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Collaborative Professional Development in Chemistry Education Research: Bridging the Gap between Research and Practice

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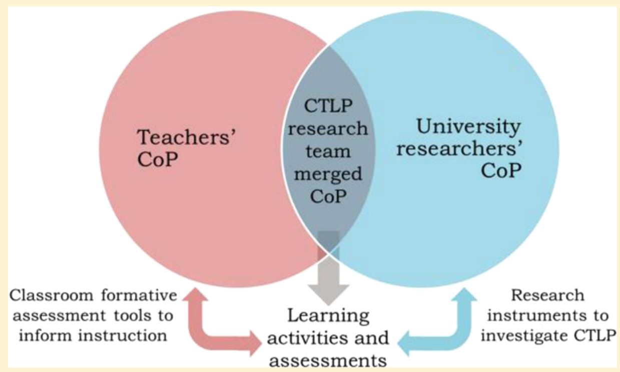
Supporting Information



ABSTRACT: Professional development that bridges gaps between educational research and practice is needed. However, bridging gaps can be difficult because teachers and educational researchers often belong to different Communities of Practice, as their activities, goals, and means of achieving those goals often differ. Meaningful collaboration among teachers and educational researchers can create a merged Community of Practice in which both teachers and educational researchers mutually benefit. A collaboration of this type is described that centered on investigating students' abilities to apply chemical thinking when engaged in authentic tasks. We describe the design-based principles behind the collaboration, the work of the collaborative team, and a self-evaluation of results interpreted through a Communities-of-Practice perspective, with primary focus on the teachers' perceptions. Analysis revealed ways in which teachers' assessments shifted toward more research-based practice and ways in which teachers navigated the research process. Implications for affordances and constraints of such collaborations among teachers and educational researchers are discussed.

KEYWORDS: *Elementary/Middle School Science, High School/Introductory Chemistry, Chemical Education Research, Public Understanding/Outreach, Testing/Assessment, Learning Theories, Professional Development*

FEATURE: Chemical Education Research

INTRODUCTION

Professional development for teachers is crucial to improving student learning, ensuring equity, and creating capacity for sustainability.[1−3] Given the social nature of teaching and learning,[4,5] collaborative and purposeful professional development can provide learning opportunities when groups of individuals discuss student learning and coinvent ideas for improving it. In particular, research has shown that when teachers and educational researchers work together toward a common goal, there is a positive impact on student learning.[6,7] For example, a collaboration among teachers and educational researchers at a university resulted in improved student understanding of the nature of science.[8] Studies of such collaborative work have identified different factors that can influence the success of collaborations. These include environment, membership characteristics, process/structure, communication, purpose, and resources.[9] In particular, the Communities of Practice framework has been used by many researchers to study ways in which members of groups collaborate productively and how the structures of their collaborations can explain the degree of success of collaborations.[5]

Design-based approaches to developing collaborations among teachers and educational researchers can result in gains for both.[10] In design-based research, instructional design and research on learning, teaching, learning environments and educational systems are interdependent.[11] Learning environments serve as context for the research, and their continuous design, study, and improvement become the focus of the collaboration. Teachers who are involved in research become better educators because they reflect more on their practice and tend to take action for improvement. On the other hand, educational researchers gain a deeper understanding of the challenges that teachers face to foster meaningful understandings in the classroom.

In this paper, we describe a collaboration among teachers and educational researchers that centered on investigating students' abilities to apply chemical thinking when engaged in authentic tasks.[12] The paper has two aims. First, we describe the design-based principles behind the collaboration and the work of the collaborative team. Second, we present the results of a self-evaluation interpreted

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through a Communities-of-Practice perspective, with primary focus on the teachers' perceptions.

We focus on the teachers' perceptions for two reasons. First, professional development is often undertaken as an outreach effort, and the anecdotal experiences of the members of our team have been that teachers often feel that professional development has been *done to* them *by* outside organizations whose intentions may include bridging gaps between research and practice. Our collaboration illustrates a successful approach to bridging the gap between chemistry education researchers and chemistry teachers, in which the teachers consider themselves members of a team whose input is necessary, unique, and valued. Second, the teachers on our team refer to our work together as "professional development", and as described below, we employed a highly regarded method of professional development design to plan the agendas and activities for each meeting. Yet, the term "professional development" also has many meanings, with both positive and negative connotations, even for the teachers on our team. Thus, we recognize nuances associated with the term and intend to promote the idea that professional development can be collaborative, positive, and productive.

