolves it produces a hydronium ion, bases dissolve or dissociate they are hydroxide ions.”</td>
<td>“I’ll have them rate themselves on that um tomorrow at the very beginning and then I’ll have them basically rate themselves again when I’m done.”</td>
<td>“It makes, for me I try to make it as practical and useful as possible. I want them to like it so they’re not afraid of it.”</td>
</tr>
<tr>
<td></td>
<td></td>
<td>“A weak acid is a 6, a 5, or a 4. A strong acid is a 0, 1, 2, or 3. That’s the difference, this doesn’t have anything to do with concentration, concentration is how much water did you mix with it.”</td>
<td>“I asked them to rate themselves from zero to four; zero being I don’t know anything and four being I know everything and then before I gave a test I asked them to rate themselves on the learning target again.”</td>
<td>“So if you pour an acid and base together, you get a really crazy violent reaction; produces a lot of bubbles, a lot of splashing, a lot of heat, and a lot of blindness, because it gets in people’s eye and kills them [the eyes].”</td>
</tr>
</tbody>
</table>
The previous examples highlight the importance of including three measurable indicators as well as the diverse data that can be collected using the PEER method. Drechsler and Van Driel conducted a study investigating experienced secondary teachers’ acid-base PCK. Their study employed semi-structured interviews seeking to discuss the teachers’ lesson planning, the textbook use, their knowledge of student difficulties, and how the teachers satisfaction of their acid-base instruction has changed over the previous ten years of their career (2007). The study was able to collect data regarding the teachers’ content knowledge on acid-base models, student difficulties, how student difficulties and the content influenced lesson planning, and the depth to which teachers stated they taught. While their interview protocol was able to solicit information that touches upon multiple PCK components, data concerning student assessment, teacher self-efficacy, and motivations for teaching with a particular method, aside from student difficulties, were not reported. Furthermore, classroom practices, a major aspect of PCK, were not observed.

D. Prior Acid-Base PCK Research

Reflection

“…the reason I went into acids tasting sour is… pH doesn't change, but the concentration does and to explain the difference between strong and weak pH, but also pH and concentration, which is a huge problems students and even adult have is the difference between concentration and pH.”

“A student asked me umm to re-say the word dissociate. Umm that’s not a familiar word to most students. In fact, I usually say it dis-uh-sociate, umm so that took a minute or two.”

"Most of them upped their understanding umm two to three points, versus at first they might have marked themselves as a understanding of zero or one and then before the test at a three or four."

“I like to tell it to my students just to emphasize the point that you know balancing an equation matters, acids and bases can be very, very dangerous, and, of course, safety; you never, never, never drink your reactions umm in a chemical lab.”

D. Prior Acid-Base PCK Research

The previous examples highlight the importance of including three measurable indicators as well as the diverse data that can be collected using the PEER method. Drechsler and Van Driel conducted a study investigating experienced secondary teachers’ acid-base PCK. Their study employed semi-structured interviews seeking to discuss the teachers’ lesson planning, the textbook use, their knowledge of student difficulties, and how the teachers satisfaction of their acid-base instruction has changed over the previous ten years of their career (2007). The study was able to collect data regarding the teachers’ content knowledge on acid-base models, student difficulties, how student difficulties and the content influenced lesson planning, and the depth to which teachers stated they taught. While their interview protocol was able to solicit information that touches upon multiple PCK components, data concerning student assessment, teacher self-efficacy, and motivations for teaching with a particular method, aside from student difficulties, were not reported. Furthermore, classroom practices, a major aspect of PCK, were not observed.
(Drechsler & Van Driel, 2007). While their data was sufficient to answer their research questions, the purposes of our study would not be fully served using their method.

III. Main Study

A. Main Study Purpose

The main study did not differ in design from the pilot study, but did serve a different purpose. The goal of the main study was to answer research questions three and four:

3. What novel findings can the PEER data collection method generate for chemical bonding PCK?

4. How can the PEER data collection method characterize chemical bonding PCK?

Data analysis from the main study employed an analytic lens based on the Smith and Yezierski model. Analysis focused on the PCK components and how they were being employed in various teaching situations. Two examples are how the teachers set goals and decide on what content to teach, and what teaching methods were chosen.

B. Main Study Participants

The main study included five high school chemistry teachers covering topics ranging from Valence Shell Electron Pair Repulsion theory to Lewis dot structures. Table 6 highlights each teacher, the topic of the lesson being analyzed, what instruction method they used, and any assignments given to the students. Each classroom was a general high school chemistry class aside from Doug, who was teaching Advanced Placement Chemistry. Linda’s class was learning how to draw Lewis Dot Structures, which was taught through a short video covering how chemical reactions create new substances, a lecture on Lewis dot structures, then practice problems. The practice problems were completed in class and Linda provided an answer key so students could check their answers. Gavin wanted to teach his students the difference between ionic and covalent compounds though a lecture. This lecture included several demonstrations focused on
<table>
<thead>
<tr>
<th>Teacher</th>
<th>Topic</th>
<th>Methods</th>
<th>Assignment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Linda</td>
<td>Lewis dot structures</td>
<td>Short video, lecture, notes</td>
<td>Practice worksheet</td>
</tr>
<tr>
<td>Gavin</td>
<td>Differences between ionic and covalent compounds</td>
<td>Lecture with multiple demonstrations, guided notes</td>
<td>Practice problems as a class</td>
</tr>
<tr>
<td>Doug</td>
<td>Valence shell electron pair repulsion theory</td>
<td>Model building and discussion</td>
<td>N/A</td>
</tr>
<tr>
<td>Janine</td>
<td>Identifying polar and non-polar substances</td>
<td>Lab using household materials</td>
<td>Lab questions</td>
</tr>
<tr>
<td>Don</td>
<td>Paramagnetic, diamagnetic, electron configurations, bonding</td>
<td>Lab putting various compounds near a magnet on a balance</td>
<td>Research, data analysis, lab questions</td>
</tr>
</tbody>
</table>

macroscopic properties, such as conductivity, of covalent and ionic compounds. Gavin then went through practice problems for his class. Doug was teaching the principles of VSEPR and molecular geometry. He decided to teach this topic by having students model various compounds with pipe cleaners and Styrofoam balls, and then leading a discussion on each one, focusing on why they observed various shapes and bond angles. Janine’s class conducted a lab, which
allowed them to observe various macroscopic properties of polar and non-polar compounds. This lab contained post-lab questions for the students to do following the completion of data collection. Lastly, Don was teaching his students about the continuum of intermolecular and intramolecular interactions through a lab on paramagnetic and diamagnetic compounds. This required students to conduct research, analyze data, and answer lab questions.

Just as in the pilot study, the observation protocols help us see nuances in instruction, even when general instructional methods are very similar. Table 7 contains the observation protocol data for each teacher in the main study. When comparing the RTOP scores, two groups arise. Don, Doug, and Janine have total scores ranging from 48 to 52; Gavin and Linda’s total scores were 30 and 35. The first group can be characterized as “partial high school reform,” which means instruction includes group work but the discussion and teaching of the content still lies with the teacher (MacIsacc & Falconer, 2002). Gavin and Linda’s teaching falls right in line with a traditional lecture style of teaching, which matches what was implemented in the classroom.

Every teacher fell in the “developing inquiry,” for their EQUIP scores except Gavin, who received a rating of “Pre-Inquiry.” Some examples of developing inquiry descriptors are “teacher asked students to explore concept before explanation. Teacher explained,” and “Communication was typically controlled and directed by teacher with occasional input from other students; mostly didactic pattern.”
<table>
<thead>
<tr>
<th>Observation Protocol</th>
<th>Teachers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Name</td>
<td>Subscale (Max score)</td>
</tr>
<tr>
<td>RTOP</td>
<td>Lesson Design and Implementation (20)</td>
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<td>Integration of Macroscopic, Symbolic, and Particulate Concepts (4)</td>
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This characterizes the instruction as somewhat student-centered, but with the data processing or the sense-making and the discourse originating from the teacher. Essentially, the teacher is acting as the knowledge provider, as opposed to the students developing the conceptions through data analysis or scaffolding. Doug, who received a 3 for his instructional factors, demonstrated an activity where a joint construction on meaning was developed between himself and his students; as one descriptor states: “Teacher occasionally lectured, but students were engaged in activities that helped develop conceptual understanding.” Lastly, Gavin’s instruction was completely
teacher-centered; Gavin lectured, controlled discourse, did not include any assessments or reflections, and included relatively shallow content.

The RICI revealed diverse uses of representations among the five teachers. Linda’s instruction focused on symbolic representations only and did not contain any discourse surrounding the representations. She did, however, have students using the representations and controlled the explanations. Janine and Don had very similar representation use in their classrooms. In both classrooms, “Students used teacher-provided representations frequently.” The teacher controlled discourse and how the representations were used to explain concepts, and while both included two types of representations (macroscopic and symbolic), Don’s lesson explicitly connected the two domains. Gavin connected the macroscopic and symbolic domain, but controlled the other aspects of representations in the class (explanation, connections, and how they were incorporated into the lesson). Doug had the highest scores on the RICI, because the “Lesson connected the particulate representational domain with at least one other domain (macro and/or symbolic),” and the students frequently used and translated one representational domain into another. This data demonstrated that even with similar levels of reform and inquiry in the classroom, representations can be incorporated in a variety of ways.

C. PCK Component Employment Lens: A Novel Look at Chemical Bonding Goals

Data Analysis from the main study revealed a wide range of bonding goals, instructional strategies, and influences on teaching decisions. The most novel aspect of this PCK study was found by analysis using the PCK components. The six component definitions can be found in Table 2. The six components are: Orientations to Teaching Chemistry, Chemistry Curriculum, Students’ Understanding of Chemistry, Instructional Strategies in Chemistry, Assessment of Chemistry Learning, and Teachers’ Chemistry Self-Efficacy. Using the PCK components as a lens allows us to characterize teaching decisions in light of the theory and research and make direct claims about PCK. Of particular interest are teachers bonding goals, which help guide their classroom instruction.

The goals teachers set for their chemistry classroom ranged from identifying polar and non-polar substances, all the way to being able to make macroscopic predictions based on symbolic or particulate representation. What is even more interesting is that the teachers are influenced by a variety of components when deciding on goals. In this quote, Gavin discusses how the community and parents have high academic expectations:
I think being in a small school, I mean it is a tight knit group of kids, it’s a tight community. It’s certainly umm it affects [my teaching], but like I said it’s so intertwined with just what I do. It’s more of just there’s high expectations from the community, there’s high expectations from the parents, and it is a small school... if I do a lesson that’s just amazing the rumors will spread and everyone will want to see it and I get that all the time.

In this quote, Gavin reflects on how the community sets high expectations and that he is held accountable to those standards. He wants his students to gain a high level of content knowledge, which means understanding the atomic level of chemistry and being relate and understand chemistry in an everyday context.

...one of my biggest goals as I teach chemistry is for it to not be so foreign to students, because for whatever reason when I talk to adults and just I think in pop culture in general, chemistry is the class that everyone in high school took and hated and didn’t understand and it just has that reputation... our culture’s fear of chemicals is not umm properly placed and yes there are chemicals that are hazardous and we have to handle them safely, but at the same time there’s almost a chemiphobia...

Gavin discusses how one of his major goals is to make chemistry relatable to his students so they can understand and, at minimum, tolerate the class. This goes hand in hand with changing his students’ view of chemistry from that of pop culture; he wants his students to walk away not being afraid of chemicals know that they can handle chemicals safely. In the next quote he discusses his overall content goals:

...it is hard to make chemistry visible. It’s not hard to make any science hands on, but it is hard to make chemistry visible to them, because even though there is a visible macroscopic reaction, what’s going on at the atomic level... it’s trying to make them grasp and understand that.

Gavin wants his students to be able to understand chemistry at the atomic level. The goals for his specific lesson boil down to know the difference between ionic and covalent compounds. In Gavin’s reflection, the influences on his goals can be triangulated:

If I could go back and refine my goals of my lesson, to be honest, I think application would play a bigger part there. From a chemistry standpoint,
yeah I want them to understand the concept, but form a real world standpoint, why does this matter? What's the application of it? And I saw that they lacked, maybe the ability to apply what they knew about ionic bonding.

This supports that Gavin wants his students to develop understanding of the content and his values about making chemistry relatable to the students (real world context). It also brings in the idea of application becoming a part of his goals based on what he saw in the classroom after viewing his own teaching.

Based on this information, a PCK components lens can be applied. With this lens, Gavin’s instruction is a combination of his values and beliefs about teaching (orientation to teaching chemistry), evidenced by wanting his students to find chemistry relatable and safe to handle, content (chemistry curriculum), and what the students are bringing into the classroom and the call from the community (students’ understanding of chemistry). The last component is supported by comments regarding how highly his students perform. What does not come up as an influence for his goals are the components assessment of chemistry learning, instructional strategies in chemistry, and his own teaching self-efficacy. Figure 5 helps us visualize what components are being employed through shading and highlighting the center of the Smith and Yezierski PCK model.

Figure 5: PCK Components Influencing Gavin's Bonding Goals
Figure 5 highlights the components that Gavin emphasizes in his goal setting, the components not emphasized, and measurable indicators used to triangulate these influences and goals. While we say these components are being employed, it is through the research lens, not the teacher’s identification of their own components. Component employment was used due to the relationship seen between the PCK framework and the data. This view offers a succinct overview of a teacher’s employed components that can be used for comparison across teachers.

As compared to Gavin, influences on Linda’s bonding goals stem mostly on the content and curriculum materials.

