Transformative Research-Based Pedagogy Workshops for Chemistry Graduate Students and Postdocs

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One-day professional development workshops for graduate students and postdocs were held at top National Research Council–ranked chemistry research departments. Attendees intend to pursue academic careers, yet their experience and knowledge about teaching and learning were small. Postsurveys indicated that despite the short duration, the workshop informed and transformed individuals in their thinking about teaching and learning and motivated them to take a next step. The workshop introduced strong instructional approaches (guided inquiry, group learning, clickers), established the importance of theory (motivation, cooperative learning, metacognition, constructivism, misconceptions), and introduced novel pedagogic structures (discourse analysis, jigsaw, shared lab data). Follow-up surveys and interviews determined that participants, even if not currently in teaching appointments, sustained interest and enthusiasm, included ideas in faculty position applications, and continued conversations in their departments.

Today's graduate students are tomorrow's professors. For a long time, the model for future faculty preparation has been to mentor students to become good scientists and trust that some will have the mix of personality, desire, and ability to also become good teachers. Believing that this should not be left to chance, some programs and departments in the last 20 years developed Preparing Future Faculty (PFF) programs through which doctoral candidates could also study educational issues, investigate curricular changes, and engage in teaching practice (Council of Graduate Schools, n.d.; Lambert & Tice, 1993; Tanner & Allen, 2006; Walker, Golde, Jones, Bueschel, & Hutchings, 2008). On many campuses, one can hear a call for moving the center of intellectual activity to students by means of "inquiry" or "student-centered" models of instruction, including in STEM (science, technology, engineering, mathematics) classrooms (Ebert-May & Hodder, 2008; Siebert & McIntosh, 2001). Yet, if you walk the halls of most colleges and universities, stopping outside STEM classroom doors to watch, you rarely see students talking and working with other students. The instructor is still the focal point. We are hard-pressed to claim that much transformation has occurred in classrooms. A systematic review of the literature on STEM faculty change and lack thereof (Henderson, Beach, & Finkelstein, 2011) recommends that strategies for established faculty should deliberately focus on changing beliefs, must involve long-term interventions, and should be structured with institutional context in mind. The first is difficult, the second takes time, and the last suggests there may be as many answers as there are institutions. This combination of barriers is an imposing challenge.

There may be an easier place to intervene. The faculty of the future, our current graduate students and postdocs, may be different. Their beliefs about teaching and learning could be more malleable, and they are not yet in a fixed institutional context where barriers to change are well defined. Their immediate barriers consist of the challenge of trading off research progress for the attention given to teaching development programs and whether their research mentors would be supportive of that diversion (Benbow, Byrd, & Connolly, 2011). Consequently, short-duration professional development opportunities would fill a need for students who want to explore their commitment to teaching and learning.

We present here evidence regarding a one-day clinic for graduate students and postdocs that shows promise for informing and transforming their knowledge and thinking about teaching and learning, such that seeds will be planted that might be harvested when they become faculty. A limited number of more expansive programs exist that create

FIGURE 1

Survey questions provided to participants regarding the workshop and themselves before the workshop, immediately after the workshop, and 6 months later.

Preworkshop survey (completed at time of online registration)

- Name of the institution from which you received your undergraduate degree?
- What are your current career plans?
- If you are in a graduate degree program, please indicate how long you have been in your program, and list your remaining requirements. If you are a postdoc, how much longer is your appointment? Did you have any teaching assignments as a postdoc?
- Describe how you yourself learn chemistry.
- Since you came here, list all the formal teaching assignments you have had (i.e., list them just like you would in a resume).
- List any other teaching experiences that you have had (for example, were you an undergraduate tutor or peer leader?).
- Have you had any formal courses on pedagogy? If so, describe content and duration.
- Describe your ideal model of a college science teacher.
- Have you attended any workshop or training session concerning pedagogy (whether specific to science or not)? If so, describe content and duration.
- How confident are you regarding your ability to help students learn? (to a great extent/somewhat/very little/not at all)
- Describe your source of confidence.
- When you have needed advice or ideas about teaching, whom have you sought out, and why that person?
- How knowledgeable do you consider yourself about teaching and learning? (very/somewhat/very little/not at all)

Immediate postworkshop survey (completed at exit)

- Identify one or two strengths of this workshop and explain why these are strengths.
- Identify one or two improvements that could be made in these workshops and explain why the changes would be improvements.
- If you were to describe this workshop to others, how would you describe what you did?
- Identify insights that you have gained about teaching and learning.
- How might these insights affect your future teaching practices?
- Has this workshop changed your perspectives on teaching and learning chemistry?
- What have you learned about teaching-and-learning research?
- What new questions do you now have about teaching and learning? Or have your questions changed?
- Were any questions not answered? Please explain.
- Are you interested in exploring POGIL more by attending a longer workshop?

