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# No Teacher Is an Island: Bridging the Gap between Teachers' Professional Practice and Research Findings

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**ABSTRACT:** Despite decades of research regarding best practices for the teaching and learning of chemistry, as well as two sets of national reform documents for science education, classroom instruction in high school chemistry classrooms remains largely unchanged. One key reason for this continued gap between research and practice is a reliance on traditional, prescriptive professional development (PD) in place of PD that focuses on changing teachers' ideas and beliefs. The former view treats teachers as technicians, workers who are supposed to follow a manual to produce student results. The latter view holds that teachers are professionals and develop good practice over time through professional reflection and interaction with other professionals. Bridging research to practice requires moving away from the standard short-term dissemination model of PD and toward a more coherent, long-term PD model in which teachers collaborate with educational researchers to transform instruction. The recent release of the *Next Generation Science Standards* encourages rethinking how we approach teacher PD to support transformation of science education. This paper outlines some key considerations for developing productive teacher collaborations and provides examples of teacher PD programs that have successfully brought chemistry education research faculty and high school chemistry teachers together to build knowledge and transform teaching.

**KEYWORDS:** *High School/Introductory Chemistry, Analogies/Transfer, Professional Development, Administrative Issues*

## ■ INTRODUCTION

We have learned much about the best practices for teaching and learning of chemistry. For example, Johnstone's work[1] suggesting that understanding chemistry requires integration of knowledge on three levels (macroscopic, particulate nature, and symbolic) has been one of the most influential ideas in chemistry education in the past 30 years.[2,3] This prompted research studies examining students' abilities to make connections among these three levels.[4] Gabel suggested that the problem was not students' ability to understand the three different levels but rather that chemistry was largely taught on the most abstract level, the symbolic level.[5] She found that most teachers did not integrate all three levels in their instruction. In the past 15 years, we have certainly seen some changes resulting from this research, for example, the incorporation of particulate level representations in chemistry textbooks. However, in our experience working with high school teachers, little of this research has been enacted in high school chemistry classrooms. This is just one key example of a disconnect between research and practice.

In addition to content-related issues, research also supports the importance of using student-centered instruction in science.[6,7] The *National Science Education Standards* (NSES) called for science classrooms where student "understanding is actively constructed through individual and social processes" and where "learning science is something that students do, not something that is done to them".[8] Now, almost two decades later, the *Next Generation Science Standards* (NGSS) call for many of the same approaches,[9] and yet, the majority of high school chemistry instruction across the country still relies on didactic methods with confirmation laboratory activities.[10]

Studies examining the gap between research and practice have found that many teachers are unaware of chemistry education research. Instead, teachers rely on personal experiences to make decisions about good teaching.[11,12] Often these experiences are related to their own high school and college chemistry classes, which frequently employed didactic methods with confirmation laboratory activities.[13] Even if teachers are aware of the research and have a desire to use evidence-based practices, many have difficulty translating research conclusions into tangible practice. Moreover, the multiple demands placed on science teachers leave little time for trying to make these connections on their own.[14]

One goal of quality professional development (PD) programs could be introducing teachers to the chemistry education research literature. However, PD programs have to

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do more than conduct one-day workshops on the innovative, research-based instructional strategies. Teachers need to be involved in trying out and analyzing their practice and making data driven decisions to transform their teaching.[15]

How then do we bridge the gap between research and the practice of high school chemistry teachers? We think one answer is to engage high school chemistry teachers as professionals and build PD with them, rather than for them, that provides ongoing, collaborative support.

## WHAT CAN PRODUCE INSTRUCTIONAL CHANGE?

Effective teaching is hard and requires more than just knowing your content and being aware of effective teaching methods. Lee Shulman[16,17] was the first to suggest that pedagogical content knowledge (PCK) is another important component of knowledge teachers must possess for effective teaching. PCK is essentially knowledge about how to connect a subject's content with specific knowledge about pedagogy so as to structure meaningful learning opportunities for students in that subject. Researchers who have grounded their work in Shulman's original ideas highlight four key characteristics of PCK:

(1) PCK involves the synergistic application of knowledge from different, discrete categories to practice.
(2) PCK is dynamic and develops throughout a teacher's career.
(3) PCK is highly content dependent.
(4) PCK is not an independent type of knowledge but rather the transformation of other kinds of knowledge (content, pedagogy, context) into meaningful instruction.[18]