■ GOALS AND STRUCTURE OF THE COLLABORATION

For the past two years, we have been involved in a design-based collaboration, involving teachers and educational researchers, focused on the exploration of students' abilities to apply chemical thinking while engaged in different types of tasks.[12] The goal of the collaboration has been to design a wide variety of instruments that have dual use, as research tools that can be used to map levels of sophistication in chemical thinking and as formative assessments that teachers can use in their own classrooms to measure students' progress along the learning progression that is mapped. The collaborative work follows Clements' Curriculum Research approach,[13] which specifies a structure for building a knowledge base for education while also attending to the needs of educational reform. This work was structured around a design cycle that is similar to the design cycle used by Nentwig et al.[14] for *Chemie im Kontext* and is illustrated in Figure 1.

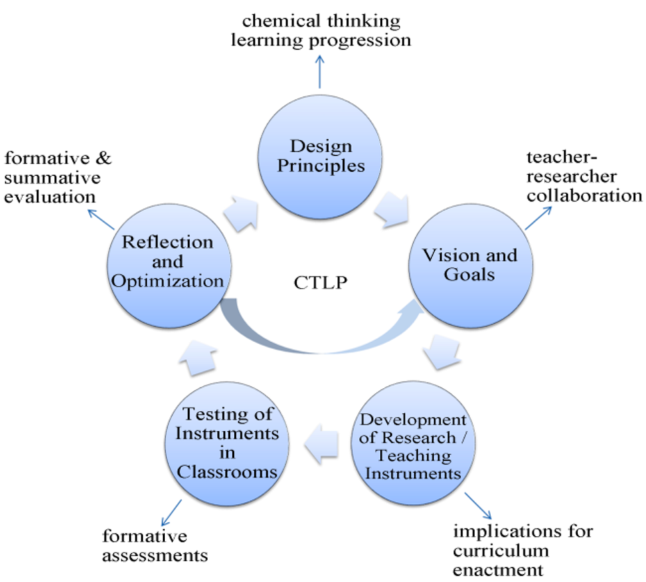

Figure 1. Design research cycle showing development process for research/formative assessment instruments for the Chemical Thinking Learning Progression (CTLP) project and the main products resulting from each stage of the process (adapted from ref 14).

The core goal of our collaborative work is to develop a learning progression on chemical thinking.[12] We define chemical thinking as the reasoning and practices involved in applying chemistry knowledge to address authentic problems. Examples of such problems could be figuring out which ingredients and conditions are needed to make bread rise best, determining the quality of drinking water, evaluating which fuels impart least damage to the planet, or designing a substance that could replace problematic refrigerants.[15] Our research on a learning progression of chemical thinking considers six crosscutting concepts of the discipline: chemical identity, structure-property relationships, chemical causality, chemical mechanism, chemical control, and benefits-costs-risks. Our team is developing several dual-use instruments to study this learning progression. The instruments employ various approaches, including laboratory-based activities, cognitive interviews, questionnaires, and multiple-choice tests. Each instrument focuses on one or two of the crosscutting disciplinary concepts. As described in more detail in another section, in this paper, we use one of these tools, the "GoKarts" instrument, to illustrate the design-based approach taken by our research team.

The design cycle shown in Figure 1 should be conceived as an iterative process; each iteration is a cycle of validation that refines the outcomes. In our case, it begins (top circle) with a hypothetical structure of the learning progression, which is a model of cognition, its associated theoretical commitments,[12] and a commitment to design-based research. Our approach is to study problems that are identified through input of multiple stakeholders in different settings (schools, community, research, industry, state department of education) in partnerships among schools and other institutions with a stake in education. For example, the crosscutting concepts of the learning progression were derived, in part, through interviews of industrial, academic, and government regulatory agency chemists.[12] The research team, whose structure and membership was determined through consultation with school district leaders, has an equal balance of teachers and educational researchers. The input of stakeholders (e.g., students, school and district administrators, researchers external to the team) is regularly sought to bolster validity of the learning progression.

The vision and goals (second circle) are clarified collaboratively, resulting in a collaborative team comprised of teachers and university researchers, before the development of instruments (third circle) begins. The instrument development, and associated activity, initiates discussion of implications for how curriculum is enacted in the classroom, as university researchers spend time in the teachers' classrooms. The instruments are tested in the classrooms of the teachers (fourth circle), both by the educational researchers and by the teachers, as all team members collect data that are collaboratively analyzed.