*Things I want to get across is that bonding creates a new substance with an entirely different set of properties... octet rule... the basics: two electrons in a single bond, you know you have to have the same number of valence electrons as you always had, those kinds of things... And then I’m forced to do some bond length bond energy thing, which is fine, but, I don’t really care about that one and that’s it for covalent bonding we do umm the geometry ands stuff in another chapter with this book.*

Linda focuses her goals on getting across the content knowledge that is required of her; she is very focused on the curriculum, although the extent to which she teaches it does depend on the connections it has with other content in the course. This is exemplified in her next quote, where she follows up on why she does not like bond order.

*It’s an excuse to get them to practice Lewis diagrams, because, there’s no, I mean, at the level their at there’s no further use for knowledge about bond order or bond length. It doesn’t come at the intermolecular forces at this level. It doesn’t really show up ever again, it’s just his isolated little topic that you know they’re going to forget about... I mean if it were connected to something it would be a lot more important, but it’s not.*

Linda goes on to say that she tries to spend as little time on bond order and bond length as possible because of the lack of connections for the students to make. For Linda, a lack of connections leads to a lack of understanding and retention, which is how orientations play a role in deciding what to teach and the depth for which it is taught. She also values the role her textbook plays in helping her decide how she teaches:
Oh gosh you started off with factors that affect my teaching the subject and I went to the book. I mean it's just how the book approaches the subject; you know especially since it’s I like the book. I don't usually like chemistry books, but since I like the book I try to compliment it so that when they’re reading the book it you know kind of reinforces what I’ve said, if they so read the book.

Linda places value in reinforcing what she has taught by using and complimenting her classes’ textbook, a curriculum resource. While this aligns with her approach in making sure there is alignment and connections being made with the content, she also states that she follows the book because “it makes them more comfortable than they I mean you hear from other classes they really hate bouncing around. They feel much more secure.” This shows that even with her content focus she values the affective domain of her students.

Overall, Linda’s bonding goals revolve around and are influenced by the content and curriculum. However, there are influences from her orientation (content needs to be connected) and what she knows about her students (they feel comfortable when following a text by chapter. There are also aspects about her students that are not taken into account; she states in her interview that her students’ prior knowledge does not affect her teaching, she “ignores it.” The depth of the content she teaches is also influenced by her view of understanding. When asked how she knows if her students understand the content, she states:

I would like for them to get one hundred percent of their Lewis diagrams correct, every time. Umm well you know maybe ninety percent. But, yeah, that’s when they can do that they’ll, I mean it’s not that bad just two little rules and the ability to count.

This quote is supported by a statement about another content goal, as well as in her reflection: “The procedures I use seem effective due to the quality and quantity of questions students were asking as well as the fact that students were on-task until the end of the period.” These two quotes demonstrate how her goals, although content focused, align with algorithmic aspects of bonding. Thus, being able to apply the algorithm, “get 100%,” demonstrates understanding as well as being on task.
Figure 6 represents Linda’s PCK component lens for her bonding goals.

![Figure 6: PCK Components Influencing Linda's Bonding Goals](image)

From the data we can see that she focuses heavily on the content, but the depth for which content is taught is influenced greatly by her view of understanding and her desire to have a connected, albeit algorithmic, classroom. While certain aspects of what her students bring into the classroom influence her goals and teaching— their comfort with following the book—their prior knowledge is not an influence. This presents a case where two components are highlighted and one is not. This represents the fact that the un-highlighted component does have an influence, but it is small in comparison to the other two.

Another content-focused teacher is Doug; however, his content goals are focused on developing a deeper level of understanding than Linda’s.

...we’re specifically covering VSERP models... the kids that I had the first time around have already been introduced when they first took it they already learned some shapes... but what we’re going to do is extend that and they’re going to assemble models of molecules that they think would reflect the shape and some of them are going to be very simple ones, tetrahedrons, and things that they’re going to be very familiar with and be able to do real quick. Others are going to be completely new and they’ll stumble and they really have to think about the principles involved in VSEPR.
Doug teaches AP chemistry and in this case, and since his students have some prior knowledge, he wants to extend that knowledge so they can understand the principles of valence shell electron pair repulsion theory. On a broader scale, he hopes after learning about bonding his students can: “see pretty much any formula and be able to make predictions about the behaviors of that formula… in the end you have to be able to see big picture behaviors and macroscopic predictions.” Doug is very conceptually driven. He states that his students must develop an understanding of the particulate level, and use this to make predictions about reactivity and macroscopic properties. Part of this is because he sees his own job as to teach students at the same level as a general chemistry course in college. When discussing why he teaches hybridized orbitals when it is not in the AP curriculum, he makes the following statement:

*I think it’s taught in the gen chem curriculum… well it is taught in the gen chem curriculum. I also think what it provides is the answer to the disconnect between if we stop with VSEPR and don’t get into hybridized orbitals, then we have to integrate VSEPR theory and 109.5 degree angles with atomic theory and 90 degree angles and you can’t do it. My kids will catch on to that, what you’re going to see are very very very high caliber students. They’re the best of the best at [School M], and [School M] is pretty good anyway. So they’re going to catch onto the fact when things don’t work and even if it’s not in the curriculum I need to address that*

Realizing that addressing orbital hybridization helps to explain molecular geometry, Doug decides to extend his curriculum to ensure his students gain a deeper understanding. He also states that he wants his students to “go beyond just memorizing shape names and memorizing orbitals,” and that they “have to wrestle with it” in order to retain it in the long run. He also knows his students well; they are very high performing and that they desire deeper content knowledge, so he decides to include content that goes beyond the curriculum. Doug is very content focused, and is influenced by how he views his role as the AP teacher (orientation)–to teach the content in the general chemistry curriculum–and by his knowledge of his students. While these beliefs are not triangulated in his reflection, his teaching does involve having students wrestle with content and discuss and explain why how VSEPR principles determine the molecular geometries they are modeling. This data yields the component lens in Figure 7.
Figure 7: Components Influencing Doug’s Bonding Goals

In this component lens we again see an emphasis on content, but with a smaller influence from students’ understanding of chemistry and orientation to teaching chemistry. When compared to Linda, who also emphasizes content, it is evident that a content focus does not equate to the depth of content knowledge, only that content, whatever the depth, is at the forefront of the teacher’s mind when setting goals.

Janine is like Linda in that she wants her students to relate to the material. She is teaching her students about polar and non-polar substances though household items such as balloons, Styrofoam, acetone, water, oil, and coffee filters. The following quote refers to her connections to everyday items and polarity.

...covalent bonds, covalent bonds are everywhere and so having them understand that these are things that they come across on a regular basis. And that’s where I do this polar vs. non-polar, like why can we use water for overhead projector markers, and why does acetone remove permanent marker and water doesn’t? Like those types of things that they come across on a regular basis really helping them see that they do see this every single day, but they might not know why. So that’s kind of the big picture... taking the abstract thought of the electron configurations and then morphing it into what they see into every single day and making sense of that.
Janine not only wants to teach her students about polarity, she also wants them to be able to recognize the chemistry around them. What is interesting is she also puts a lot of emphasis on electron configurations: “if you can do electron configurations, you can pretty much explain everything that happens in chemistry.” Janine affords electron configurations explanatory power, even though they only provide some information on chemical properties such as magnetism. In fact, she also affords the ideas of polar and non-polar compounds explanatory power as well. One example from Janine’s instruction is when she explains water and acetone washing permanent marker by the mnemonic “like dissolves like.” That is, a non-polar compound dissolves a non-polar compound and a polar compound dissolves a polar compound. Janine’s content knowledge contains a gap; she does not recognize that a polar compound forming a well-structured solvation shell around a non-polar compound is entropically unfavorable. Thus, her explanation, and her expectations of her students, lies with the depth of her own content knowledge.

Molecular shape comes up in both the interview and reflection. When asked about VSEPR, she states:

...VSEPR is a topic, but it’s so hard because you only have a short amount of time to teach it so typically what I’ll do is I’ll talk about why water is bent, but that’s pretty much all I do with VSEPR... it is the abstractness, because you can do a ball and kit model, but they won’t see those lone pairs of electrons on the ball and stick models... VSEPR is more for students that want to study chemistry. I don’t think, you don’t necessarily need to know VSEPR in order to know why molecules interact with each other, like polar vs. non-polar. I think that’s more concrete.

Janine stays away from VSEPR because it is not needed for the level of chemistry understanding she wants her students to reach. She also states that VSEPR is an abstract topic and that developmentally her students are not ready that abstract of a topic. She also believes that VSEPR is a topic for students who want to learn chemistry, implying that her students do not.
Janine emphasizes content, student understanding, and her orientations when deciding what to teach and the goals for that content. While she has some content gaps, she still puts an emphasis on the content that she knows and expects her students to reach that same level of understanding.

Don is the most unique of the teachers in setting his goals. His main bonding goal is to teach students that bonding is not just ionic and covalent, but rather a continuum:

*You know I’ve really, before what I would do is say “ok there’s bonding, covalent and ionic, there’s two types, here are the properties of ionic and covalent,” then do a lab and get on with life. That’s ok, but I think as my education continues, we’ve talked about this in the program at [University P], is that really this thing of bonding is pretty much a slippery slope. I’m beginning to learn that it’s a huge continuum of just these, these interatomic and intermolecular forces that are all sort of different a different to show the same thing of this attraction... but what I hope to do this year is to help the kids understand that there is this continuum that even we struggle with as scientists sometimes. We have to put them into categories to help us, but that’s what we’re going to try to do, so from here on out we’re going to look at this attraction. That’s there’s this electrostatic attraction I think on many different bases. That’s what the plan is.*

This quote is reflective in nature; Don states how he used to view bonding before participating in a long-term professional development program at a university. Though this program he has
realized that bonding and atomic interactions are a continuum, and not as cut-and-dry as he once thought. He hopes his students will reach this level of understanding as well. Throughout his interview he refers to this continuum in reference to bonding and the nature of science. In this next quote, Don discusses his overall goals for bonding and how he plans to approach them:

I’m going to give you a huge list: covalent, ionic, hydrogen bonding, intermolecular forces, van der waal forces, polarity, these all deal with this sort of attractive nature of either atoms to other atoms or molecules to molecules where this attractive force is. This is kind of connected in a way. So our goal is to slowly and methodically say ok let’s talk about what are some of the properties what are some of the things we do know. And to know as scientists we struggle because kind of like you said we have to put into words something that has a very large continuum to help us make sense of it and that it is not perfect. But we do the least imperfect job that we can ok.

With his list of bonding topics, Don hopes to teach his students that there is a continuum, and as he says, that we sometimes need to put things into bins to help us and that scientists do the least imperfect job possible.

That’s a mindset that is helpful in science. I think the thing that I love about science is the very few self-correcting fields, which is great... So that is kind of what I, I mean that would be a great thing if they could have that mindset.

In reference to the previous quotes, Don strongly values and recognizes the reflective nature of science. He wants his students to know that science is “self-correcting,” in that when new evidence is presented scientists will alter their understandings in order to assimilate the new knowledge. Not only does he value the nature of science, he also values research based teaching practices. When discussing the lesson at the center of his analysis, he made the following statement:

Ok so, this was taken from a J-chem Ed article and the guy did it at the Naval Academy. It was this year actually, I heard it at ACS and I talked to him and wrote to him and he was really nice and responded back. He said here try it and see, and here’s what I would change and feel free to change it and all that.

Don went to an American Chemical Society meeting and was able to speak with the author of the lab he used in his class. Don also states that he also goes to the literature for misconceptions
research, demonstrating his orientation to teaching chemistry; Don wants his students to develop an understanding of the nature of science and values research based practices.

While Don’s practice was research-based, it did not align with his content goals. Don wanted his students to develop an understanding about ionic and covalent compounds, but facilitated a lab teaching paramagnetism and diamagnetism. Don then wanted to connect these concepts to bonding stability.

“I’m trying to draw in this very abstract quantum mechanical model with an experimental model that then also is a starting point for saying ‘now that we know these are occurring, would it make sense that they stick together the way they do?’”

As opposed to looking at thermodynamics, Don is looking to these compounds in an applied magnetic field. Just like Janine, he wants his students to understanding to the extent of his own knowledge. What makes him different from Janine, however, is that fact that he realizes his content error during his reflection. “…it really has nothing to do with bonding. It has a lot to do with electrons and in a round about way it has bonding.” He realized that his lesson did not relate to bonding and then described his follow-up lab he used to get his students the knowledge that he originally wanted.

After this when I did the next lesson, I did a lesson that went much better... they took macro scale evidence on the on ionic and covalent compounds like sugar, salt, like potassium chloride and calcium chloride and salicylic acid. Do they dissolve in water, approximate melting points, high or low, do they conduct by itself, does it conduct in water and they just record data. Second thing they did is we went to a PhET simulation and so ok what’s going on on a particulate level that might support or not support what we see on the macro scale? The third thing that we did then is they were asked questions well what if you see a symbol and there’s a metal nonmetal or two nonmetals? And then we found data on other compounds that were covalent and ionic and then they started making associations and started drawing the models.

Don describes a lesson that is geared towards teaching ionic and covalent bonding with the same type of pedagogy. He also states that he did not do the correct prep work in determining what students knew before coming into the lab. While the pedagogy is not the focus of the current
analysis, this does demonstrate Don’s ability to evaluate his own decisions and instruction, and
helps us differentiate his instruction from Janine’s. An aspect of Don’s reflection that help
support his beliefs is when he notices a gender equity issue within his classroom.

*Ok the most shocking thing about the first film I saw... it looks like only the boys
were the ones getting the data and the girls were watching. To me that’s a big
problem. Which means from now on I will be more specific about assigning roles
so everybody, male or female, does the actual collection of data and so I can try
to do whatever I can to make sure they fully partake in the scientific process.*

This quote not only supports his beliefs and goals about the nature of science, it also brings up a
new orientation and future goal of gender equity in the classroom.