Six-month postsurvey (online)

- How did you find out about the workshop, and did anyone specifically encourage you to attend? If so, who encouraged you? [would have been better in registration survey]
- To what extent have you attempted to implement POGIL in your teaching?
- To what extent have you attempted to apply any ideas from the workshop in your teaching?
- To what extent have you changed your teaching strategies?
- How has your confidence in your teaching abilities changed?
- To what extent has your understanding of teaching chemistry changed?
- To what extent has your understanding of how students learn chemistry changed?
- To what extent have you read or referred to the books that you were given or to other written resources?
- Write down any questions you have now about teaching and learning chemistry.
- Have you attended or planned to attend any other workshop or sessions on teaching and learning?
- Have you discussed teaching and learning chemistry issues with others in your department or at some other university meeting? If so, what did you talk about?
- Have your career plans changed since you attended our workshop? If yes, please explain.
- Do you plan to apply for a postdoc or tenure track teaching position within the next year?
- If the previous answer is yes, to what extent do you plan to incorporate information about your workshop experience in your job search materials?

opportunities for graduate students and postdocs (Ebert-May, 2009). Often, there is a reliance on *inform-then-practice* models—students hear or read about pedagogic theories or approaches and then have the chance to create lessons or modify curricula in an attempt to apply that knowledge. Stronger versions of this approach involve scholarly teaching: a cycle of lesson creation, trial, assessment, reflection, and adaptation (Center for the Integration of Research, Teaching and Learning, www.cirtl.net; National Association of Geoscience Teachers, n.d.). All of these require substantial commitment of personnel and time, and face the tension that exists regarding devotion of time to an activity that research mentors might consider of secondary importance.

The workshop described here, designed and led by the first two authors, is based on a distinctly different pedagogic philosophy and method. Our approach is active, guided inquiry into research-based teaching and learning events designed to create intentional intellectual discomfort, to uncover and challenge implicit assumptions, and to model facilitated group instruction. It is not a workshop "about" teaching with a superficial survey of a variety of active-learning approaches. It is an authentic immersive learning experience using a narrow set of pedagogic structures. It starts not by having participants be teachers, but by having them be students in a new learning environment, experiencing what it's like to be lost and struggling, thrown in with other students and asked to work together productively. This disequilibrium creates a need to know (Workshop Event 1), from which explicit links to cognitive and social dynamic theories are made (Event 2). Examples show how theory provides guidance for teaching scientific writing and argumentation (Event 3), designing laboratory instruction (Event 4), and building awareness of student misconceptions (Event 5).

Methods and participants

The workshop is the centerpiece of a National Science Foundation–funded project specifically targeting graduate students and postdocs at elite research-intensive Chemistry Departments. Four Chemistry Department chairs from large top-ten National Research Council–ranked academic chemistry research programs (two private, two public) responded to our invitation to conduct a workshop for their students. At each site, 35 registrants signed up within 2 days of registration opening, and workshop attendance was 90% (suggesting an eagerness for the opportunity). Workshops were conducted in a department classroom and with the assistance of a local liaison. At each site, the ratio of graduate students to postdocs ranged from 1:2 to 2:1, and there were balanced numbers of male/female and domestic/international students. Graduate students tended to be more senior and closer to thinking about their professional futures.

Participants were provided open-ended questions at registration, immediately at the end of the workshop (n = 124) and 6 months afterward (Figure 1). The return rate was 33% at that time, a typical rate for online surveys (Sheehan, 2001). Nine participants who were engaged in the job search process were interviewed by phone a year later. Three of the paper's authors independently engaged in survey and interview design and analysis, with results being integrated for this report. Preworkshop questions explored background, prior knowledge and experience, academic history, self-efficacy for teaching, and motivation. The majority (90%) planned academic careers, equally citing undergraduate institutions and PhD research institutions. Nearly all (86%) had been laboratory teaching assistants for a few semesters or had been tutors or participants in outreach activities (77%). A few (12%) had appointments as lecturers or mentored research students in labs. Five volunteered that they had participated as students or instructors in process-oriented guided-inquiry learning (POGIL) or peer-led team learning (Gafney & Varma-Nelson, 2008). Nearly all participants described themselves as pedagogic novices: Few had taken formal courses (10%) or workshops (27%) about how students learn chemistry. Despite their lack of knowledge and experience, 35% claimed to have a great amount of confidence that they could help students learn. They based their confidence on their certainty of their own content knowledge and positive feedback from students in tutorial relationships. Fewer were highly confident (10%) when discussing taking responsibility for a full course.