Careful attention is paid to developing the instruments so that they can be used by other classroom teachers as formative assessments. The team develops district-wide performance-based assessments, and designs and leads professional development both locally and nationally, based on the instruments. The team also develops written resources on the use of the instruments, with examples of student responses that indicate characteristic reasoning patterns within different levels of sophistication of the learning progression, and recommendations for ways that teachers can support students to advance along the learning progression.

Finally, the team engages in reflection and optimization (fifth circle) through a variety of processes, such as meetings with internal stakeholders (e.g., the district science director) and other experts (e.g., advisory board) as well as self-evaluation. This also feeds back to improving the collaboration (arrow shown in center).

Recruitment of members of the collaborative team began in January, 2013. The resulting team includes two middle school science teachers and four high school chemistry teachers from an urban school district; two graduate students, a postdoctoral researcher, and a professor at a public urban commuter university located in the same city; and one graduate student and a professor at a public research university not in the same city. The two professors are chemistry education researchers and are the principal investigators of the project. The graduate students and postdoctoral researcher were identified based on research interests and previous experience working with schools. The teachers were identified and recruited by the Director of Science in the urban school district in collaboration with the professor at the local university. These two individuals developed specific criteria for identification of teachers to invite. In particular, teachers would be teaching chemistry, willing to learn something new, interested in research, representative of the diverse types of schools in the district, and likely to benefit from the experience. Prior to joining the team, permission of the school's principal for participation of the teacher, and consequent participation of students as research subjects (pending appropriate parent consent/student assent) were requested and obtained, according to the school district's IRB policies.

Throughout this paper, we refer to two types of team members: *teachers* (the six individuals who teach chemistry in public secondary schools, grades 6–12) and *university researchers* (three graduate students, a postdoctoral researcher, and two professors). When we use the more general term "researchers", we intend it as reference to everyone on the team, as all are part of the research process.

Monthly team meetings began in March, 2013. Meetings lasted for 3 h during the school year and 6 h during the summer. Dates, times, and locations were mutually agreed upon by all researchers. Some meetings took place in the school district and others at the local university. The nonlocal university researchers connected by Skype or Google Hangout.

■ COLLABORATIVE WORK

The postdoctoral researcher in our team served as the project coordinator and was responsible for developing the agendas for each meeting, initially in conjunction with the two professors, and later with the input of the entire team. The meetings were carefully planned to provide opportunities for professional growth, particularly for the teachers and the graduate students, while also serving as a forum for all team members to work collaboratively to accomplish the research-related work of the team. Although all members contributed to the tasks of gathering and analyzing data, the graduate students took on significantly more responsibility for this aspect of the work. All team members worked together to determine the course and direction of the research and its related written products.

Monthly meetings were planned using the Professional Development Design Framework,[3] considering all members of the team to be participants who would benefit from the research team meetings as professional development. Briefly, this method involves several phases of planning, including:

- Examining knowledge and beliefs to develop an overarching vision of the professional development
- Considering context in analyzing teachers' needs regarding student learning
- Identifying critical issues to set goals for the professional development
- Determining strategies that become the action plan
- Executing the professional development
- Evaluating whether and how the goals were met, for whom, and how the professional development could be improved

The vision had been substantially laid out in the overall project design; however, a major emphasis of the professional development included creating a shared sense of vision. We found two aspects of this process to be particularly important for our work. First, in effecting the Vision and Goals of the collaboration (see Figure 1), both explicit and unwritten goals were carefully selected by the local professor and the project coordinator. Explicit goals included the overt tasks and skills to be addressed in the meetings, and the unwritten goals included entities such as developing cohesiveness as a team and building investment and buy-in of the members. Second, internal evaluation became central to the work (see Reflection and Optimization in Figure 1).

The content of the meetings varied as the project developed. Initial meetings focused on specific research strategies, such as instrument development, cognitive interviewing, data entry, and data analysis using qualitative coding software, which were necessary to move the research forward. Once a significant amount of data was collected and coded, the team began to work together to draw inferences and to arrange the findings into potential learning progressions, as well as to collect and examine pilot data from other research instruments that we collaboratively developed. As the project progressed, the work shifted to focus more on examining literature from related research, as well as designing professional development for others (in the form of workshops in the school district and nationally) to disseminate the knowledge generated from the collaboration. We also planned for the written products of this work, including this paper, a research paper based on the first research instrument developed, and a related product for teachers to use the instrument as formative assessment and apply our research findings to classroom instruction.