Researchers agree that PCK is not just something teachers possess; it is also a tool that they use in planning and carrying out instruction.[18] Moreover, studies looking at teacher development of PCK stress the importance of reflection on teaching practice as a key component.[19] Thus, it should come as no surprise that traditional short-term, workshop PD formats that focus on dissemination of step-by-step teaching methods or curriculum materials have little to no effect on changing practice.[20]

What kind of PD does effect change? In a recent analysis of the literature surrounding facilitating change in undergraduate STEM instruction, Henderson et al.[21] identified four unique categories of change strategies that they placed on two continua: (1) intended outcome, which could either be prescribed (predetermined without participant input) or emergent (determined with the participants during the PD), and (2) aspect of system to be changed, which was either individual or environment/structures. By using these two continua to construct quadrants, four broad categories of change practices were identified: development and dissemination of STEM curricula and pedagogy (prescribed and individual); developing reflective STEM teachers (emergent and individual); enacting policy for instructional practices in STEM education (prescribed and environment); and fostering a shared vision among STEM teachers (emergent and environment). The researchers concluded that "two commonly used change strategies are clearly not effective: developing and testing "'best practice"' curricular materials (prescriptive and individual) and then making these materials available to other faculty, and "'top-down"' policy-making meant to influence instructional practices (prescriptive and environment)". This suggests that we simply cannot prescribe change in education. The key players, the teachers, must be involved in the change process. This systematic analysis of change strategies yielded the following conclusions about the necessary components for effecting change: (1) the strategy must seek to change individuals' beliefs; (2) interventions must be long-term; and (3) an effective strategy must recognize that institutions are complex systems, and so, the strategy needs to be compatible with the system.

Though we share the opinion of Henderson et al.[21] that one should be cautious in directly comparing higher education institutions and secondary education schools, we believe there are sufficient parallels, at least in examining the common features of effective approaches for fostering teacher change. One way to support these connections is to examine Henderson's findings in light of PCK development.

Instructional change requires changes to PCK, but PCK development is not only content dependent, it also is very personal. Teachers come to teaching with a unique combination of knowledge, personal characteristics, and experiences that are juxtaposed with differing student populations and school environments. Effective PD strategies aimed at teacher change must be flexible in accounting for the complex and differing backgrounds and environments as well as providing opportunities for meaningful reflection on practice.[18,19] Therefore, it is not surprising that the one size fits all types of change strategies that Henderson et al. classified as those with prescriptive outcomes are largely unsuccessful. Moreover, instructional change takes time, much more than the traditional 2−5 day workshop programs that currently dominate the PD landscape. Thus, in synthesizing the literature on PCK development with Henderson's analysis of effective change methods in fostering teacher change, we propose that PD models that will serve to bridge the gap between research and practice and promote lasting instructional change for high school chemistry teachers should incorporate the following key elements:

(1) Emergent objectives.
(2) Reflection on teaching of particular content.
(3) Adaptability.
(4) Ongoing/long-term intervention.
(5) Teachers who are partners in the PD.

## EXAMPLES OF COLLABORATIVE PROFESSIONAL DEVELOPMENT PROGRAMS THAT HAVE SUCCESSFULLY BRIDGED THE RESEARCH-PRACTICE GAP

There is no single formula for bridging the gap between research and practice, but there are programs that have brought about substantial instructional change. Examining these programs, we can see that each has in essence established collaborative PD between middle/high school chemistry teachers and college chemistry education faculty that incorporates the five key elements for effective instructional change listed previously. The following section describes three examples and highlights ways in which each program incorporated the five key elements.

### Chemical Thinking Learning Progression

In this program, college faculty, postdoctoral researchers, graduate students, and middle and high school chemistry teachers collaborated to develop a series of instruments to be used as research tools.[22] These instruments map the development of students' chemical thinking about particular topics.[23]



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The two elements of the design-based cycle (Figure 1) that were noted as particularly important for their collaborative work (development of a shared set of vision and goals, and reflection)[22] align well with the key elements we have identified for promoting lasting instructional change.