Workshop description

Authentic learning, explicit links to research, and rich instructional models are critical design components for the workshop. It was important for participants to be out of comfort zones early, to have their beliefs and understanding challenged, and to see the two instructional facilitators (first two authors) practicing what we preach all day. Five instructional events occurred over 6 working hours.

Event 1: Out-of-field chemistry learning

Participants sit in groups of four by research area (e.g., analytical, organic). One member, the "manager," assigns other roles (spokesperson, recorder, reflector). Each group works through a different well-tested POGIL (Moog & Spencer, 2008) undergraduate chemistry activity that is *not* in their realm of expertise, (e.g. organic students work on an analytical activity). They were analytical "interlaboratory comparisions" (Bauer, 2009), physical "the ideal solution" (Spencer, Moog, & Farrell, 2004), and organic "chirality" (Straumanis, 2004). This creates a realistic learning experience. Then, guiding questions ask about activity structure—length, question sequence, and what they consider or do. Public debriefing of all activities elucidates common features: (a) students being guided to explore, describe, develop, express and apply concepts, and (b) development and assessment of learning processes (information processing, problem solving, critical thinking) and group interaction (teamwork, management, communication). These two components of the POGIL model emerge in the discussion. POGIL was selected as the pedagogic approach because the workshop leaders each had a decade of experience with design, implementation, and evaluation of this well-established model.

Event 2: Pedagogic and cognitive theories for beginners

Following a jigsaw structure, groups read excerpts about one of four theories of central importance to understanding learning: motivation (McKeachie, 1994; Pintrich & Schunk, 1996), cooperative learning (Astin, 1993; Johnson, Johnson, & Smith, 1991), constructivism (Mestre & Cocking, 2002; Moll, 1990; Treagust, Duit, & Fraser, 1996), and metacognition (Bransford, Brown, & Cocking, 1999; Bruer, 1999; Metcalfe & Shimamura, 1994). The groups then discuss that topic using guiding questions, after which they split into new groups with one person from each topic. The new groups follow another set of questions, first to summarize each theory and then to analyze how POGIL is supported by these theories. Groups report out. Discussion emphasizes how learning theory may guide curriculum and instruction decisions; POGIL is grounded in constructivism (Tobin, 1993), a theory of cognitive development that argues that each individual must build his or her own understanding of how the world works (here, how POGIL works). Moreover, because the group negotiates meaning through discussion, a social constructivist model is an appropriate description. Group organization and roles are from the literature on cooperative learning (Johnson & Johnson, 2009). The purpose of Event 2 is to demonstrate how pedagogy may be based on and explicitly developed from theories of learning. Existence of theoretical structures and a research base were eye-openers for participants, who had never heard of this literature. In fact, they were only able to name the *Journal of Chemical Education* as a likely resource. We did not expect participants to emerge from the workshop with a comprehensive understanding of these ideas. We did expect that their awareness and curiosity would be sufficiently engaged so that the books we gave them via the grant would be ideal as follow-up reading. Some participants commented in surveys that they did begin to explore and use these resources.

Event 3: Argumentation analysis

Participants do a POGIL activity designed by one of the workshop leaders for his organic class involving Toulmin analysis (Toulmin, 1969) of student discourse and arguments. A table of boiling points for a set of structurally related compounds is presented, along with several mock student interpretations. Participants rank these interpretations in terms of perceived quality. Then the Toulmin approach (claim, data, warrant) is presented so that participants can apply that to the same interpretations. This leads to additional applications and an expanded discussion of argumentation structure. Basing a classroom activity on the Toulmin model is a sophisticated way to help students learn scientific argumentation and exemplifies for future faculty a systematic way to evaluate student writing. Including it in the workshop also allowed highlighting its use in research on the development of student understanding (Cole et al., 2012).