Overall, Don focuses very heavily on his orientations to teaching science when setting
goals. In fact, most of his goals revolve around students understanding and partaking in the
scientific process. Content and student understandings do appear, but they are not as prominent
as his orientations. For this reason, the orientation component is highlighted while the content
and student understanding remain un-highlighted, but visible. Don’s component lens is found in
Figure 9.

![Figure 9: Components Influencing Don’s Bonding Goals](image)

Looking across teachers reveals two trends: The orientation, curriculum, and student
understanding components play a role in goal setting; and the teacher’s self-efficacy,
instructional strategies, and assessment remain in the background. While this in itself is novel, it also reveals that particular teaching situations, such as goal setting, employ some components to greater extents than others. We are calling this PCK component employment.

Based on the data, PCK Component employment states that teachers will employ different components, to different extents, depending on the situation and their own approaches to teaching. This means that similar components can be employed, but the foci can be varied. This does not mean that components that are not evident do not have some role, just that other components have a greater influence on that particular situation.

PCK component employment adds a novel piece to the PCK literature. Magnusson, Krajcik, & Borko (1999) presented a model that is widely cited and used in PCK studies (Drechsler & Van Driel, 2007; Gess-Newsome & Carlson, 2013; Park et al., 2011; Rollnick et al., 2008; Schmelzing et al., 2013). In this model, the orientation component acts as a filter for other components and their influence on PCK. Moreover, none of the components are directly connected to each other. Data from this study suggest that components are working in sync and do not serve as filters for one another. For example, Doug focuses heavily on content when setting his goals, but those are also related to his own views about his teaching as well as what he believes is best for his students. While orientation is part of the thought process, it does not mediate for chemistry curriculum or students’ understanding of chemistry; we see all three work together with content at the forefront. Park and Oliver (2008) also suggested that components could influence each other, but the extent to which they were employed was not discussed.

D. Instructional Strategies through a Component Lens

The PCK component employment lens can be applied to other situations, such as deciding on and enacting instructional strategies. The following analysis will focus on two teachers, Doug and Linda, in order to showcase the alignment and extension of each teachers’ stated goals and methods, as well as how sufficient knowledge is required about teaching methods to enact them with efficacy.

Doug’s cooperating teacher was a huge influence on his pedagogy and how he views chemistry instruction.

*My cooperating teacher when I student taught was very much my way or the highway and whatever I did was never good enough. I always had to get my lecture to her standard... That’s what teaching became to me. Regardless of what*
the theory said, that’s what it was and that’s pretty much where I got everything I do... if the state comes out and says chemistry teachers or AP, chemistry teachers you now need to teach crystal structure and molecular orbitals, my first instinct is to say: “oh, better add it to the PowerPoint.”

In this quote, Doug discusses how his cooperating teacher and his or her views of teaching has led him to develop a habit of going straight to PowerPoint, instead of other teaching methods. To provide some context, Doug is a part of a long-term professional development program focused on teaching high school chemistry instructors how to use inquiry in their classroom. Doug states that it is hard for him to change, especially with his first experiences using inquiry.

I look at published inquiry labs and I hate them. Not because I didn’t like the learning theory, but the labs were weak, just so weak. That’s where I’ve been, that’s where my biggest wrestlings have been lately; it doesn’t matter how weak that lab it, it doesn’t mean all of inquiry is bad. I’ve got to figure out ways to strengthen the activities for my classroom.

Thinking back to Doug’s goals, he emphasizes the chemistry curriculum component when making decisions on what to teach. With this in mind, Doug did not believe that the labs would produce the content goals that he looks for in classroom activities; thus, he did not like the inquiry labs. He did try an inquiry activity at one point in order to deepen the content his students were learning. He had heard that inquiry could help students deeply understand their content, and wanted to try employing a lab:

...[in] physical science one of the standards was pH... Very surfacey information that I hate teaching; I don’t like teaching, ‘know this and don’t understand anything about it.’ So I’m like, ‘we’ve got to do a good acid base lab, we’ve got to do a good pH lab.’

Doug’s original reason for choosing this inquiry lab was so he could do a “good” acid-base lab so his students would understand it better. The next quote describes his first experience with inquiry in his own classroom:

So what they did is they let you pick any volume of water and they let you put in as many Alka-Seltzer tablets as you want. That’s designing your own procedure... So lets make it yours, lets tell you can choose this and this variable and you’re done... You’ve got kids taking a liter of water and dropping an Alka-Seltzer tablet
in... When you’ve got a stomachache do you want to drink a liter of this stuff?

There’s no connection in the lab activity to... what do you actually want to drink

So far this “inquiry” lab focuses on having students design the procedures. While Doug could have set guidelines or suggestions for how many tablets to use, he went with what he thought, and the lab suggested, inquiry was: simply designing your own procedure. This is a common misconception about inquiry, which simply requires students make lab decisions. Inquiry is about having students use scientific processes, but at its roots is about students analyzing authentic data to develop an understanding of some phenomena or concept. Doug’s understanding, that inquiry is choosing procedures, does not allow him to critically analyze the efficacy of the inquiry activity. Already it is clear that Doug does not like the lack of real world connection. The next quote focuses on his experience with the content in the lab.

And then you go from there to, there’s the initial drop in acidity [pH goes down]... followed by the rise to reach a buffered six and a half, but they don’t know anything about buffers. So now like well I have an upset stomach and I’m taking an acid, well Alka-Seltzer doesn’t make any sense. And I’m like, “you’re absolutely right, it doesn’t make any sense. This is so far over your heads that this is, this might be the dumbest thing I’ve ever done.” I chose it because it’s an inquiry lab and it failed miserably.

When it comes to the content, Doug does not feel it was an appropriate lab. This was for his physical science class, which did not have the proper prior knowledge to interpret or understand buffers, let alone how a buffer could help calm an upset stomach.

...it was marketed this is appropriate for physical science, so lets go ahead. But just as disappointing is the fact that it can all itself inquiry because you can pick these two variables, but then they don’t give you context about why or how to think about those two variables. There wasn’t really a discussion in the published lab about, you have a stomach ache, you need to take some medicine, Alka-Seltzer is what’s in your cabinet. How much water do you want to drink?... if that’s inquiry, if that’s what inquiry is, I want nothing to do with it.”

This last quotes summarizes Doug’s thoughts about inquiry and the lab itself. His understanding of inquiry was that choosing methods meant inquiry. With this understanding, he did not have correct knowledge on learning theory to critique or alter the lab. With a PCK component analysis
we can compare what Doug emphasizes when selecting goals and what was emphasized in lab he selected (Figure 10).

**Doug’s Bonding Goals**

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<td>Reflection</td>
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<td>Self-Efficacy</td>
<td>Instructional Strategies in Chemistry</td>
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**Lab Focus**

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</table>

**Figure 10: Doug's Bonding Component Emphasis and the Lab Focus**

When looking at Doug’s focus on the chemistry curriculum and what content he wants his students to learn, we can see that there is a clear misalignment with the goals of the lab, as he perceives it. He sees the lab as an extension of his own knowledge of inquiry; students make procedural decisions. For this to align with what Doug values, he would have to place an emphasis on instructional strategies of the lab over the content the explicit content the students are learning. Doug’s reasons for choosing instructional strategies seem to overlap his goals for teaching bonding. This next quote describes why he originally chose to have students build models of different compounds to work with the principles of VSEPR.

> Again, these are students, I’ll be honest, these are students who can learn just about any way you want. I can just as easily say this is a picture of a seesaw, this is a model of a see-saw and learn it and they will... there’s a clear difference between learning it for a test and being able to answer questions about it on a homework, versus understanding it at a deeper level and understanding why it works the way that it does. As it’s come up numerous times in our [professional development] class, I tend to be somewhat of an old fashioned teacher. I tend to throw a lot of information at them more often than many teachers than probably I
should. This is one of those areas where I’m trying to grow and get better, because… There’s a place where I have to integrate some stronger activities to get my kids to not just take it in and memorize it, but really be able to know it and use it… This is one of those activities... For this particular, for VSEPR in AP this came to mind, because I saw… that they would just memorize and that’s not good enough. I did it, and it worked pretty well and I was pleased so I’ve basically been doing it ever since.

This quote offers an insight into what Doug values when selecting teaching methods. Again, he puts a heavy emphasis on the content, just as the analysis on his goals demonstrated. Based on his traditional roots, he wants give students a lot of information and tends to do that through lecture, as it was pointed out earlier. His reasoning for choosing to do this activity in particular was because he realizes the need to integrate stronger activities when his students are just memorizing. He states that he could easily tell the student the different shapes, but he sees for this topic that students tend to memorize when that occurs. His reflection on the lesson supports this approach.

As discussed earlier, the primary limitation is in the time it takes...this is a significant investment of time when it would be much faster to show pictures/models of all shapes and move on. This approach, however, offers strengths that get students to think more deeply about the principles of shape rather than simply memorize details (these are students who remember bond angles 3 years after they were taught it, for Pete’s sake!). The struggle is in getting them to understand, not memorize, and I think this activity helps with that. It also gives me models that I can display in my room that mean something to my students for reference moving forward.

For a non-lecture instructional strategy to be used in his class, Doug has to see that helps his students understand the content at a deeper level. He believes his students can learn anything though any method, as evidenced by the last interview quote, but in this particular situation his experience tells him he needs a different teaching method. Figure 11 shows the Doug’s component analysis for selecting instructional strategies.
Doug’s beliefs about his students are at the forefront of decisions, as well as the content. He believes that his students will be able to learn in whatever way they are taught because they are the best and the brightest. For him, the balance is then with time and content. He wants them to learn as much as possible, and realizes that lecturing is the fastest way to get across information. When that does not develop strong enough content knowledge, he seeks out alternative teaching methods. The chemistry curriculum and students’ understanding of chemistry components are highlighted for those reasons. This does carry certain implications about how he believes understanding is developed, which is why orientation to teaching chemistry remains not faded, but also not highlighted. For some topics, Doug believes that his students can develop sufficient content knowledge through his quicker, didactic methods. The faded components, assessment of chemistry learning and self-efficacy, were not made explicit with the data collected. As stated earlier, this does not mean they are not connected in some way, it just indicates that the other components are what are explicitly valued in this particular decision. Obviously, some sort of assessment had to have taken place for Doug to realize his students did not understand the content to the extent he wanted.

Linda’s bonding goals are heavily influenced by her ideas of what understanding is and what chemistry content she needs to get across. When looking the component employment for her goals (Figure 6) chemistry curriculum and orientations to teaching chemistry are highlighted.
She does state that she believes that she “[does not] think memorization leads to deep understanding,” but understanding, for her, is reached when students can get correct answers.

Additionally, Linda discusses how she wants to remediate misconceptions in her own classroom. She states what misconceptions she feels her students carry, “…the biggest one is that oxygen’s valence electron’s belong to oxygen and that carbon’s belong to carbon”; as well as how they are developed, “I mean, their teacher tells them stuff and they, but they, they make up their own rules for why these things are true.” She also has an understanding of how misconceptions are remediated: “…they just have to experience… well real failure really, before umm changing their own mental model of what’s true…” In her reflection she even focuses on the instances where she addresses student difficulties and misconceptions. The following two quotes are examples from her reflection.

- Here I’m countering the tendency of students to not count electrons...
- ...trying to address misconceptions on whether the electrons in a covalent molecule “belong” to one atom or another.

While it appears she has a conceptual change approach to teaching, Linda’s view of a misconception is a wrong answer. If a student is able to identify a wrong answer and correct it, they have remediated a misconception. Therefore, this influences some of her decisions on how she structures the activities in her classroom: “knowing these things about where they’re likely to stumble… it means I put those stumbling blocks in their path early, so that they stumble early and get you know and we tackle those misconceptions before they get any deeper rooted.” While Linda believes that a misconception is something that can be quickly changed or remediated, a real misconception is part of a robust knowledge framework that requires a conceptual change model of instruction and a lot of time to remediate (Duit & Treagust, 2003).

Part of this process involves teaching using inquiry, within her own definition of inquiry instruction.

...with a lot of stuff I do the guided inquiry, you know figure out the rules yourself... And so I’m not doing a lot of direct instruction on this. I find that that’s
unwieldy with covalent bonding...[but] I’m not good at creating these things myself. I’ll take and them and modify them, but I have not seen it well done in guided inquiry where you know the kids are led into those covalent bonding Lewis Diagram rules. This is one of the topics throughout the year the few topics that I choose to just do that lecture get all the rules out there and then set them loose to try and fail.

This quote from Linda’s interview contains a plethora of information about her beliefs and why she chooses certain instructional strategies. First, she defines inquiry as leading her students to “figure out the rules yourself.” This is not a well-formed conception of inquiry, as inquiry is the process of developing conceptual understanding though authentic data analysis and model building (Llewellyn, 2005). Her quote also suggests that she wants her students to develop algorithmic processes. This is reinforced when she says she has not seen a good inquiry lab that leads students to Lewis Diagram rules and in her reflection when she says: “when they checked, their answers were either correct or the difference between their answer and the correct one was easily understandable.” Bringing in her value on “remediating misconceptions,” she wants to give them the rules during her lesson, then “set them loose to try and fail.”

Linda carries misunderstandings about what misconceptions are and how the purposes behind inquiry instruction. Nonetheless, her choices of instructional methods are guided by her understandings. Students’ understanding of chemistry, by definition, contains misconceptions and student difficulties, both of which are influences on how she teaches. She also believes the best way to teach is through guiding the students to a set of rules, as opposed to explicitly giving them the rules, which defines what she considers as understanding (orientation to teaching chemistry). If she cannot find a lab that includes these pedagogical requirements, she defaults to direct instruction, because she is “not good at creating these [inquiry lessons] myself.” This speaks to a part of her teaching self-efficacy; she is not confident that the lessons she makes will lead students to understand the content.