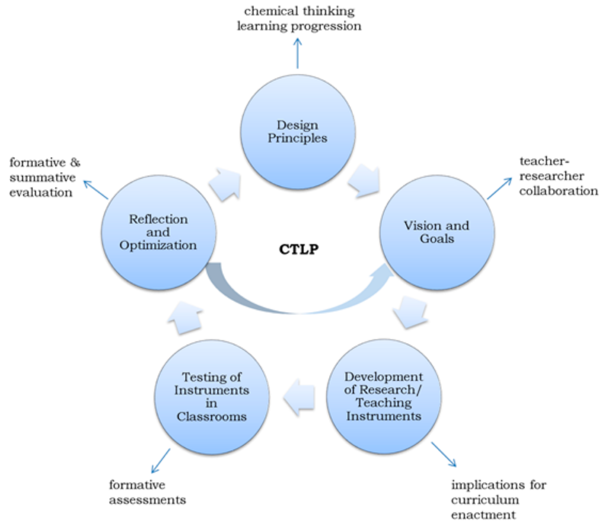


**Figure 1.** Design research cycle showing development process for research/formative assessment instruments for the Chemical Thinking Learning Progression (CTLP) project[22,23] and the main products resulting from each stage of the process (Reprinted from ref 22. Copyright 2014, American Chemical Society).

**Emergent Objectives.** Szteinberg and colleagues described how it was critical to engage each member of the team in the process in developing shared vision and goals.[22] For example, everyone was asked to consider how he or she might challenge students thinking about whether water and ethanol boil at the same time. Each team member contributed to the conversation from their experience teaching this content. In reflecting on the collaborative process, teachers expressed that their own ideas were an integral part in the development of the goals of the program.

**Reflection on Teaching of Particular Content.** This educational research collaboration provided teachers with an opportunity to reflect on their teaching methods and how these aligned with research supported practices. Teachers indicated that participating in this project changed the way they viewed teaching and learning in their classroom. They said that they were more willing to ask students open ended questions as they felt more prepared to interpret and use students' answers to guide their instruction. They had developed a more sophisticated understanding of student thought processes and noted a greater likelihood of reading and using the chemistry education literature. Teachers no longer viewed research as a linear process following the traditional "scientific method" but rather that research often changes directions and gets redefined throughout cycles.

**Adaptability.** Though CTLP served as a PD program, it was also a research collaboration, which lent itself naturally to the need for flexibility and adaptability. In fact, some of the teachers in the CTLP program indicated that they struggled with the frequent changing of directions as the project progressed. However, teachers also indicated that they felt this experience gave them a more authentic understanding of the research process.

**Ongoing/Long-Term Intervention.** Across the two-year time frame, initial meetings focused on instrument development and research strategies. They then progressively moved to data analysis, examination of the research literature from related work, and plans for dissemination. Teachers also recognized that this time together was necessary for building trust and respect so that all team members could equitably voice ideas.

**Teachers Partners in the PD.** Several teachers commented that their contributions were valued equally with those of the university faculty and trusted in the collaboration.

## Target Inquiry Program

In the Target Inquiry (TI) program, high school chemistry teachers, chemistry education faculty, and chemistry faculty formed a community of scholars designed to help teachers gain a better understanding of the process by which scientists construct knowledge. The ultimate goal of the TI program is sustained change in instructional practices that align with those called for in national science education reform documents.[8,9] Toward this goal, TI engaged teachers in three core activities over 2.5 years: (1) a research experience for teachers (RET), (2) adaptation and development of materials, and (3) action research. Continuous support for the teachers was provided through collaborations with faculty and their peers as well as in structured reflection opportunities (Figure 2). A long-term study supports that TI changed teachers' beliefs about the process of science[24] and beliefs about inquiry-based instruction.[25] It also brought about significant and lasting change in teachers' classroom practice because participating teachers shifted toward the use of research based teaching practices.[26,27]

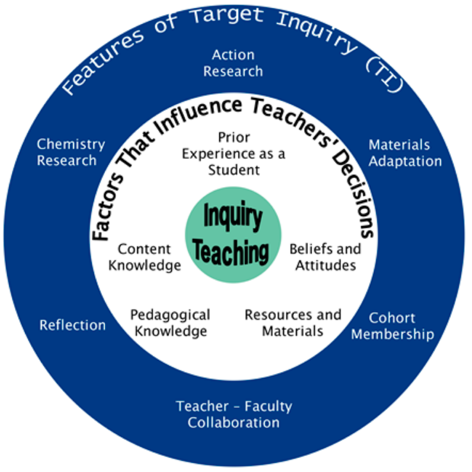


**Figure 2.** Target Inquiry model for professional development (Reprinted from ref 26. Copyright 2013, American Chemical Society).