Event 4: Cooperative knowledge construction in laboratory

A paper-and-pencil simulation of an authentic experiment is conducted, whereby each student carries out the same procedure but with different chemical substances such that results may be pooled as evidence to develop a concept ("discovery chemistry" model; Ditzler & Ricci, 1994). The skill was determining boiling points by distillation (Creegan, 2006). Each student group had a small set of pure substances. First they predicted boiling point order and proposed a chemical rationale, and then they were provided distillation data. Judicious selection of substances provides a combined data set that allows development of the concept of intermolecular forces and effects of molar mass, polarity, hydrogen-bonding, and molecular shape.

Event 5: Exploring student misconceptions via clickers

Clickers (student response systems) were used with PowerPoint to ask forced-choice questions concerning the literature on chemical misconceptions. Questions about bond energy and heat capacity demonstrated misconceptions among the graduate students and postdocs. Using Mazur's "peer instruction" approach (Crouch & Mazur, 2001), groups discussed the initial poll and could change their minds in a second poll.

FIGURE 2

Direct quotes from workshop participants supporting assertions.

Increased confidence for implementing active learning

- I always knew students learned better with hands-on activity, I just never knew how to effectively use that approach to teach chemistry beyond the laboratory.
- I feel much more comfortable thinking explicitly about pedagogy.
- The workshop helped me to be more aware of how I teach.
- My confidence in my understanding of student learning has increased. This has increased my confidence in teaching.
- I have become even more confident in my abilities because now I know that many people share my ideas about teaching. In a word, I feel validated.
- I've always believed that learning/teaching science should be less memorization and facts and numbers and more just using logic to figure things out. I guess the workshop helped show me that such an approach can work.

Restructuring beliefs about role of teacher

- Before [the workshop] . . . I was oriented towards institutions with mainly research duties for my future work; after . . . I considered also undergraduate-only institutions. In fact, I have decided to work at a undergraduate institution.
- Now my focus in teaching has shifted from clear and accessible presentation of facts to motivation-oriented teaching.
- I have a completely different view of teaching chemistry. I will never be able to be happy with lecture notes and a textbook. . . . However, my experience with POGIL has helped me question students differently when they do not understand something. I now ask more guiding questions and am very careful to not "give" my students information.
- I do feel more prepared to try these techniques and have applied for a Future Faculty Fellowship Program . . . I will design and implement new coursework based on POGIL.
- Started reading J Chem Ed and I attended 40+ Chem Ed talks at the ACS conference.
- I have extensively applied the ideas from the workshop given that the course that I just finished teaching was designed by the instructors to incorporate POGIL. The workshop has encouraged me to allow the students to struggle through concepts on their own.

Awakened regarding literature and research-base for pedagogy

- I have realized that there are different ways to approach teaching . . . that new research and techniques are showing that the traditional routes are not always the best approach.
- Understanding a bit more about how people learn will help me to be a better teacher.
- Providing an environment free of judgment may allow people to feel more comfortable and become more involved than they would otherwise.
- The students themselves can help one another to reinforce what is being taught. . . . I see that it's important to have a dialog with students to see what their perceptions are.
- The concrete examples from the workshop have given me a much more thorough understanding of both the process and application to chemistry.
- The workshop helped me understand the importance of student motivation and discovery-based methods as opposed to traditional lecturing.

Attention turning to learning and students

- I have a better understanding of how I should learn chemistry myself in graduate school.
- I realized that most students learn slowly.
- I have learned that students learn better by doing, rather than being lectured at.
- Students are VERY good at memorizing facts, understanding them is a different story.
- Fuller understanding of the different ways students make connections about concepts.
- I was surprised about how many misconceptions survive in my students.
- I was prompted to think more about the learning process of an average student.

(They did.) To illustrate the resistance of misconceptions to instruction, questions from the Mulford and Robinson (2002) study of general chemistry students were shown. Attendees predicted the most popular wrong answer (reasonably successfully) and how the answer distribution would change after a semester of instruction (overestimating student learning gains greatly; Bauer, 2011). Clickers and this research were unfamiliar to most attendees. This unfamiliarity is disturbing because the research on conceptual misconceptions is perhaps the most influential body of work in the past 20 years in attracting attention across the scientific disciplines to problems with science teaching and learning from elementary through college levels (National Research Council, 2012). As a lighter end-of-day activity, Event 5 did provide an introduction to the misconceptions research base and an opportunity to describe conceptual change theory (Nersessian, 2008; Posner, Strike, Heweson, & Gertzog, 1982).