During the spring of 2014, the team gathered reflections from all members in order to evaluate the effectiveness of different aspects of our approach. The data that were collected, our analysis, and what we learned from it are reported after the next section, which describes one of the instruments we developed and our process of development.

Example: "GoKarts" Instrument Development

The team has, so far, fully developed two instruments through a full design cycle, and is in the process of developing two more. One of the two fully developed instruments is a cognitive interview research instrument (the "GoKarts" instrument) to investigate underlying assumptions in chemical thinking around the core ideas of chemical identity and benefits–costs–risks analysis of middle school, high school, and undergraduate students.[12] This instrument focuses on two of the six crosscutting disciplinary concepts for the CTLP: (1) Chemical identity addresses the question of how to identify substances and considers what types of matter there are and what cues are used to identify matter.[16] (2) Benefits–costs–risks thinking addresses how the impacts of chemically transforming matter are evaluated and considers what the effects are of using and producing different matter types and how the effects of this can be controlled.[17]

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We describe the development of this instrument to illustrate the nature of our collaborative work.

In the GoKarts instrument, participants are presented with a scenario in which they are asked to evaluate what fuel to use in a GoKart at an amusement park. They are asked to select from one of four available fuels: gasoline from petroleum, gasoline from wood pellets, natural gas, and E85. Participants are told that the first two fuels are composed primarily of octane, natural gas is primarily methane, and the main component of E85 is ethanol. A semistructured interview protocol is used to probe participants' reasoning about chemical composition, structure, reactivity, outcomes, and consequences of using and producing different fuels (see Supporting Information). Additional information about the fuels is presented sequentially—normal states of matter of each fuel, elements from which the fuels are comprised, and ball-and-stick pictures of the molecular structures—and participants are asked whether the additional information is relevant and influences the decision. Finally, participants are asked to elaborate on whether one fuel is better in terms of impact on the environment.

Initial development of this instrument occurred over several months of meetings. In our first meeting (in March, 2013), all members of the team were introduced to the main theoretical constructs underlying the research (Design Principles in Figure 1), with particular focus on chemical identity and benefits—costs—risks analysis. For example, to introduce chemical identity, as part of developing ownership by all members of the team (Vision and Goals in Figure 1), each researcher was asked to consider how she or he might challenge students about whether water and ethanol boil at the same or different temperatures. The concept was introduced in this way because all team members have had experiences teaching chemistry concepts, albeit at different educational levels, and could bring expertise to thinking about ways to teach about this. As the discussion moved to how one could engage students in an activity to tell the difference between ethanol and water in unmarked bottles, the team considered various perspectives on interpreting ways that the teachers thought students might think about how the substances are different.

To initiate the Development of Research/Teaching Instruments (see Figure 1), an early version of the instrument that was designed by the university researchers was presented along with an interview conducted by one of the university researchers with a middle school student in one of the teacher's classes. To introduce the strategy of cognitive interviewing, researchers were asked to provide feedback to improve the interview, specifically to discuss the interview technique (e.g., ways in which questions were asked, wait time) and how to better elicit students' ideas. Discussion then centered on general principles for conducting cognitive interviews using this instrument and ways to improve the instrument. Researchers afterward worked in pairs and practiced interviewing each other, recording the interviews, playing them back, and discussing strengths and shortcomings of the interviews in eliciting ideas of the person who was interviewed. Ethics in human subjects research was also discussed. The school district's IRB does not require human subjects training; however, the university researchers felt it was important to establish common understanding of ethical issues, reasons for using consent/assent forms, and what data could and could not be collected.

Subsequently, the university researchers visited the schools of one middle school and one high school teacher and interviewed several students selected by each teacher, initiating Testing of Instruments in Classrooms (see Figure 1). Teachers selected one student who "gets it" and one student who "struggles but works earnestly". Prior to interviews, the teachers requested student assent and parent consent. Teachers maintained all records associating code names of students to real names. These pilot interviews were transcribed and the transcripts were used during the following two monthly meetings to refine the instrument, improve all team members' cognitive interviewing techniques, and practice qualitative coding using the categories of underlying assumptions specified in the Chemical Thinking framework.