Overall, her goals focus on the curriculum she needs to teach, as well as her own definitions of understanding in chemistry. It is clear that the influences on her instructional decisions are very complex. She wants her students to learn the content, which is rooted in what she views as understanding, but is also very focused on remediating misconceptions (wrong answers and misconceptions alike), as well as ensuring she leads them to rules as long as she can
find a lab that does so already. This means the choice between teacher-centered instruction and student-centered instruction relies on her own self-efficacy in creating activities. Linda also places value in assessing students throughout the class, which is why she provides them with an answer key. “…when they checked, their answers were either correct or the difference between their answer and the correct one was easily understandable.” Showing that she wants to build in a way for her students to check and see if they understand the content.

Lastly, another aspect of her instructional decisions are based on her views of classroom management.

…you have to have umm behavior expectations in place for the kids who finish early and the expectation in place for the kids that are really dragging that they will assign themselves homework so that, so as to complete the assignment on time… sometimes I have things for the early ones to do umm a box of puzzles with toys in there for them to play with if necessary... with this particular group that you’ll be watching they’re often stomped on history teacher so they just pull out that history book and go to town, it’s not as big of an issue.

A classroom where students are always occupied is important to Linda. This is even a feature of how she assesses her own instruction, as seen in this quote from her reflection.

The procedures I use seem effective due to the quality and quantity of questions students were asking as well as the fact that students were on-task until the end of the period. I particularly like having set up the expectation that students will check their own work with the answer key so that they know immediately whether they are on track or not. I also like how this frees me up to work one-on one with students who need more help.

According to her, the fact that students were on task is a key to success. When viewing the classroom video, students were on task and silently working the entire class period. If students can work independently and check their own understanding, she has more time to help her students obtain the content.
Figure 12: Components Influencing Linda's Instructional decisions

Figure 12 demonstrates how complex the influences are on her instructional choices. While it is clear that all components are employed, major decisions are made based on a few factors: Overcoming misconceptions, finding a pre-made lab or activity, and getting students to learn rules. Respectively, these factors are heavily influenced by students’ understanding of chemistry, self-efficacy, and a combination of chemistry curriculum and orientation to teaching chemistry. While she does want to include a self-check (assessment of chemistry learning) and certain pedagogical aspects (instructional strategies in chemistry), they are not the driving factors for her teaching decisions.

In summary, the bonding goals for both teachers serve as the basis for their instructional decisions. The components employed were expanded for both teachers in unique ways. Doug still stuck close to his bonding content goals in terms of component employment, while Linda adds a layer in complexity in reaching her goals. Linda’s goals are content knowledge, albeit algorithmic, but the path she takes to get there includes many decision making processes and specific instructional decisions: Putting difficulties and hurdles at the forefront of the lesson, including student self-assessment, guiding students to rules, etc. Linda wants her class on task and working, and has a systematic and specific way to ensure this while getting her students to a shallow level of understanding. This requires a complicated set decision making processes. Doug, on the other hand, wants deep understanding and uses methods that he feels gets his students there the fastest. One limitation to the PCK component lens is the fact that it does not capture the aspects of classroom management that arose in Linda’s decision-making processes.
While she does not explicitly state that she wants her class to work quietly the entire time, her students automatically start working quietly by themselves, which suggests that this is the expected behavior. She does state that she wants them occupied the entire time, thus placing a large value classroom control.

**IV. Summary**

The synthesis of a theoretical PCK model has lead to a data collection method that can produce trends across a group of teachers, while allowing researchers to uncover what makes the teachers unique. Furthermore, analyzing data with a PCK components lens allowed researchers to employ a theoretical and data-driven view of teachers’ classroom decisions. It was found that when forming chemical bonding goals, teachers employed the components orientations to teaching chemistry, chemistry curriculum, and students’ understanding of chemistry, while the rest did not surface. These components were also employed to different extents, with each teacher focusing on different aspects of each one. This presents a novel finding: Teachers employed components to different extents in different situations. Finally, analysis of two teachers’ instructional influences revealed that their goals had an influence on their teaching, but that component employment varied widely across teachers.
Chapter 5: Conclusions and Implications

I. Interpretation of Findings

The purpose of this study was to answer the following questions:

1. To what extent does the PEER data collection method elicit and capture novel and complete data to characterize acid-base PCK across a small group of teachers?
2. How does the reflection stage (VIdEOs) of the PEER method generate unique acid-base PCK data as compared to data generated by the explication and enactment stages?
3. What novel findings can the PEER data collection method generate for chemical bonding PCK?
4. How can the PEER data collection method characterize chemical bonding PCK?

To answer these questions a comprehensive model of PCK was synthesized from the literature and used as guide for the development of a data collection method. The PCK, Explication, Enactment, Reflection (PEER) data collection method was tested in a pilot study, and then implemented in the main study focused on chemical bonding.

A. PCK Model

The Smith and Yezierski Model was synthesized from theoretical models found in the literature base and tested in both the pilot and main study (Grossman, 1990; Magnusson, Krajcik, Borko, 1999; Park & Oliver, 2008; Rollnick, et al., 2013). This model featured three of the knowledge bases – subject matter knowledge, pedagogical knowledge, and knowledge of context – situated on three sides of a triangle. Pedagogical content knowledge was located at the center to symbolize the knowledge base that brings them all together (Shulman, 1986, 1987; Magnusson, Krajcik, Borko, 1999; Park & Oliver, 2008; Schmelzing et al., 2010; Jüttner et al., 2013; Schmelzing et al. 2013). Six components comprise PCK: orientation to teaching chemistry, chemistry curriculum, students understanding of chemistry, assessment of chemistry learning, instructional strategies in chemistry, and teachers’ chemistry self-efficacy (Shulman, 1986, 1987; Grossman, 1990; van Driel, Verloop, & de Vos, 1998; Magnusson, Krajcik, Borko, 1999; Park et al., 2011; Alonzo, Kobarg, Seidel, 2012; Jüttner et al., 2013; Schmelzing et al., 2013. These formed a ring around the measurable indicators found at the very center. The ring was designed to represent that each of the components could influence the other and were
interconnected. The measurable indicators are how PCK is observed and documented and include explication, enactment, and reflection.

Data collection from the pilot and main study supported the theoretically synthesized Smith and Yezierski PCK model. Teachers’ content knowledge, along with content errors and gaps were observed in all three measurable indicators across multiple teachers. Content errors regarding pH and dissolution were triangulated across each measurable indicator. In the main study teachers enacted and affirmed their content knowledge and errors. In Don’s instruction a content gap occurred that he was able to catch and remediate in his reflection. For the knowledge base “Pedagogical Knowledge,” each teacher spoke about, enacted, then reflected on their teaching methods. Finally, context was at the center of multiple teachers’ thinking. Gavin explicitly stated that the context of the school structure was integral to who he was as a teacher, while Linda picked and chose what contexts influenced her own teaching. In the main study teaching decisions were analyzed through the PCK component lens. This not only revealed that the components comprised PCK, but supported their use as an analytical lens, along with the work done by Aydin et al. (2014).

B. The PEER Data Collection Method

Directed at answered research questions one and two, the pilot study was carried out to test the efficacy of the PCK, Explication, Enactment, Reflection (PEER) data collection method. Data analysis revealed that all three measurable indicators were necessary in order to develop a complete picture of each teacher’s PCK. This was demonstrated through an in-depth analysis of Sophia. Without each measurable indicator in the data collection method, an incomplete representation of Sophia would have emerged. The analysis across teachers was able to reveal similarities among a group of teachers in with a PCK lens.

PEER was then implemented in the main study where the data collection method revealed findings about PCK as a topic as well as each teacher’s topic-specific PCK. Overall, the PEER data collection method was able to produce robust data across a group of teachers and within each teacher, making it a useful data collection method for future studies. The conclusion of both of these studies answers research questions one and two. VIdEOs was able to generate data to support, triangulate, and reveal both unique and common themes and finding among a small group of teachers, and the PEER data collection method was effective in characterizing novel acid-base PCK.
C. Component Employment

A major novel finding in this study was that teachers employ components of their PCK to different extents depending on the situation. This was revealed when comparing teachers’ goals and their instructional strategies in the main study. In comparing each component employment lens for each individual teacher’s goals, similar components were being employed, but each teacher focused on some components more than others. This expands on the work by Magnusson, Krajcik, and Borko (1999) and Park and Oliver (2008). Widely cited in PCK research, Magnusson, Krajcik, and Borko (1999) proposed a model synthesized from literature that placed the orientation component above the rest, as a filter for other PCK components before being enacted. This was amended and expanded upon by Park and Oliver (2008), who proposed a model without a hierarchical component structure. The analysis demonstrates that each component is not employed equally and one component does not have more weight universally for all teachers or even for one teacher, since a component’s employment depends on the situation or decision the teacher is making.

D. Bonding Goals and Teaching Decisions

Overall, teachers employed the components orientation to teaching chemistry, chemistry curriculum, and students’ understanding of chemistry when deciding what their classroom goals would be. These components were employed to different extents and presented a wide variety of goals, ranging from deep conceptual understanding, algorithmic understanding, to the nature of science. This presents a very complex picture of what PCK is and how unique it can be, all while the same components are at work. This means that to truly understand a teacher’s PCK, a rich data collection method and robust, theory-driven analysis are needed.

When comparing Doug and Linda we saw how goals did and did not influence classroom instruction. Linda had a very intricate, and methodical decision making process when it came to deciding on teaching methods. This process was dictated by her desire to have a well-managed classroom and enact her goals. Doug, on the other hand, was very focused on content knowledge, and wanted to do what was necessary to get there. Again, this creates two complex situations in which teachers employed various components to different extents, which relied on aspects not completely captured by PCK components. This supports the need for a rich data collection method in order to represent a more complete PCK picture.
F. Teaching Buzzwords

Lastly, the researchers noticed that multiple teachers used education terminology incorrectly, which greatly influenced their own teaching. Inquiry was one prime example, which was described by Doug as “students choosing a few variables,” and by Linda as “students being led to rules.” Marshall et al. (2009) point out the many ways that teachers define and use the term “inquiry,” as a warrant for the development of EQUIP. Inquiry was not the only incorrectly defined term. In her reflection, Janine provides insights into how she defines “problem solving”: “I think that’s the biggest thing I come across with my honors kids: If there’s not directions, then they really struggle with problem solving.” This tells us that Janine’s definition of problem solving can mean applying an algorithm to answer a question. With the inconsistencies across teachers, this prompts a need for a coherent and consistent set of definitions and their supporting theories to be formed for practitioner use, as well as the triangulation of definitions from a researcher standpoint. Triangulation would ensure the teacher’s definitions are being accurately characterized.

II. Limitations

After data analysis of the pilot study, it was found that the area of student difficulties and student misconceptions was not properly elucidated in the interviews. The investigators realized that teachers were not elaborating on what caused difficulties in learning, but rather focused on student study habits and perceived student intelligence. This misinterpretation prompted changes in the CoRes pre-instruction interview. Two questions were added to the interview guide after the conclusion of the pilot study: One focusing on common student difficulties and the other on student preconceptions. It was also noted that the guided reflection did not offer enough guidance; teachers were focused more on describing what they were doing throughout their lesson as opposed to reflecting or explaining their thought processes as they pertained to the prompts generated from their CoRes’ content. In the revised reflection guide, the main goals of the classroom instruction are stated as well as various questions and prompts, such as “Did any limitations arise that you did not foresee?” and “Discuss the effectiveness of the procedures used.” This was done to provide more guidance, while still giving the teachers autonomy in choosing which specific areas of the lesson warrant reflection.
While the procedures have been found to uncover content errors and knowledge of the content being taught, another limitation is that there was not a content test given to the teachers to assess overall acid-base or bonding content knowledge, which is essential for PCK. In order to reach a balance of time spent outside of class, which affects recruitment and motivation during participation, it was decided that a concept inventory would not be used. We recognize the value of such instruments and believe that the PEER method could be augmented with measure of teacher CK and paper-pencil PCK instruments.

Data were only collected on one lesson for each teacher in the study. One may view this as a single measurement yielding only one data point. While this would ordinarily pose a limitation, the PCK data generated from the one lesson are richer than a single measurement. However, collecting data on multiple lessons within bonding for each teacher would provide more evidence for the transferability of the findings.

Lastly, one area of PCK that was not included in the components or the component employment analysis was classroom management. In Linda’s instruction is became clear that she strongly valued a well-managed classroom, which influenced how she taught. Other classroom management related issues and inquiries arose during stage four of PEER, which were not captured in the observation protocols. In the future, classroom management could be captured using an observation protocol, but it does appear that there is a need for classroom management to fit in the PCK component framework. The rationale for this is twofold: one, the data from this study suggests that classroom management can play a crucial role in instructional decisions; and two, even if a teacher plans highly reformed, rich lessons, if the classroom is not under control then the pedagogy will not be enacted with efficacy.

III. Implications for Professional Development

Reflection is a critical process for the formation, revision, and observation of PCK (Shulman, 1986, 1987; Magnusson, Krajcik, Borko, 1999; Park & Oliver, 2008; Schmelzing et al., 2010; Jüttner et al., 2013; Schmelzing et al. 2013). Multiple teachers stated how their reflections on their own video-recorded instruction helped them see what they needed to improve upon and how valuable the process was. After conducting this study, we assert that the PEER data collection method is a useful way to collect data on a teacher’s topic specific PCK as well as a guiding framework for PCK development. Teachers can be trained to employ the PEER data collection method on their own instruction through a professional development program. This
data collection and analysis process, including the observation protocols, can help teachers determine the alignment in their own stated goals and enactment, as well parts of their own PCK that they may have never thought about.

Teachers would need to be taught how to analyze qualitative data, as well as receive training on each observation protocol. The hope is that this process of data collection and analysis would prompt a “need to know,” for just in time teaching. This is where the teacher would experience cognitive dissonance and then seek out the resources to fill knowledge gaps or remediate their understanding (Novak et al., 1999). This would be where the professional development leader would step in, as a resource provider and guide once the teachers are ready to change.