Survey results

Postworkshop reflective questions (immediate and after a 6-month hiatus) sought comments on insights, beliefs, concerns, and plans. To the question, "Has the workshop changed your perspectives about teaching and learning?" 89% of participants said yes, citing each of these insights as contributing equally:

- Student group interaction can support effective learning.
- Being immersed in the student role provides a learner's perspective—wrestling with the scientific concepts is important.
- An accessible theoretical base and literature exist regarding learning theory.
- Students learn differently and motivation is important.
- Diverse teaching approaches, including hands-on activities, are needed.
- Developing an understanding of learning processes is as important for the learner as content knowledge acquisition.

Further analysis of the surveys and interviews leads us to make the following assertions based on consistent and robust themes identified therein. Direct quotes from participants from across the participant pool illustrate the pervasiveness of these themes (Figure 2).

1. Many participants described increased confidence in their self-perceived ability to implement active learning pedagogies. Of the participants who characterized themselves as being only somewhat or not very confident that they could help students learn, 50% indicated that their perspectives on teaching and learning had changed, that they clearly intended to implement or try active learning because they felt enabled, and that they wanted to participate in future workshops. Self-efficacy is an antecedent of motivation (Major & Dolly, 2004; Zimmerman, 2000) and a recent focal point for studies of teacher development.
2. Participants are restructuring their beliefs in their role as "teacher." They make explicit statements that they could now appreciate how groups can learn effectively when a clear cooperative structure exists and that a clear delivery of information was not equivalent to effective learning.
3. Participants developed a new awareness of a valuable literature they didn't know existed, expanded their repertoire of teaching models, and demonstrated what it meant for a model to be "research based." Preworkshop responses had indicated that only 13% of participants considered themselves "very" knowledgeable about teaching and learning.
4. In the preworkshop survey, participants only focused on teaching and on how they learned chemistry. In postworkshop comments, the same participants talked about learning—their own and that of students. They began to display awareness that students may learn differently from themselves and thus need different learning experiences. They found it very valuable to be put in the position of being a student working on a topic that requires some struggle—to have an authentic learning experience.

We argue that all of this evidence indicates that the workshop, as compact as it was, encouraged participants to reconstruct their beliefs about teaching—from being a toolbox of skills and methods to being a cognitive activity informed by research on human learning and interaction. They describe dissatisfaction with their prior ideas, which has been identified as a critical precursor for creating change (Gess-Newsome, Southerland, Johnston, & Woodbury, 2003). Furthermore, they demonstrate enhanced self-efficacy for implementing these new understandings, with many talking about how they could take next steps. After 6 months (n = 36), 71% of those responding indicated that they had discussed teaching and learning issues with departmental colleagues, 30% had used or referred to the books and materials provided as a start for their library (Allen, 2003; Bunce & Muzzi, 2003; Mintzes, 2006; Moog & Spencer, 2008; Pienta, Cooper, & Greenbowe, 2005, 2008), 20% had attended at least one other pedagogy workshop, nearly 50% included their workshop experience in their resumes or teaching philosophy statements for academic positions, and nearly 50% intended to incorporate POGIL-like structures into their future teaching. Most notably, 25% expressed a change in career direction toward academic positions that focused on and valued undergraduate education.

Implications

One clear message is that most of the workshop participants were novices as far as their knowledge, skill, and sophistication regarding teaching and learning is concerned. A second message is that they are eager to learn, jumping at the opportunity to work with experts in pedagogy in the discipline. A third message is that their existing opportunities are limited or unexplored. When asked where they would go for advice about teaching, many participants mentioned mentors at their undergraduate institutions—not proximate resources, like their research mentors or teaching and learning centers (which did exist at their institutions). It is our belief that the learning challenges in chemistry are sufficiently unique that having professional development workshops tailored for the discipline is an important issue to establish credibility and value. Last, though our institutional sample is limited, there is no reason to believe that our population of graduate students and postdocs was different from those at other research intensive institutions. This workshop and study demonstrate that a short intervention provided to a population whose professional identity is still being forged can plant seeds for change. There is evidence that some of these workshop participants are incorporating these ideas as they consider job searches. Results here parallel the outcomes of a larger study where graduate students were often engaged for a semester or more (Benbow et al., 2011). What happens in the future as they enter demanding faculty appointments, of course, depends on whether other constraints begin to reduce motivation to pursue their initial enthusiasm (Ebert-May et al., 2011). ■

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