Following question testing and pilot testing of versions of the instrument, the teachers and university researchers conducted and analyzed interviews with 5 middle school students, 13 high school students, 32 undergraduate students, and 5 professors. Every teacher interviewed at least two of his or her own students (Testing of Instruments in Classrooms, Figure 1). All of the middle and high school student interviews, and some of the undergraduate and faculty interviews, were coded by pairs of researchers, with one teacher and one university researcher per pair (refining Design Principles, Figure 1). Data were coded using Dedoose, with pairs meeting via Skype or Google Hangout in between research team meetings. Inter-rater reliability tests on some of the data were also conducted in this way. Time during several subsequent meetings was allocated to developing inferences from the codes to create hypothetical learning progressions about chemical identity and benefits-costs-risks. A research paper based on analysis of these interviews is being separately developed by the collaborative team. The GoKarts instrument is available in the supporting documents. The GoKarts instrument, and associated cognitive interviewing approach, also serves as the basis for district-wide performance-based assessments, designed by teacher leaders in the district, and our collaborative team is leading professional development to introduce teachers to it. Members of the collaborative team will also present a workshop based on this instrument at a national conference.

■ SELF-EVALUATION: CONCEPTUAL FRAMEWORK AND METHODOLOGY

Evaluation Questions and Instrument

In order to assess perceptions of all of the researchers' experiences in the collaborative effort, all team members ($N = 12$) were provided with a questionnaire (Table 1) and asked to write narrative responses about their experiences (positive and negative), assumptions, and implications for their profession. The questions

Table 1. Questions Provided to the Collaborative Research Team As Prompts in Order to Obtain Narratives about the Researchers' Experiences in the Collaboration

Question Number	Question
Q1	What did you gain from the process of working in this collaborative effort?
Q2	What were your assumptions going into the collaboration?
Q3	How did your perspective change throughout the process?
Q4	Why do you think the process worked? What was positive about your experience?
Q5	Was there anything that did not work for you? What was negative about the experience?
Q6	What do you think are the implications for your profession?
Q7	If there is anything about your history that you think influenced your experience, please describe it.
Q8	Is there anything else that you think is important about the research, your experiences, or the process of the collaboration that you have not written about above?

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in the questionnaire were derived from Kisiel's study of a school–aquarium collaboration.[18] The intent of the self-evaluation was to answer two questions:

1. What characteristics of this collaboration worked well?
2. In what ways can the collaboration be improved?

Conceptual Framework

Data collection and analysis were guided by existing work in the area of Communities of Practice. A Community of Practice (CoP) refers to an entity of people who are actively working together and collaborating toward a common goal.[5] CoPs share activities, goals, and means for achieving those goals. This conceptual framework is based on the idea that learning is both a social activity and is situated within a context. Members of a CoP have three identifiable characteristics: a *mutual engagement* (shared activities and actions), through which emerges a *joint enterprise* (informally negotiated shared goals of the community), with a *shared repertoire* (the artifacts used and developed by the community).

The CoP framework explains the use of people and objects that assist with interactions between one CoP and another. *Boundary objects* are defined as entities or processes that help interconnect CoPs.[19] *Brokers* are individuals within or outside (but related to) the communities that facilitate communications and, therefore, help to carry the work as well. Relationships among members of a CoP develop and evolve over time, which leads to mutual engagement. To be successful, members must purposefully meet and engage with each other on a regular basis to discuss and process elements of the domain that are important to the community. Throughout the development of a CoP, several pieces of the shared repertoire emerge and tools are created to summarize and communicate the knowledge of the community.

Generally, teachers in schools (e.g., K–8, high school) are considered to belong to different CoPs than educational researchers (e.g., at universities, informal science institutions) because their activities, goals, and means often differ. Meaningful working relations between teachers and researchers have the potential to "cross the chasm of inside–outside in ways that have the potential to positively impact both communities".[20] Additionally, collaborations among teachers and educational researchers have been shown to provide teachers with intellectual stimulation that mitigates disengagement.[21]

A CoP lens can shed light on how and why collaborations between teachers and educational researchers may result in benefits for members of both communities when the communities become intertwined. For example, in a comprehensive three-year study using a CoP lens, Kisiel[18] demonstrated that a school–aquarium collaboration resulted in increased time on science learning at the elementary school because teachers reflected more deeply on instructional practices and learned how to use the aquarium as an educational setting. Aquarium science educators gained more appreciation for the teaching practice because of the relationships they developed with teachers and students.