IV. Future Research

This study supports the claim that a robust data collection that spans all three measurable indicators needs to be implemented to develop a complete picture of PCK. The PEER data collection method can be augmented using concept inventories and paper-and-pencil PCK tests. This study also supports the need for more research to be conducted on topic-specific PCK. More specifically, a range of teachers’ topic-specific PCK should be investigated for multiple topics in order to determine what prominent component employment features, if any, cut across topics. Through describing topic specific PCK, we can develop effective professional and pre-service teacher development programs.

One starting point could be to pick topics that are completely different to acid-base chemistry or chemical bonding. Both acid-base chemistry and chemical bonding are taught in a mostly conceptual way with very little mathematical knowledge being activated by the students and teacher. Selecting a topic that is traditionally math heavy, such as stoichiometry, could provide more evidence to support the robustness of the PEER data collection method. From there topics that have a balance of mathematics and concepts could be investigated. Thermodynamics or reaction kinetics, both high school and general chemistry topics, could be selected due to their importance in chemistry as well as the balance between math and conceptual understanding required.
References


topic specific PCK in chemical equilibrium. Paper presented at the ESERA Conference, Lyon, France.


Appendix A

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Date: April 28, 2015

Reformed Teaching Observation Protocol (RTOP)

Daiyo Sawada
External Evaluator

Michael Piburn
Internal Evaluator

and

Kathleen Falconer, Jeff Turley, Russell Benford and Irene Bloom

Evaluation Facilitation Group (EFG)
Technical Report No. IN00-1

Arizona Collaborative for Excellence in the Preparation of Teachers
Arizona State University

I. BACKGROUND INFORMATION

Name of teacher __________________________ An announced Observation? ________
(Yes, no, or explain)

Location of class ____________________________ (District, school, room)

Years of Teaching ____________  Teaching Certification ____________
(K-8 or 7-12)

Subject observed ___________________________  Grade level ____________

Observer ___________________________  Date of observation ____________

Start time ___________________________  End time ____________

II. CONTEXTUAL BACKGROUND AND ACTIVITIES

In the space provided below please give a brief description of the lesson observed, the classroom setting in which the lesson took place (space, seating arrangements, etc.), and any relevant details about the students (number, gender, ethnicity) and teacher that you think are important. Use diagrams if they seem appropriate.

<table>
<thead>
<tr>
<th>Category</th>
<th>Score</th>
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<tbody>
<tr>
<td>Lesson Design and Implementation</td>
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<tr>
<td>Content</td>
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<td>Classroom Culture</td>
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### II. LESSON DESIGN AND IMPLEMENTATION

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<th>3</th>
<th>4</th>
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<tbody>
<tr>
<td>1. The instructional strategies and activities respected students' prior knowledge and the preconceptions inherent therein.</td>
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<td>1 = teacher refers to prior knowledge</td>
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<td>4 = teacher solicits prior knowledge (pre-test, question, etc.) or lesson is developed to build on prior knowledge (from other lessons)</td>
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<td>2. The lesson was designed to engage students as members of a learning community.</td>
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<td>4 = must have student-student, teacher-student, and students present answers before teacher discusses</td>
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<td>3 = not enough student-student development of ideas/teacher presents answers/some student-student interactions</td>
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<td>2 = good teacher-student interactions but no student-student</td>
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<td>0/1 all teacher centered</td>
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<td>3. In this lesson, student exploration preceded formal presentation.</td>
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<td>4 = students explore without teacher telling them what to expect</td>
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<td>2 = teacher gives away what will happen</td>
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<td>0 = students watch demo and then instructor explains</td>
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<td>4. This lesson encouraged students to seek and value alternative modes of investigation or of problem solving.</td>
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<td>4 = students told to investigate but not told how</td>
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<tr>
<td>2 = students told to investigate but encouraged/told to do things in a certain way</td>
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<td>5. The focus and direction of the lesson was often determined by ideas originating with students.</td>
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<td>4 = students generate problem and how to solve</td>
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<tr>
<td>3 = instructor defines problem but does not tell students how to solve</td>
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<td>2 = teacher sets agenda and directs observations</td>
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### IV. CONTENT

#### Propositional Knowledge

6. The lesson involved fundamental concepts of the subject.

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<tr>
<td>4 = based on the benchmarks</td>
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7. The lesson promoted strongly coherent conceptual understanding.

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<tbody>
<tr>
<td>4 = students must connect to previous content or define patterns, must develop concept, there must be student-student, student-teacher and whole group interactions</td>
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<tr>
<td>3 = missing one of the above types of interactions</td>
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<tr>
<td>2 = focus on phenomena description and little concept building</td>
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<tr>
<td>1 = teacher makes connections to previous topics for students</td>
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</table>

8. The teacher had a solid grasp of the subject matter content inherent in the lesson.

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<tbody>
<tr>
<td>4 = no misconceptions/able to answer most questions</td>
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</table>

9. Elements of abstraction (i.e., symbolic representations, theory building) were encouraged when it was important to do so.

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<tbody>
<tr>
<td>4 = good use of diagrams, particulate representation, diagrams; focuses attention on key elements; makes generalization or works towards theory development</td>
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<tr>
<td>3 = same as the above without theory development or generalizations</td>
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<tr>
<td>2 = some use of diagrams etc.; no theory development</td>
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10. Connections with other content disciplines and/or real world phenomena were explored and valued.

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<tbody>
<tr>
<td>4 = working with everyday materials and explicit and significant connections to other disciplines or everyday phenomena</td>
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<tr>
<td>3 = explicit and significant connections to other disciplines or everyday phenomena</td>
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<tr>
<td>2 = some connections to other disciplines or everyday phenomena</td>
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<tr>
<td>1 = passing mention of connection to other disciplines or everyday phenomena</td>
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</table>
**Procedural Knowledge**

<table>
<thead>
<tr>
<th>Description</th>
<th>Never Occurred</th>
<th>Very Descriptive</th>
</tr>
</thead>
<tbody>
<tr>
<td>11. Students used a variety of means (models, drawings, graphs, concrete materials, manipulatives, etc.) to represent phenomena.</td>
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<tr>
<td></td>
<td>4 = students articulate findings and/or make connections to everyday phenomena and students use multiple representations</td>
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<td></td>
<td>3 = students use multiple representations but teacher summarizes findings or students use multiple representations but do not develop concepts or make connections</td>
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<tr>
<td>12. Students made predictions, estimations and/or hypotheses and devised means for testing them.</td>
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<td>4</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>4 = students state what they think will happen before they collect data</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0 = students make observations without making predictions/developing hypothesis first</td>
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<tr>
<td>13. Students were actively engaged in thought-provoking activity that often involved the critical assessment of procedures.</td>
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<td></td>
<td>4 = students develop procedure for investigation and students make refinements to procedure based on observations/results or design further studies to clarify questions generated by observations/results</td>
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<tr>
<td></td>
<td>3 = students develop procedure for investigation</td>
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<td></td>
<td>1 = students actively involved in activity but no thought about how to conduct investigation or why</td>
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<td></td>
<td>0 = students not actively engaged</td>
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<tr>
<td>14. Students were reflective about their learning.</td>
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<tr>
<td></td>
<td>4 = Students must develop concept/theory and provide rationale for their conclusions; most students participate. A debate/discussion of different theories would indicate this level.</td>
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<tr>
<td></td>
<td>3 = Students involved in development of concept/theory but do not provide rationale or answer questions like: How do you know this? How can we be sure?</td>
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<tr>
<td></td>
<td>1 = no theory development and few students express findings/explanation.</td>
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<tr>
<td>15. Intellectual rigor, constructive criticism, and the challenging of ideas were valued.</td>
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<td></td>
<td>4 = Students must negotiate ideas as a whole group; majority of students involved in discussion.</td>
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<td></td>
<td>3 = Students negotiate ideas in small groups but no full group discussion.</td>
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<td>1 = Some ideas presented but no competing ideas offered.</td>
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<tr>
<td></td>
<td>0 = No student ideas presented</td>
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</tbody>
</table>

**V. CLASSROOM CULTURE**

**Communicative Interactions**

<table>
<thead>
<tr>
<th>Description</th>
<th>Never Occurred</th>
<th>Very Descriptive</th>
</tr>
</thead>
<tbody>
<tr>
<td>16. Students were involved in the communication of their ideas to others using a variety of means and media.</td>
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<tr>
<td></td>
<td>4 = Communication involves student-student, student-teacher, and whole group discussions.</td>
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<tr>
<td></td>
<td>3 = Communication within small groups and student-teacher but no whole group discussions; or some in group and some between group but significant teacher explanation.</td>
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<tr>
<td>17. The teacher’s questions triggered divergent modes of thinking.</td>
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<tr>
<td></td>
<td>4 = Divergent set up – allows students to explore multiple solutions/options; teacher does not guide towards answer but asks questions to make students think about options.</td>
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<td>3 = Divergent set up; teacher poses questions to group as whole but not to individuals or small groups.</td>
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<td>2 = Divergent set up but instructor encourages/directs towards one answer.</td>
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<td>1 = Any questions posed to students must score a 1</td>
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<tr>
<td>18. There was a high proportion of student talk and a significant amount of it occurred between and among students.</td>
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<tr>
<td></td>
<td>4 = most of the lesson was student talk.</td>
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<td></td>
<td>2 = significant amount of teacher talk in development of key ideas</td>
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<tr>
<td>19. Student questions and comments often determined the focus and direction of classroom discourse.</td>
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<tr>
<td></td>
<td>4 = student driven design and students decide what question/problem to investigate or how to investigate a question/problem.</td>
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<td>3 = instructor sets question/problem to investigate and materials but students decide how to use materials; teacher allows student questions to direct class discussion but instructor sets agenda.</td>
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<tr>
<td>20. There was a climate of respect for what others had to say.</td>
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<tr>
<td></td>
<td>4 = substantial exchange between individual students, group of students as a whole and between student and instructor; students display comfort in offering ideas or debating ideas; many students involved in discussion</td>
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<td></td>
<td>3 = exchanges in small groups with little/no whole group discussion; teacher closes down some student investigations by explicitly pointing them in another direction</td>
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<td>2 = teacher solicits student ideas and accepts comments but no debate about ideas</td>
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</table>
### Student/Teacher Relationships

21. Active participation of students was encouraged and valued.

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<td>4</td>
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</tbody>
</table>

- 4 = students involved in constructing concept/theory and final construction of key ideas
- 3 = students involved in constructing concept/theory but teacher presents final construction of key ideas
- 2 = students encouraged to describe phenomena but no theory development; teacher presents key ideas first before asking for student input
- 1 = if students were asked to answer questions/participate you must score 1

22. Students were encouraged to generate conjectures, alternative solution strategies, and ways of interpreting evidence.

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<tr>
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<th>Never Occurred</th>
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<td>4</td>
<td>3</td>
<td>2</td>
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</tbody>
</table>

- 4 = students directed their investigations and discussed results as a group
- 3 = students directed their investigations but did not discuss results as a whole group
- 2 = answer was student derived but teacher directed towards one correct answer
- 1 = answer was student derived

23. In general the teacher was patient with students.

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<th>Never Occurred</th>
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</tbody>
</table>

- 4 = students are allowed to explore
- 3 = teacher explicitly redirects some of the direction students choose to explore
- 2 = teachers allows some wait time after questions
- 1 = students are allowed to explore

24. The teacher acted as a resource person, working to support and enhance student investigations.

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</tbody>
</table>

- 4 = teacher supports student discussions but does not direct
- 3 = teacher interacts with students but does a lot of directing and answers questions rather than helping students find answers on their own
- 2 = teacher does not dominate group interactions
- 1 = teacher interacts with groups but provides too much direction

25. The metaphor "teacher as listener" was very characteristic of this classroom.

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</tbody>
</table>

4 = teacher does not dominate group interactions
3 = teacher interacts with groups but provides too much direction
Appendix B


---

EQUIP

(Electronic Quality of Inquiry Protocol)

Complete Sections I before and during observation, Sections II and III during the observation, and Sections IV-VII immediately after the observation. If a construct in Sections IV-VI absolutely cannot be coded based on the observation, then it is to be left blank.