**Emergent Objectives.** Teachers were not shown examples of "good inquiry-based teaching," despite them asking for this on several occasions. Instead they developed their own understanding of good science inquiry activities through a series of experiences, which included reflecting on how they could better model for their students the processes they were using in their summer research experience.

**Reflection on Teaching of Particular Content.** Reflection was deliberately incorporated throughout this program. At the beginning of the program, teachers were asked to think about how they could better model for their students activities that they used frequently in their own research project. This included analyzing data and communicat-


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ing results with others. Later, teachers identified ways they could model inquiry processes and confront misconceptions. They piloted lessons with peers and faculty who provided feedback about making lesson revisions. Finally, teachers collected data to evaluate the impact of their activity on students. One teacher commented on this process, "I still feel like I've got a lot to learn and implement, and I really appreciated being involved in the program...just even having somebody to reflect on my teaching with has been helpful, and I hope that continues. I don't want to just drop it."

**Adaptability.** Teachers had flexibility within each primary TI activity, to select the research project they worked on, the topic of the lessons they developed and how they wanted to present that content, and what aspects of student impact they wanted to investigate with their action research projects. Moreover, throughout the program, teachers continually shared their trials and successes and collaborated with their peers and the chemistry education faculty to determine how best to approach a particular problem or issue. This helped to develop shared values in the PD and to provide teachers with the necessary support and encouragement to make changes. For example, one teacher commented, "It was so useful to practice the labs on each other...to have college professors looking over the lab and giving you feedback on chemistry content and concepts, to address misunderstandings the students will have, to just come at it from a different level. It's like a pat on the back, like hey you're worth investing in, the kids are worth investing in, and this activity is worth investing in. It was just very rewarding."

**Ongoing/Long-term Intervention.** Its duration (2.5 years) coupled with the fact that it was a coherent, cohort program made TI unlike typical PD programs that span the same amount of time, but where teachers choose unrelated courses from a menu of options. In comparing TI to other PD experiences, one teacher said, "It was certainly the most organized [PD program I have been involved with] and...a program that was focused on inquiry for several years and had different pieces to it, but that was the goal and it changed how I think and how I do things in a way that certainly no 1 week or a 2 day or a conference is going to do because it's a mindset, and you don't change a mindset in 1 day or 1 afternoon or 1 45 min session. All you can give is little pieces that somebody might plug into their current curriculum."

**Teachers Partners in the PD.** The TI cohort model allowed teachers to feel supported and secure while also holding them accountable. In the words of one teacher, "It was certainly an environment where if you weren't pulling your weight that somebody would let you know that, and I think that was, you know, it forced me to be invested in the program."

## Families, Organizations, and Communities Understanding Science, Sustainability, and Service Program

The Families, Organizations, and Communities Understanding Science, Sustainability, and Service (FOCUSS) program brought together high school teachers, informal educators, graduate students, and college faculty for the common goal of developing a student-centered program aimed at enhancing students' understanding of chemistry within an environmental context as well as promoting pro-environmental behaviors of students and their families. FOCUSS provided a platform to develop what participating teachers cared about in their daily teaching: connecting chemistry concepts to meaningful contexts for their students. The purpose was to enhance teachers' adaptive expertise and refine their pedagogical content knowledge for using contexts as a means to develop understanding of chemistry principles.

At the two-year mark of the program, FOCUSSS demonstrated that participation in programmatic activities was directly related to the observed and reported improvements in pro-environmental behaviors of students and their families.[28] Such behavior changes were even observed for students who merely were part of these teachers' classrooms and did not participate in the broader FOCUSSS program, which included out of school activities.

Teachers' participation in FOCUSSS not only impacted students and their families, but also improved teachers' practice overall. Even though differences existed among the schools where teachers worked, they all agreed that the only constant they dealt with from year to year was change, change in district policies or school priorities, change in colleagues around them, change in rules. Work in FOCUSSS fostered an adaptive expertise[29] as it helped teachers grow confident in their ability to excel in both routine and unpredictable and shifting conditions.