Data Analysis

Responses to the questions listed in Table 1 were collected and deidentified and then randomly distributed to all members of the team. All researchers contributed to the overall structure of the coding scheme. Google Drive was used to share documents and to compile coding from all researchers. Working in groups of three, the researchers were assigned narratives (not their own) to analyze qualitatively using iterative, open-coding analysis.[22] Each three-person group coded four interviews. The groups came to agreement on code assignments and resolved any discrepancies among them. After coding was complete, the postdoctoral researcher on the team compiled the narratives, coded excerpts, and listed codes. To check for inter-rater reliability, the postdoctoral researcher coded all of the narratives separately. Final codes were compared between the code set by the postdoctoral researcher and the code set by the rest of the researchers.

A constant comparative method was used for analysis. The benefit of using this method is that the research begins with raw data and, through constant comparisons, a substantive theory can emerge.[22,23] The method occurred in four steps:[23] (1) comparing incidents applicable to each category, (2) integrating categories and their properties, (3) delimiting the theory, and (4) writing the theory. Using these four steps, the researchers continually sorted through the data collection, analyzed and coded the information, and reinforced theory generation through the process of theoretical sampling.[24] For example, it became apparent that some of the codes fell into categories corresponding to the three aspects of CoPs (mutual engagement, joint enterprise, shared repertoire) and the two entities that assist with interactions (boundary objects, brokers). Most of the other codes corresponded to the process of the collaborative team's work and how individual researchers' thinking changed over the course of the collaboration. These two groupings became the major themes of the findings. Data were uploaded and analyzed using Dedoose. Major code categories were counted and used to create assertions, which became the essence of the findings described in the following section.

The coding agreement between the code set by the postdoctoral researcher and the code set of the other researchers was 84.4%, which indicates high inter-rater reliability.[25] The open coding and constant comparative method revealed some major themes that were consistent throughout the researchers' responses to the questionnaire.

■ SELF-EVALUATION: MAJOR FINDINGS

The analysis of the responses to the questions in Table 1 gave us insight into the researchers' perceptions of (a) the nature of the collaborative effort and (b) its major affordances and constraints. We summarize the core results in these two different areas in the following subsections, with focus on the perspectives of the teachers, as our aim is to highlight how this collaboration bridged gaps between research and practice.

Perceptions of Characteristics of the Community of Practice

The majority of the researchers perceived the collaborative effort as a *joint enterprise* in which goals, processes, and products were shared and mutually developed. As an example of this perception, consider this excerpt from the narrative of one of the high school teachers:

> *My perspective changed dramatically and quickly. I found it quite interesting that the criteria for the research had not fully been developed. As a matter of fact, our input was an integral part of the process which guided the way the research was to develop...Our input was not only about our opinions about students' learning and thought processes, but also used to determine new goals for our collaboration. We came up with new directions for the papers and for the training planned for our colleagues.* [high school teacher, narrative 6]

The researchers developed a sense of *mutual engagement* in collaborative work, where all researchers engaged in similar activity:

developing instruments, conducting interviews, analyzing data. The collaborative work was perceived to be successful because it took advantage of the different strengths of the various researchers in an environment in which all contributions were equally valued and respected:

I think the process works because each member of the research team brings a perspective that is needed in order for this project to be successful and because we all have great respect for each other's work and expertise. [university professor, narrative 11]

Teachers considered that each researcher's views were taken seriously and considered central to the work:

Despite carrying out design elements and dedicating a great deal more time to the research end, the research team [university researchers] never 'pulled rank' over the educators, and valued our input and contribution to the coding, planning, and discussions that have taken place over the time that the collaboration has been in existence. This is extremely important for the collaboration to continue to work, as I could imagine our buy-in to the process slipping if the teachers' sole role was to contribute to research. Everybody has been open-minded, flexible, and participatory throughout our meetings, which has led to a strong sense of community that motivates us to continue to try and produce the best possible outcomes regarding professional development offerings, journal publications, and future research. [high school teacher, narrative 4]

Narrative responses to the questionnaire consistently referred to pieces of a *shared repertoire*, including the theoretical framework employed and tools that were created. For example, most respondents (N = 6 teachers, N = 3 university researchers) referred explicitly to the shared repertoire of *assumptions* (underlying ideas that guide but may also constrain student reasoning), which is a central theoretical construct of the Design Principles (Figure 1). Many respondents (N = 4 teachers, N = 1 university researcher) also referred to the importance of the tools that were created through the work, such as the GoKarts instrument and the professional development workshops.