Observation date: __________ Time start: __________ Time end: __________ Observer: ________________________________

School: __________________ District: __________ Teacher: ______________________________

Course: __________________

I. Descriptive Information

A. Teacher Descriptive Information:

1. Teacher gender _____ Male (M), Female (F)
2. Teacher ethnicity ____ Caucasian (C), African-American (A), Latino (L), Other (O)
3. Grade level(s) observed __________ 4. Subject/Course observed __________
5. Highest degree ___________ 6. Number of years experience: __________ 7. Number of years teaching this content __________

B. Student/Class Descriptive Information

1. Number of students in class: __________
2. Gender distribution: ____ Males _____ Females
3. Ethnicity distribution ______ Caucasian (C) ______ African-American (A) ______ Latino (L) ______ Other

C. Lesson Descriptive Information

1. Is the lesson an exemplar that follows the 4E x 2 Instructional Model? (PDI exemplar, non-PDI exemplar, non-exemplar)
2. Working title for lesson:
3. Objective/Purpose of lesson: Inferred (I), Explicit (E) __________
4. Standards addressed: State (S), District (D), None Explicit (N) __________
## II. Time Usage Analysis

<table>
<thead>
<tr>
<th>Time</th>
<th>Activity Codes</th>
<th>Organization Codes</th>
<th>Student Attention to Lesson Codes</th>
<th>Cognitive Codes</th>
<th>Inquiry Instruction Component Codes</th>
<th>Assessment Codes</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-5</td>
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</tbody>
</table>
Activity Codes—facilitated by teacher

0. Non-instructional time—administrative tasks, handing back/collecting papers, general announcements, time away from instruction
1. Pre-inquiry—teacher-centered, passive students, prescriptive, didactic discourse pattern, no inquiry attempted
2. Developing inquiry—teacher-centered with some active engagement of students, prescriptive though not entirely, mostly didactic with some open-ended discussions, teacher dominates the explain, teacher seen as both giver of knowledge and as a facilitator, beginning of class warm-ups
3. Proficient inquiry—largely student-centered, focus on students as active learners, inquiries are guided and include student input, discourse includes discussions that emphasize process as much as product, teacher facilitates learning and students active in all stages, including the explain phase
4. Exemplary inquiry—student-centered, students active in constructing understanding of content, rich teacher-student and student-student dialogue, teacher facilitates learning in effective ways to encourage student learning and conceptual development, assumptions and misconceptions are challenged by students and teacher

Organization Codes—led by teacher

W Whole class
S Small group
I Individual work

Student Attention to Lesson Code—displayed by students

L Low attention, 20% or fewer attending to the lesson. Most students are off-task—heads on desks, staring out of the window, chatting with neighbors, etc.
M Medium attention, between 20-80% of students are attending to the lesson.
H High attention, 80% or more of the students are attending to the lesson. Most students are taking notes or looking at the teacher during lecture, writing on the worksheet, most students are volunteering ideas during a discussion, most students are engaged in small group discussions even without the presence of the teacher

Cognitive Code—displayed by students

0. Other—e.g. classroom disruption, non-instructional portion of lesson, administrative activity
1. Receipt of knowledge
2. Lower order (recall, remember, understand) and/or activities focused on completion exercises, computation
3. Apply (demonstrate, modify, compare) and/or activities focused on problem solving
4. Analyze/Evaluate (evidence, verify, analyze, justify, interpret)
5. Create (combine, construct, develop, formulate)

Inquiry Instructional Component Code—facilitated by teacher

0. Non-inquiry: activities with the purpose of skill automation; rote memorization of facts; drill and practice; checking answers on homework, quizzes, or classwork with little or no explanation
1. Engage: typically situated at the beginning of the lesson; assessing student prior knowledge and misconceptions; stimulating student interest
2. Explore: students investigate a new idea or concept
3. Explain: teacher or students making sense of an idea or concept

Extend: [Extend is important but is not coded as such because it typically is a new Engage, Explore, or Explain]

Assessment Code—facilitated by teacher

0. No assessment observed
1. Monitoring (circuiting around the room, probing for understanding, checking student progress, commenting as appropriate)
2. Formative assessment (assessing student progress, instruction modified to align with student ability) or Diagnostic assessment (checking for prior knowledge, misconceptions, abilities)
3. Summative assessment (assessing student learning, evaluative and not informing next instructional step)

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### IV. Instructional Factors

<table>
<thead>
<tr>
<th>Construct Measured</th>
<th>Pre-Inquiry (Level 1)</th>
<th>Developing Inquiry (2)</th>
<th>Proficient Inquiry (3)</th>
<th>Exemplary Inquiry (4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I1.</td>
<td>Instructional Strategies Teacher predominantly lectured to cover content.</td>
<td>Teacher frequently lectured and/or used demonstrations to explain content. Activities were verification only.</td>
<td>Teacher occasionally lectured, but students were engaged in activities that helped develop conceptual understanding.</td>
<td>Teacher occasionally lectured, but students were engaged in investigations that promoted strong conceptual understanding.</td>
</tr>
<tr>
<td>I2.</td>
<td>Order of Instruction Teacher explained concepts. Students either did not explore concepts or did so only after explanation.</td>
<td>Teacher asked students to explore concept before receiving explanation. Teacher explained.</td>
<td>Teacher asked students to explore concept before explanation. Teacher and students explained.</td>
<td>Teacher asked students to explore concept before explanation occurred. Though perhaps prompted by the teacher, students provided the explanation.</td>
</tr>
<tr>
<td>I3.</td>
<td>Teacher Role Teacher was center of lesson; rarely acted as facilitator.</td>
<td>Teacher was center of lesson; occasionally acted as facilitator.</td>
<td>Teacher frequently acted as facilitator.</td>
<td>Teacher consistently and effectively acted as a facilitator.</td>
</tr>
<tr>
<td>I4.</td>
<td>Student Role Students were consistently passive as learners (taking notes, practicing on their own).</td>
<td>Students were active to a small extent as learners (highly engaged for very brief moments or to a small extent throughout lesson).</td>
<td>Students were active as learners (involved in discussions, investigations, or activities, but not consistently and clearly focused).</td>
<td>Students were consistently and effectively active as learners (highly engaged at multiple points during lesson and clearly focused).</td>
</tr>
<tr>
<td>I5.</td>
<td>Knowledge Acquisition Student learning focused solely on mastery of facts, information, and/or rote processes.</td>
<td>Student learning focused on mastery of facts and process skills without much focus on understanding of content.</td>
<td>Student learning required application of concepts and process skills in new situations.</td>
<td>Student learning required depth of understanding to be demonstrated relating to content and process skills.</td>
</tr>
</tbody>
</table>
## V. Discourse Factors

<table>
<thead>
<tr>
<th>Construct Measured</th>
<th>Pre-Inquiry (Level 1)</th>
<th>Developing Inquiry (2)</th>
<th>Proficient Inquiry (3)</th>
<th>Exemplary Inquiry (4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>D1. Questioning</td>
<td>Questioning rarely challenged students above the remembering level.</td>
<td>Questioning rarely challenged students above the understanding level.</td>
<td>Questioning challenged students up to application or analysis levels.</td>
<td>Questioning challenged students at various levels, including at the analysis level or higher; level was varied to scaffold learning.</td>
</tr>
<tr>
<td>Level</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>D2. Complexity of</td>
<td>Questions focused on one correct answer, typically short answer responses.</td>
<td>Questions focused mostly on one correct answer; some open response opportunities.</td>
<td>Questions challenged students to explain, reason, and/or justify.</td>
<td>Questions required students to explain, reason, and/or justify. Students were expected to critique others' responses.</td>
</tr>
<tr>
<td>Questions</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>D3. Questioning</td>
<td>Teacher lectured or engaged students in oral questioning that did not lead to</td>
<td>Teacher occasionally attempted to engage students in discussions or investigations but was not successful.</td>
<td>Teacher successfully engaged students in open-ended questions, discussions, and/or investigations.</td>
<td>Teacher consistently and effectively engaged students in open-ended questions, discussions, investigations, and/or reflections.</td>
</tr>
<tr>
<td>Ecology</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>D4. Communication</td>
<td>Communication was controlled and directed by teacher and followed a didactic pattern.</td>
<td>Communication was typically controlled and directed by teacher with occasional input from other students; mostly didactic pattern.</td>
<td>Communication was often conversational with some student questions guiding the discussion.</td>
<td>Communication was consistently conversational with student questions often guiding the discussion.</td>
</tr>
<tr>
<td>Pattern</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>D5. Classroom</td>
<td>Teacher accepted answers, correcting when necessary, but rarely followed-up with</td>
<td>Teacher or another student occasionally followed-up student response with further low-level probe.</td>
<td>Teacher or another student often followed-up response with engaging probe that required student to justify reasoning or evidence.</td>
<td>Teacher consistently and effectively facilitated rich classroom dialogue where evidence, assumptions, and reasoning were challenged by teacher or other students.</td>
</tr>
<tr>
<td>Interactions</td>
<td>further probing.</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### VI. Assessment Factors

<table>
<thead>
<tr>
<th>Construct Measured</th>
<th>Pre-Inquiry (Level 1)</th>
<th>Developing Inquiry (2)</th>
<th>Proficient Inquiry (3)</th>
<th>Exemplary Inquiry (4)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>A1.</strong> Prior Knowledge</td>
<td>Teacher did not assess student prior knowledge.</td>
<td>Teacher assessed student prior knowledge but did not modify instruction based on this knowledge.</td>
<td>Teacher assessed student prior knowledge and then partially modified instruction based on this knowledge.</td>
<td>Teacher assessed student prior knowledge and then modified instruction based on this knowledge.</td>
</tr>
<tr>
<td><strong>A2.</strong> Conceptual Development</td>
<td>Teacher encouraged learning by memorization and repetition.</td>
<td>Teacher encouraged product- or answer-focused learning activities that lacked critical thinking.</td>
<td>Teacher encouraged process-focused learning activities that required critical thinking.</td>
<td>Teacher encouraged process-focused learning activities that involved critical thinking that connected learning with other concepts.</td>
</tr>
<tr>
<td><strong>A3.</strong> Student Reflection</td>
<td>Teacher did not explicitly encourage students to reflect on their own learning.</td>
<td>Teacher explicitly encouraged students to reflect on their learning but only at a minimal knowledge level.</td>
<td>Teacher explicitly encouraged students to reflect on their learning at an understanding level.</td>
<td>Teacher consistently encouraged students to reflect on their learning at multiple times throughout the lesson; encouraged students to think at higher levels.</td>
</tr>
<tr>
<td><strong>A4.</strong> Assessment Type</td>
<td>Formal and informal assessments measured only factual, discrete knowledge.</td>
<td>Formal and informal assessments measured mostly factual, discrete knowledge.</td>
<td>Formal and informal assessments used both factual, discrete knowledge and authentic measures.</td>
<td>Formal and informal assessment methods consistently and effectively used authentic measures.</td>
</tr>
<tr>
<td><strong>A5.</strong> Role of Assessing</td>
<td>Teacher solicited predetermined answers from students requiring little explanation or justification.</td>
<td>Teacher solicited information from students to assess understanding.</td>
<td>Teacher solicited explanations from students to assess understanding and then adjusted instruction accordingly.</td>
<td>Teacher frequently and effectively assessed student understanding and adjusted instruction accordingly; challenged evidence and claims made; encouraged curiosity and openness.</td>
</tr>
</tbody>
</table>
## VII. Curriculum Factors

<table>
<thead>
<tr>
<th>Construct Measured</th>
<th>Pre-Inquiry (Level 1)</th>
<th>Developing Inquiry (2)</th>
<th>Proficient Inquiry (3)</th>
<th>Exemplary Inquiry (4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1. Content Depth</td>
<td>Lesson provided only superficial coverage of content.</td>
<td>Lesson provided some depth of content but with no connections made to the big picture.</td>
<td>Lesson provided depth of content with some significant connection to the big picture.</td>
<td>Lesson provided depth of content with significant, clear, and explicit connections made to the big picture.</td>
</tr>
<tr>
<td>C2. Learner Centrality</td>
<td>Lesson did not engage learner in activities or investigations.</td>
<td>Lesson provided prescribed activities with anticipated results.</td>
<td>Lesson allowed for some flexibility during investigation for student-designed exploration.</td>
<td>Lesson provided flexibility for students to design and carry out their own investigations.</td>
</tr>
<tr>
<td>C3. Integration of Content and Investigation</td>
<td>Lesson either content-focused or activity-focused but not both.</td>
<td>Lesson provided poor integration of content with activity or investigation.</td>
<td>Lesson incorporated student investigation that linked well with content.</td>
<td>Lesson seamlessly integrated the content and the student investigation.</td>
</tr>
<tr>
<td>C4. Organizing &amp; Recording Information</td>
<td>Students organized and recorded information in prescriptive ways.</td>
<td>Students had only minor input as to how to organize and record information.</td>
<td>Students regularly organized and recorded information in non-prescriptive ways.</td>
<td>Students organized and recorded information in non-prescriptive ways that allowed them to effectively communicate their learning.</td>
</tr>
<tr>
<td>Summative view of Instruction</td>
<td>Comprehensive Score**</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-------------------------------</td>
<td>-----------------------</td>
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<td></td>
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</tr>
<tr>
<td>Summative view of Discourse</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Summative view of Assessment</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Summative view of Curriculum</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overall view of Lesson</td>
<td></td>
<td></td>
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</tbody>
</table>

*Provide brief descriptive comments to justify score.

**Score for each component should be an integer from 1-4 that corresponds with the appropriate level of inquiry. Scores should reflect the essence of the lesson relative to that component, so they need not be an exact average of all sub-scores in a category.

### Appendix C

**Representations in Chemistry Instruction (RICI) Protocol**

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Pre-Inquiry (Level 1)</th>
<th>Developing Inquiry (Level 2)</th>
<th>Proficient Inquiry (Level 3)</th>
<th>Exemplary Inquiry (Level 4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>R1: User Description</td>
<td>Teacher incorporated representations into lesson.</td>
<td>Students used teacher-provided representations to a small extent.</td>
<td>Students used teacher-provided representations frequently.</td>
<td>Students developed and tested their own representations.</td>
</tr>
<tr>
<td>R2: Conceptual Understanding</td>
<td>Teacher connected one type of representation (macroscopic, symbolic, or particulate) to chemical concept.</td>
<td>Teacher directs students in using more than one type of representation to describe chemical concept.</td>
<td>Students translated one representation of a chemical concept into another representation type (e.g., macroscopic to symbolic, or symbolic to particulate).</td>
<td>Students generated or selected appropriate representations of a concept to make explanations, predictions, or justifications.</td>
</tr>
<tr>
<td>R3: Quality of Discourse Around Representations</td>
<td>There was no discourse around the representations.</td>
<td>Teacher typically controlled and directed the explanation of chemical concepts using the representation. Occasional student input focused on description.</td>
<td>Students used representations to explain chemical concepts but did not debate about scope and limitations of representations.</td>
<td>Students engaged in classroom discussion which included explanation and debate about the scope and limitations of the representations.</td>
</tr>
<tr>
<td>R4: Integration of Macroscopic, Symbolic, and Particulate Concepts</td>
<td>Lesson focused on one view of chemical phenomena (macroscopic, symbolic, or particulate).</td>
<td>Lesson focused on two views of chemical phenomena but did not explicitly connect multiple domains of chemical knowledge.</td>
<td>Lesson explicitly connected macro and symbolic representational domains.</td>
<td>Lesson connected the particulate representational domain with at least one other domain (macro and/or symbolic).</td>
</tr>
</tbody>
</table>
Appendix D

To whom it may concern:

I am graduate student in the Department of Chemistry & Biochemistry at Miami University conducting a study that proposes a method for closing the gaps in observing and documenting pedagogical content knowledge (PCK), and seeks to describe what prominent features are seen in chemical bonding PCK. Your chemistry teacher, Chad Hustling, would like to participate. This study will take place in her classroom. She will be videotaped while teaching a chemical bonding lesson and interviewed before and instruction. Following instruction, she will narrate a guided reflection of a video recording of her own teaching.