**Emergent Objectives.** FOCUSSS was guided by a framework that included common topic areas (such as, "air and atmosphere") and sustainability principles (such as, the triple bottom line: the social, environmental, and financial impact of decisions), which were built collaboratively by teachers before the first year of implementation. Though resources for each topic area were developed collaboratively by the entire team using research to inform the use of contexts in lessons, each teacher had freedom to create the classroom experience that was most appropriate for their curriculum to address needs of his or her students. FOCUSSS did not dictate what and how lessons would be taught, but it provided the scaffolding and common threads for the work across schools.

**Reflection on Teaching of Content.** The FOCUSSS group met monthly and conducted shared reflection about how students were responding not only to lessons in the classroom, but also to out-of-school time FOCUSSS activities. The basis for these reflections was students' work and project artifacts. Reflection and discussion concentrated on these particular areas: classifying students' responses to learning experiences; determining how to capitalize on results that showed improvement; finding research-based instructional approaches that could address recognized needs (such as a POGIL activity[30] or a Science Writing Heuristic lab experience[31]); and tailoring lessons based on this information. These reflections produced key instructional artifacts that formed a critical collection of FOCUSSS resources for building ongoing classroom and out of school experiences for students.

**Adaptability.** FOCUSSS resources provided the basis for teachers to create lessons to best fit the learning needs of the students in their classrooms. Each teacher shared his or her lessons and student results during group meetings. Participating members then gave feedback on each presented lesson. This process was agreed by participants to follow research-based practices for fostering effective ongoing professional development.

**Ongoing/Long-Term.** The initial FOCUSSS cohort implementation was for two years but was built upon already established relationships from a cohort of teachers in a Master's in Chemistry Teaching program that had lasted for three prior years and had established the foundation for using chemistry education research results to inform classroom practices.



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**Teachers as Partners in PD.** The group that included teachers, informal educators, graduate students, and college faculty acted as a true collaborative group, which required that teachers be equal partners and collaborators. No one FOCUSSS activity was built in isolation. All participants had a voice in sharing or even challenging ideas. The trust that was necessary and present in this work allowed for true collaborative, productive work. As one teacher participant put it, "I found a constant sense of purpose and direction, a 'true north,' and maintained a passion for teaching and a desire to improve my craft."

## IMPLICATIONS FOR CHEMISTRY EDUCATION

Conducting and publishing research on best practices in chemistry education is critical to our craft. The reality, though, is that if these research results are never translated into practice, then they cannot and do not impact practice. Childs[11] points out that chemistry education research is often not read and applied to practice but rather is primarily used as citations to support other papers. It is likely that this is because many practitioners do not have the necessary background or knowledge of the chemistry education research literature to read these results and apply them to practice. In the case of high school chemistry teachers, there is also the issue that even if teachers are aware of the research literature and have the time, incentive, and necessary background to read it, they often do not have access to the journals in which the research is published. If we want to move forward as a discipline, we need to think more critically about how to provide access to and translate research results into practice.

The three programs highlighted in this paper indicate that it is possible to effectively harness the talents of teacher professionals and substantially change the way they approach the teaching and learning of chemistry. Other programs also show clear examples of effecting teacher change when using parallel approaches to those described here.[32] As a result, we assert that creating teacher change requires more than a 1 day workshop. It requires a significant investment of time and resources so that more teachers can be involved in meaningful learning communities. It requires training and treating teachers as professionals who are able to develop quality materials and make data driven decisions about teaching and learning in their classrooms. It requires making teachers aware of the research literature, discussing what research has found and how it might impact our classrooms, and collaboratively engaging in the process of data driven decision making for teaching. It requires recognizing teachers for the time and efforts they contribute to such communities and rewarding them accordingly. It requires advocating for funding to sustain and enhance these types of long-term programs.

Almost 20 years have passed between the *National Science Education Standards*[7] and the *Next Generation Science Standards*,[8] and though we have made changes, have we truly transformed teaching to bring about more meaningful learning for our students? We have the research to support the best practices for teaching and learning chemistry. Let us not find ourselves looking at another 20 years with very little change in how chemistry is actually taught, but instead let us engage with teachers in the critical process of translating this research to practice.

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### Notes

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