Several narrative responses identified *boundary objects*. For example, the school district's Science Department central office facilities were the site of most of our monthly meetings. Much of the science professional development in the school district takes place there, and two of the university researchers have spent a great deal of time in this space. These facilities served as a boundary object acting as a familiar space where all of the teachers felt comfortable. The analysis also suggested that two individuals, as well as one subset of the researchers, served as critical *brokers* for the CoP. The professor from the local university was a broker for the CoP due to her long-standing working relationships with many of the teachers and with the Director of Science in the school district. The following excerpt is representative of the thoughts expressed by teachers:

I would like to think that bringing researchers and practitioners together to collaborate on a project would work under any conditions but I cannot negate the fact that there was already an existing familiarity and respect among the teachers and one of the principal researchers. I think this enabled trust to be quickly established and empowered individuals to be open and honest about ideas, concerns, and lack of chemistry, pedagogical, or statistical knowledge. [middle school teacher, narrative 8]

The school district's Director of Science was also identified as a broker, for although she did not participate as one of the researchers, she was present for parts of several of the meetings, and consideration of her perspectives was often evoked in her absence. Third, middle school teachers perceived that high school teachers served an important brokering role by providing content knowledge support and guidance:

Personally, I think the presence of both middle school and high school teachers had a big impact on the success of the project. I feel that the high school teachers provided a bridge between the middle school teachers and the researchers. The high school teachers, in general, have a deeper understanding of the content and also have pedagogical experience. I felt more comfortable with my more elementary understanding of chemistry because I had the high school teachers to provide clarification and interpretation. (middle school teacher, narrative 8)

Perceptions of Challenges That Reveal Affordances and Constraints

Affordances are relationships between the situation and the participants in the situation that allow for certain actions or changes. Constraints are relationships between the same that present restrictions. Analysis of the narratives suggests that the work within the CoP had a strong influence on teachers' beliefs and perceptions of assessment, as well as on their ability to assess and interpret student learning and understanding. In other words, the collaboration created affordances in relation to the teachers' views of assessment. Several teachers cited examples of changes in their assessment practices (N = 3 of 6). For example, consider the following from one teacher:

Just recently, I gave my students a very open ended prompt in response to a demonstration they witnessed. I gave them very little information about what was happening or why I showed them the demonstration, and collected data from them on what they thought was happening on a particulate level. In the past, I think I shied away from asking such open-ended questions without giving the students more of a basis for answering them, partly because I was not sure how to interpret incorrect ideas I would see. After working on this project, however, I felt more equipped to read their answers and interpret them based on what assumptions or models the students were using in their reasoning. [high school teacher, narrative 1]

Similar to the teacher in the above narrative, teachers also commented on changes in their ability to interpret student answers and guide student learning (N = 4 of 6):

Over the course of the past year I have developed a new way of thinking about my students' thought process, specifically their thinking around "misconceptions". I started to try to find reason in students' statements even if they did not have a correct answer. Prior to this experience I was able to identify misconceptions and even expect them from the students, however I never really thought about the implications of those misconceptions...Rather than just seeing what students wrote correctly or incorrectly I started to look at responses on a continuum and began to understand what their writing or discussions could teach me about their understanding. [middle school teacher, narrative 3]

The value placed on listening carefully to students' answers to assessment questions seemed to increase, and teachers gained confidence in interpreting students' thinking:

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I had never done qualitative research before. And while I did not need to be convinced of its value, I did have a learning curve to master the practices that quantify student understanding beyond the "test grading" metrics I was used to using...The big revelation for me...was the idea that that some student "misunderstandings" are better thought of as stepping stones, and that there may be a pattern and progression in the stepping stones...Before this, my approach was dichotomous—a student understood or did not. Now, my perspective is more nuanced, in that I seek to identify where a student is in his or her understanding—students are no longer "wrong", but in a place that can be identified, characterized, and moved forward from. [high school teacher, narrative 12]

Some teachers (N = 3) judged that their increased ability to assess student understanding would have a positive effect on other areas of their teaching practice, such as lesson planning, use of instructional materials, and creation of richer learning environments:

I believe that the act of being involved in developing these tools has given me new perspectives about ways in which I could use lessons from interviewing and coding to revise and redesign lesson plans in a manner that encourages students to explain their thinking, models, and assumptions in a more complete and detailed way. [high school teacher, narrative 4]

Teachers attributed much of their expanded views to learning and teaching to being involved in qualitative research, particularly to having to carefully code and analyze students' interviews:

We as teachers often read and hear what our students' responses are and determine whether they are right, wrong, or even close. We have to make instantaneous decisions about what and why they think the way they do in order to come up with responses or to correct a misconception. This effort has allowed me more time to delve into the whats and whys of their thought processes since we had to code their transcripts in a concrete manner. [high school teacher, narrative 6]

There were also challenges perceived by the teachers that revealed constraints of the collaboration. Some seemed to struggle with the uncertain and flexible nature of research, as expressed in the following excerpt:

It was difficult to keep on changing the direction and focus of our work. I understand that it is the process of research to do so, but my preference is to have a clear objective and to achieve it efficiently and with excellence. The monthly meetings often changed directions and it took a while to acclimate to the new processes and input that were being asked for. This is not a bad thing per se. I would not say that it is negative, just not as smooth as I would like. [high school teacher, narrative 6]

However, those who expressed anxiety also shared that they were learning to better deal with uncertainty, were empowered by participating in the collaboration, and felt a strong sense of community among the group. In fact, some teachers voiced benefits that came from struggling with the research process:

My experience with research has always been that you start with a hypothesis, design a method for collecting data that will prove if the hypothesis is correct, and then determine if the data supports or refutes the hypothesis. This project did not fit that mold and as a result of my limited experience, I was skeptical of the research process...Being able to be part of the process from the beginning has given me a stronger understanding of research in education. I no longer am hesitant or skeptical and will read research papers with a very different "eye." [middle school teacher, narrative 8]

DISCUSSION

Despite considerable advances in science and chemistry education research in the past 30 years, the impact of such research in teaching practices at different education levels has been limited.[26] Educational researchers and teachers are often members of CoPs with different goals, interests, knowledge, and beliefs about teaching and learning.[27] Bridging the gap between these two communities may thus not be easy, but it is critical in bringing to fruition the vision outlined in recent reform documents for science education in the U. S.[28,29] The professional development work described in this paper may serve as a model to move chemistry education in such a direction by illustrating ways in which researchers and teachers can engage in collaborative work.

The analysis of collaborative activities and the researchers' perceptions in our collaboration suggests that the design-based research cycle (Figure 1) had the effect of merging two CoPs, teachers and university researchers, into a new CoP centered on the shared work of developing instruments with a dual purpose: investigating students' ability to apply chemical thinking and formatively assessing student understanding in the chemistry classroom. Our results indicate that collaborative work centered on the development of such tools can have a major impact on teachers' views of assessment of student learning. Changing teachers' beliefs about and approaches to assessment, looking to focus their attention on the substance of student thinking,[30] rather than on the mere selection of assessment strategies and techniques, is of central importance in the implementation of more effective forms of teaching.[31,32]

One of the major affordances of the Design Framework (Figure 1) that guided our collaborative work was that it provided clear expectations for the types of products that would result from the collaboration. These products were seen as useful and beneficial to all members of the CoP. Their development and implementation, together with the collaborative analysis of student data collected using these instruments, helped to merge the goals and interests of teachers and researchers and to make explicit different approaches to interpret student thinking. Equally important were the affordances conferred by individuals who were able to bring together diverse collaborators. Their presence facilitated interactions among different constituents and helped build trust in the research process. Our results suggest that collaborations between teachers and researchers are likely to benefit from the presence of individuals who have experience transitioning between the different CoPs and are respected by their members.

Although some teachers expressed some level of discomfort with the flexibility and uncertainty of certain aspects of the research process, their active involvement in the design and implementation of the investigation seemed to have helped them better understand the benefits of more deeply engaging in the analysis of students' ideas. The university researchers were challenged to communicate their goals and research framework in manners that were meaningful to teachers. Evidence indicates that teachers began incorporating into their assessment practices key elements of the research framework and that they assumed ownership of the goals of the collaboration.

Overall, this design-based research collaboration had the effect of bridging research-practice gaps, particularly views of assessment and students' learning progress. The CoP framework provides a powerful lens for considering the characteristics of the collaboration. It permitted us to identify ways that the collaboration both challenged us and changed our views. We hope that the description of our collaboration will encourage other researchers to design and evaluate similar enterprises around the globe.

■ ASSOCIATED CONTENT

Supporting Information

The GoKarts interview protocol is included in the Supporting Information. This material is available via the Internet at http://pubs.acs.org.

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Notes

The authors declare no competing financial interest.

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