I am requesting your permission to conduct classroom observations. The Miami University Human Subjects Institutional Review Board has approved this study and the attached teacher consent form.

The results of the study will be presented at professional meetings and published in research journals. To maintain confidentiality, teachers’ and school names will not be used. Video will not be presented in any form. Records, data, and video will be stored in a locked cabinet in 360B Hughes Laboratories on the Oxford Campus for 2 years after the close of the study and then destroyed.

If you have further questions about the study, please contact Tommy Smith at 614-314-1715 or email: smithrt2@miamioh.edu. If you have questions about your rights as a research participant, please call the Office of Advancement of Research and Scholarship at 513-529-3600 or email: humansubjects@miamioh.edu.

Thank you for your participation. I am grateful for your help and hope that this will be a rewarding experience for your teacher. You may keep this portion of the page.

Sincerely,

R Thomas Smith
Principal Investigator

Dr. Ellen J. Yezierski
Advisor

Cut at the line, keep the top section, and return the bottom section.

I give consent for teachers in my school to participate in the PCK study.

__________________________________
Name

__________________________________
Signature

__________________________________
Date
Appendix E

Dear ____________________,

I am a graduate student in the Department of Chemistry & Biochemistry at Miami University conducting a study that proposes a method for closing the gaps in observing and documenting pedagogical content knowledge (PCK), and seeks to describe what prominent features are seen in chemical bonding PCK. This study will take place in your classroom, and you will be videotaped while teaching a chemical bonding lesson. You will also be asked to take part in a 60 to 90 minute audio-recorded interview within a few days before and after instruction takes place.

I am requesting your voluntary participation. You are free to decide not to participate in this study or to withdraw at any time without adversely affecting your relationship with the investigators at Miami University. You may withdraw from the study by emailing Tommy Smith (smithrt2@miamioh.edu) a message including your name and that you wish to withdraw. Additionally, you have the right to request that taping be stopped at any time.

The results of the research study will be published at professional meetings and in research journals. To maintain confidentiality, you will be assigned a code and your name will not be used. Video of your classroom will not be shown at professional meetings. Records, data, and video will be stored in a locked cabinet in 360B Hughes on the Oxford campus for 2 years after the close of the study. After the researchers analyze these data, records/data will be destroyed.

Participation in the study will provide you with the compensation of a $50.00 Flinn Scientific gift certificate, as well as the opportunity to deeply and significantly reflect on your own teaching practices.

If you have further questions about the study, please contact Tommy Smith at 614-314-1715 or email: smithrt2@miamioh.edu. If you have questions about your rights as a research participant, please call the Office of Advancement of Research and Scholarship at 513-529-3600 or email: humansubjects@miamioh.edu.

Thank you for your participation. I am grateful for your help and hope that this will be an interesting experience for you. You may keep this portion of the page.

Sincerely,

R. Thomas Smith  
Principal Investigator

Dr. Ellen J. Yezierski  
Advisor

Cut at the line, keep the top section, and return the bottom section.

I agree to participate the study including being captured on video. I understand my participation is voluntary and that my name will not be associated with my responses. By signing below, I acknowledge that I am 18 years or older.

Participant’s signature ___________________________ Date: ______________
Appendix F

Dear

My name is Tommy Smith and I am a graduate student working with Dr. Ellen Yezierski at Miami University in Oxford, OH.

I am conducting a study on pedagogical content knowledge (PCK) with a focus on chemical bonding and am in need of exemplary teachers (Ellen provided me with your contact info saying you are a reflective and conscientious teacher).

My study seeks to close gaps in the literature about how to observe and document PCK while uncovering prominent features in chemical bonding PCK. This study has the capacity to improve teacher quality, teacher prep programs, and produce a protocol that can be carried out on other chemistry topics for future use to observe and document PCK.

My study would only require an hour interview, a videotape of one of your chemical bonding lessons (preferably at the beginning of the unit), and then a guided reflection of your video afterwards. In the pilot study, these tasks usually lasted only about two hours outside of normal class time.

As I realize that distance is an issue, a phone or Skype interview would suffice. The video could be uploaded to YouTube or sent to me via a file transfer site (I already tested one that works great) and the reflection can be emailed to me. All data would be kept confidential and have all identifying information stripped from it once it is received and the video will not be presented at any time.

Benefits to you include having a significant, in depth reflection on your teaching and your students’ learning, as well as a $50.00 Flinn Scientific gift certificate as thanks for your participation.

Please reply to this email and let me know if you are interested.

Thank you and I look forward to hearing back from you.

Sincerely,

Tommy Smith
Appendix G

CoRe’s Interview Prompts

1. What are the main concepts you hope that your students learn; the “big ideas?”
2. Out of those big ideas, what specifically do you intend for students to learn?
3. What else do you know about those concepts that students will not be required to learn?
4. What are learning impediments, common student misconceptions, or limitations to this topic?
5. What are some difficulties that your students have with this topic (Push and be thorough)?
   a. What makes this topic tough for students?
   b. Why is this content hard?
   c. Why is it hard for students?
6. How does student thinking influence your teaching decisions?
7. What factors influence your teaching of this topic?
   a. Context?
   b. Kids?
   c. Teacher?
   d. Content?
8. What sort of teaching procedures and methods do you use in teaching this and why (Models, particulate representations, card sorting, etc.)?
9. What are the limitations to your procedures and methods?
10. How can the limitations affect student learning?
11. How do you plan on ascertaining students’ understanding or confusion on the topic?
12. What counts as understanding?
Appendix H

Annotation Prompts

Instructions:

• Please make sure you are in a quiet place when you do your video annotation.
• If using a voice recorder, please wear headphones when watching your video.
• If using a voice recorder, speak freely into the voice recorder or microphone built into your computer and report the timestamp on the video when you begin speaking.

While annotating your instruction video, use these prompts and a few key ideas quoted from your pre-instruction interview to guide your reflection.

Here are some learning outcomes you stated in the interview

   Explain phenomena in everyday life through polarity
   Identify polar and non-polar substances
   Explain the differences between polar and non-polar substances

Prompts

1. To what extent did your expected outcomes match the actual outcomes of your lesson? How do you know? What evidence is there for this?
2. Did any student misconceptions or learning impediments arise that you did not foresee?
3. Discuss the effectiveness of the procedures you used. Did they help you attain your expected outcomes? If so, to what extent? Did any limitations arise that you did not foresee?
Appendix I
Don's Interview Segment

Me: So we're going to be talking about the bonding lesson that you said you are going to be doing for academic chemistry?

Don: Right.

Me: So tell me a little bit about academic chemistry. What makes academic different from a different chemistry class?

Don: Ok we have four different types of chemistry. One is standard. Standard is basically kind of our lowest level. Typically kids in standard need physical science credit, they might be juniors or even seniors and are probably not going to go on in science, they've pretty much decided they're not going to go on in science. Academic chemistry would be the next level. These are kids that will most likely go into college, but most likely they are not thinking of a science background. Then we teach accelerated, which would be somewhat like an honors chemistry. These are kids that are thinking, “yes, they want to go on in college,” and they're probably looking in a science background and they probably may want to take AP chemistry. Then we have AP chemistry. And so the kids I have in academic are juniors and maybe a couple seniors.

Me: For bonding just overall as a unit, what are some of the big goals you want your students to take away?

Don: You know I’ve really, before what I would do is say “ok there’s bonding, covalent and ionic, there’s two types, here are the properties of ionic and covalent,” then do a lab and get on with life. That’s ok, but I think as my education continues, we’ve talked about this in the program at [University M], is that really this thing of bonding is pretty much a slippery slope. I’m beginning to learn that it’s a huge continuum of just these, these interatomic and intermolecular forces that are all sort of different a different to show the same thing of this attraction. Some of these forces would be very much similar to the traditional ionic part and some would be more covalent. But then you know at some point down the road we’ll get into hydrogen bonding, which is really crazy because they say, “well it's not really a bond.” Well what do you mean it’s not a bond? How do you tell a sixteen year old I’m using the word bonding by it doesn’t count in this case. Then you’ve got these intermolecular forces and then the other thing too is well when you dissolve something. Kids get really confused on that because they’re like “well is it breaking a bond? Is it a chemical or physical change?” And I’m like well it depends on how you look at it. I used to say you know duh, it’s just dissolving you don’t see the signs. But on the particulate level you see two things separate right? I’ve really, I hope I’m able to answer your questions, but what I hope to do this year is to help the kids understand that there is this continuum that even we struggle with as scientists sometimes. We have to put them into categories to help us, but that’s what we’re going to try to do, so from here on out we’re going to look at this attraction.
That’s there’s this electrostatic attraction I think on many different bases. That’s what the plan is.
Me: So to sum that up, you’re going to teach those categories but then try to get the student to understand that there is this continuum though that we just try to make it easier for ourselves to put it in covalent and ionic.

Don: Yeah and it’s going to take well beyond just a couple of days. This is a theme that we’re going to be hitting for a while I think.

Me: How long does it usually take to go through bonding? Or how long do you think it will take?

Don: Before it would only take a couple of days because I would do ionic, covalent, we would do a lab where they would say “oh look, the conductivity tester goes off when I dissolve salt, but it doesn’t go off when I dissolve ethanol,” or something. One is covalent, one is ionic, that’s it we’re done, but now it’s going to take longer. It might be a theme we spiral back to, if that makes sense.

Me: Before it was more focused on the macroscopic properties, like conductivity, whereas now you are trying to get to the particulate?

Don: Yes.

Me: With that particulate understanding for this academic level, what do you want the students to know?

Don: Basically the idea of electrostatic attraction and electrons. What are electrons doing? What is the role of electrons and how do those change? So I have some ideas to try different this year, so we’ll see if it works.

Me: tell me a little about the lesson that I’m going to be in here to see.

Don: Ok so it’s funny because I was just working on this this morning. We have done the history of the atom, we talked a little bit about the Bohr model, and we just got to quantum numbers, electron configuration, and orbital notation. So when they come back I’ll probably give them just four questions that says what an ionic bond, what’s a covalent bond, and we haven’t gone over this, this is a pre-assessment, what the electron’s role and I think there was one other question. Then I’m going to say “tell me what you think, this is just for me getting information.” Just kind of see where they’re at, because they, some kids have probably had this in junior high or something and sometimes they toss out the word oxidation and reduction, but I don’t think they really know what that means. Ok so the first thing I’m going to do is “Ok let’s, now that we’ve had exams, let’s go back and let’s just learn if we can just do electron configuration in orbital notation for a handful of items.” So I’ve got that and we’ve got the, we’ve talked about the Aufbau principle, Hund’s rule, Pauli Exclusion, and then there’s a little cheat sheet on the back that’s a guide that kind of says here’s how we follow the different orbitals and if you look at the periodic table here are all
the S’s P’s and D’s and so on. Then what I hope to do is I’m going to say “ok so we’ve got that, I’ve checked that off,” then what I’m going to do is have them take some data. And essentially what the data is, I’m going to take neodymium magnets, place them on an analytical balance and they’re going to go and take a number of compounds in film canisters and just carefully hold them over the neodymium magnet to where it’s barely touching it, like a half centimeter. The balance will be set to zero and I’m going to say “all I want you to do is to tell me, is it going, does it when you look at it, attract or repel, that’s it.” What they’re going to find is some of them attract and some of them repel, including our hands. If you do that, you just barely put your hand over it you’ll get a response right? So I’m going to have them come back and say ok, this is kind of weird, why do you think this is? What do you think we would have to do to figure this out? Let’s just brainstorm for a minute. I’m hoping they come up with something about magnetism. Then I’ll say ok lets learn more about magnetism so I’m going to give them the second handout which says I want you to figure out, tell me a little bit about para and diamagnetic. Ok so let’s look those up and we figure those out and also just for the heck of it let’s look up ionic and covalent bond. Just research it draw a picture tell me what you think, what do electrons have to do with all this? So we’ll start talking about para and diamagnetic and then what I’m going to do is the third part that I hand out is for each of the compounds, like NaCl, I’ll say ok “here’s Na⁺¹ and Na⁺². I would like you to draw the electron configuration for both of those and do Cl⁻¹ and Cl⁻² as an example.” We’ll do that for each of, so a large number of ions that maybe in the compounds that they’ve done. So I have an example in here, so we’ll do like NaCl, simple ionic compounds I think we’re doing, calcium oxide or calcium chloride. I think calcium chloride is one. The goal is hey let’s take a look at these and let’s draw the electron configuration. Now, let’s go back to our data, so for instance, NaCl was it repelled the magnet, they get a positive thing, the we know something about di and paramagnetic. So diamagnetic, that means all the electrons are paired up, so let’s look at some of these charges, so ok of Na plus one and Na plus two, which one was paired up? And then for Cl minus one and Cl minus two, which ones were paired up. Can we put together, these two for instance, that would be experimental evidence or with the experimental evidence and the drawings we have here would this make sense that these two would go together? And so we’ll do that for a number. Then the next set that they’ll do are the transition metals. Now the transition metals, when we get to the ones one here think we do iron, cobalt, there may be another, but there’s iron and cobalt and then what happens is those are paramagnetic and it just so happens the data shows that those attract. So they’ll say wow for these ones they attract and that means that in those and if it attracts its paramagnetic, lets see which one, like the cobalt or the iron, which one would make the sense that it would be, would these match up with what we’re finding? The last set, which is set C, are things like iodine, I₂, ethanol, water, and it says ok they all repel to lead them to think they’re diamagnetic, but then there’s a little explanation in the post lab part that says “hey now we’re talking about molecules,” and these have something called a covalent bond. Would you expect these to have electrons that are paired or unpaired and does it show that? I’m trying to draw in this very abstract quantum mechanical model with an experimental model that then also is a starting point for saying “now that we know these are occurring, would it make sense that they stick together the way they do?” I’m hoping that makes sense to you because I have to try and explain that to a sixteen year old. And I
don’t really want to just give them the answer, but I have to give them something or otherwise we will never get there. Kind of like a guided inquiry activity.

Me: So basically you want them to collect all this data, write down the electron configurations, and then...

Don: and then say here’s the data, here’s the electron configuration, which ones would match up knowing what we know about para and diamagnetic.

Me: So is the end goal to try and get them to be able to figure out what makes sense to bond with something else?

Don: Yeah and then so why and so that say we have experimental evidence that Na\(^{+1}\) doesn’t seem to be plus two, because we would get a whole different thing. Then, well, if I had something that is a plus one charge and something that is a minus one charge, how would those two go together? Because we really haven’t talked about bonding at all yet, we really haven’t talked about the ratios and how they fit together.

Me: So there’s no talk about ratios or...

Don: No

Me: ok I got you.

Don: Ok so, this was taken from J-chem ed article and I’ve got it, the guy did it a the Navel Academy, it was this year actually, I heard it at ACS and I talked to him and wrote to him and he was really nice and responded back. He said here try it and see, and here’s what I would change and feel free to change it and all that, so this is not my idea. I’m stealing this from someone else and I’ve got the, I can get the source and all that should you need it. So once we get to that point then I’ll give them the sort of like the post questions and the and we’ll go through... when I say post-questions, I should back up, there’s the analysis questions here to say here’s para and diamagnetic, that’s page one and two and page three. So here’s the questions: for part A, use the possible electron configurations for each ion to give the chemical ions that are present in the compound, consistent with your experimental results. I’m hoping they’ll find that yeah we probably can’t have Na\(^{+2}\) and Cl\(^{-2}\) those would both be paramagnetic. So it’s Na\(^{+1}\) and Cl\(^{-1}\) and then later on I can say well if that’s what the experiment is showing, a plus one or minus one charge, can we just get, I mean would it make sense that we would get a one to one ratio. And then so, and then it goes through here and talks about the molecular compounds as well. So that’s kind of the ending one thing and leading a jumping point into bonding. And then the and then so and that’s sort of like a mini preview of the lesson that I’ll be doing on bonding, but we’ll probably be doing a lot more over the next few weeks. But I’m going to have to wait and see how this goes before I decide. I would love tell you “here’s the next two or three labs,” but first I need to say ok where are they at as a class? So then what I’ll do is I’ll have the same three or four questions that I asked at the beginning and I’ll ask those again. “Ok well now that we’ve gone over this a little bit, what do you think is going on with the electrons, what’s ionic,
what’s covalent, what do you thinks occurring and see if there’s a change. So in a sense that’s kind of, it’s like bonding, this isn’t a full-blown lesson on bonding completely, but its hopefully starting the initial stages to get them thinking about.

Me: So this is them developing ideas; what initially bonding is before you get into more of the nitty gritty bonding stuff.

Don: Yeah and probably so in an ideal world probably if we were to get into... so depending on how this goes, if they do well on this, what I would then do for bonding is I would say ok I’m going to give you a huge list: covalent, ionic, hydrogen bonding, intermolecular forces, van der waal forces, polarity, these all deal with this sort of attractive nature of either atoms to other atoms or molecules to molecules where this attractive force is. This is kind of connected in a way. So our goal is to slowly and methodically say ok let’s talk about what are some of the properties what are some of the things we do know. And to know as scientists we struggle because kind of like you said we have to put into words something that has a very large continuum to help us make sense of it and that it is not perfect. But we do the least imperfect job that we can ok. I’m going to kind of have to see where it goes from there, because we also have a really good lab we do on intermolecular forces. So in a sense that’s an attractive force that we can say we could somehow lump this in this idea of bonding or attractive forces. We have the traditional one that says these are very covalent; these are very ionic, let’s look at those properties. We could certainly talk about polarity and molecular structure. That kind of has to do with quantum mechanics and attractive forces. You know? But I have to be careful to bit e off or to make it a small enough chunk that it won’t blow up their minds. Because there’s so much that this could just get into.

Me: So where do you think you’ll stop at? At what point do you think “you know ok this is the point where academic is, we’re done with bonding for academic.

Don: So do you mean when you say stop, do you mean like what depth of knowledge?

Me: Yeah how deep do you want them to get?

Don: Well ideally I what I would like them to be able to do is to be able to look at a, well first of all understand what a compound is. The difference between a molecule that probably has something to do with sharing and covalent bonds, a formula unit, an ionic would be something with slightly different properties. Probably polarity
Appendix J

Don’s Reflection Segment

Hey this is [Don] I’m watching the first tape, it’s at about oh, lets see six minutes or so. Bottom line is I think this is the worst possible lesson I’ve ever done on bonding. Because essentially I mean I can watch it and annotate it, but I tried to do pre-tests, like a little pre and post. I watched the kids. A couple things that made this horrible for bonding: number one, it really has nothing to do with bonding. It has a lot to do with electrons and in a round about way it has bonding, but there’s really three things going on. First, they have to be able to do electron configuration. Second, which I tried to check at the very beginning about five minutes into this film, second thing, they then have to be able to do orbital configuration assuming they’ve done all of their work. Third, we then have to talk about ions and do the orbital configuration for ions assuming they know how those ions for. And then those ions forming ionic compounds and then para and diamagnetic. Essentially, way too much to swallow and way too many connections. Its really didn’t get to the heart of bonding. So I thought this was a horrible lesson. I’ve completely revamped it for the next round of kids that I’m doing it. I’m only going to use a few elements. I’m not going to mess with the compounds. I’m just going to have para/diamagnetic, look at the compounds and see if they can have evidence for Hund’s Rule. Once we do that we’ll do electron configuration and then I may do one compound and say ok these electrons are going to be (mumble), just as a bridge. After this when I did the next lesson, I did a lesson that went much better that I wished you’d taped and I mean it was my fault, they took macro scale evidence on the on ionic and covalent compounds like sugar, salt, like potassium chloride and calcium chloride and salicylic acid. Do they dissolve in water, approximate melting points, high or low, do they conduct by itself, does it conduct in water and they just record data. Second thing they did is we went to a PhET simulation and so ok what’s going on on a particulate level that might support or not support what we see on the macro scale? The third thing that we did then is they were asked questions well what if you see a symbol and there’s a metal nonmetal or two nonmetals? And then we found data on other compounds that were covalent and ionic and then they started making associations and started drawing the models. That was a much better lesson. So this lesson, unfortunately, that you’re seeing is really not a good lesson on bonding. It’s really just trying to set up a whole idea for evidence for quantum numbers and again like I said if I would do it over, which trust me I will, I would just pick four or five elements, a couple transition metals, have them draw the electron configuration first, then draw the orbital notation and say ok if we look at these D orbital notation, how do we know if we paired these up or not? There’s a thing called para and diamagnetic, let’s get some data, ok based on the data, how now do you think these interact? And finally I would say ok here’s a sample that I’m going to give you, I tell you you what the sample is, you tell me if this is going to repel or attract as a type of practice, assessment, sort of like a lab assessment. And maybe, maybe put a covalent compound in there and say hey this is diamagnetic and it’s sort of repelling then whatever is going on with these electrons they much all be paring up. This might lead into this idea of covalent bonds, but at the very end only to serve as a bridge. So I apologize for this lesson and it really doesn’t make me feel any better that you caught this on tape too.
## Appendix K

<table>
<thead>
<tr>
<th>Component</th>
<th>Definition</th>
<th>Code(s)</th>
<th>RTCP</th>
<th>EQUIP</th>
<th>RCI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Assessment of Chemistry Learning</td>
<td>Assessment includes all the possible dimensions available for assessment in a high school chemistry classroom and the possibilities for corresponding types of assessments.</td>
<td>Q-11</td>
<td>III-1</td>
<td></td>
<td>A-1, 3, 4, 5</td>
</tr>
<tr>
<td>Chemistry Curriculum</td>
<td>The chemistry curriculum is comprised of horizontal and vertical alignment, curricular materials and programs, the tension between depth and breadth of the material in a high school chemistry classroom, and the core concepts underlying conceptual understanding.</td>
<td>Q-1, 2, 3, 11, 12, V-6, 7, 8, 9, 10</td>
<td></td>
<td></td>
<td>i-5; A-4; C-1, 3</td>
</tr>
<tr>
<td>Instructional Strategies in Chemistry</td>
<td>This includes general strategies and topic specific strategies for chemistry. Topic specific strategies may include labs, demonstrations, investigations, representations, activities, etc. General strategies may include learning cycles, eliciting pre-conceptions, debate, inquiry based activities, discussion, etc.</td>
<td>Q-7, 8, 9, 10, 13, 14, 15, V-16, 17, 18, 19, 20, 21, 22, 23, 24</td>
<td>III-1, 2, 3, 4, 5, 10, 11, 12, 13, 14, 15, V-16, 17, 18, 19, 20, 21, 22, 23, 24</td>
<td></td>
<td>A-1, 2, 3, 4, 5; D-1, 2, 3, 4, 5; C-2, 3, 4</td>
</tr>
<tr>
<td>Orientation to Teaching Chemistry</td>
<td>This includes the teacher’s beliefs about the nature of science, and decision making for a lesson, based on the topic being taught. This includes different philosophies and types of teaching along with the role of the teacher and student. Nine orientations have been reported: process, academic rigor, didactic, conceptual change, activity driven, discovery, project-based, inquiry, and guided inquiry.</td>
<td>Q-6, 7, 8, 9, 10</td>
<td>III-1, 2, 3, 4, 5, V-4, 7, 9, 10, 11, 12, 13, 14, 15, V-16, 17, 18, 19, 20, 21, 22, 23, 24</td>
<td></td>
<td>A-1, 2, 3, 4, 5; D-1, 2, 3, 4, 5; C-2, 3, 4</td>
</tr>
<tr>
<td>Students’ Understanding of Chemistry</td>
<td>A teacher’s knowledge of their students’ understandings, prior knowledge (pre-conceptions and schemas), difficulties, needs, interests, degree of motivation, and developmental level.</td>
<td>Q-4, 5, 6, 7, 9, 10</td>
<td>III-1</td>
<td></td>
<td>A-1, 4, 5</td>
</tr>
<tr>
<td>Teacher’s Chemistry Efficacy</td>
<td>Efficiency is related to chemistry in general as well as the specific topic.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
## Appendix L

<table>
<thead>
<tr>
<th>Component</th>
<th>Strategy</th>
<th>Evidence</th>
<th>Implications</th>
<th>Test</th>
<th>Impact on BM</th>
<th>Summary</th>
</tr>
</thead>
<tbody>
<tr>
<td>Descriptive Testing Overview</td>
<td>The strategy involves identifying potential defects in the system prior to deployment. This strategy emphasizes proactive measures to ensure the reliability and security of the system.</td>
<td>The evidence shows that this approach is effective in reducing the number of defects and improving the user experience. Unintended changes or modifications can lead to security vulnerabilities.</td>
<td>The implications are significant for the safety and stability of the system.</td>
<td>Test</td>
<td>Impact on BM</td>
<td>Summary</td>
</tr>
<tr>
<td>Knowledge of system</td>
<td>The strategy involves understanding the system's architecture and components. This strategy is essential for effective testing.</td>
<td>The evidence indicates that a deep understanding of the system leads to more comprehensive testing.</td>
<td>The implications are crucial for identifying potential vulnerabilities.</td>
<td>Test</td>
<td>Impact on BM</td>
<td>Summary</td>
</tr>
<tr>
<td>Impact on coverage</td>
<td>The strategy focuses on maximizing the test coverage. This strategy aims to ensure that all aspects of the system are thoroughly tested.</td>
<td>The evidence shows that increased test coverage leads to higher system reliability.</td>
<td>The implications are critical for the overall quality of the system.</td>
<td>Test</td>
<td>Impact on BM</td>
<td>Summary</td>
</tr>
<tr>
<td>Assessment</td>
<td>The strategy involves evaluating the test results to determine their validity.</td>
<td>The evidence supports the effectiveness of this approach in identifying defects.</td>
<td>The implications are significant for improving system performance.</td>
<td>Test</td>
<td>Impact on BM</td>
<td>Summary</td>
</tr>
<tr>
<td>Actual待定</td>
<td>The strategy involves ensuring that the tests are executed as intended. This strategy is crucial for maintaining test accuracy.</td>
<td>The evidence indicates that consistent execution of tests is necessary for reliable results.</td>
<td>The implications are important for maintaining test integrity.</td>
<td>Test</td>
<td>Impact on BM</td>
<td>Summary</td>
</tr>
<tr>
<td>Final待定</td>
<td>The strategy involves reviewing the testing process to identify areas for improvement. This strategy is essential for ongoing improvement.</td>
<td>The evidence shows that regular review leads to continuous improvement.</td>
<td>The implications are significant for maintaining testing effectiveness.</td>
<td>Test</td>
<td>Impact on BM</td>
<td>Summary</td>
</tr>
</tbody>
</table>