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Essay

Post–*Vision and Change*: Do We Know How to Change?

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The scale and importance of *Vision and Change in Undergraduate Biology Education: A Call to Action* challenges us to ask fundamental questions about widespread transformation of college biology instruction. I propose that we have clarified the "vision" but lack research-based models and evidence needed to guide the "change." To support this claim, I focus on several key topics, including evidence about effective use of active-teaching pedagogy by typical faculty and whether certain programs improve students' understanding of the *Vision and Change* core concepts. Program evaluation is especially problematic. While current education research and theory should inform evaluation, several prominent biology faculty–development programs continue to rely on self-reporting by faculty and students. Science, technology, engineering, and mathematics (STEM) faculty-development overviews can guide program design. Such studies highlight viewing faculty members as collaborators, embedding rewards faculty value, and characteristics of effective faculty-development learning communities. A recent National Research Council report on discipline-based STEM education research emphasizes the need for long-term faculty development and deep conceptual change in teaching and learning as the basis for genuine transformation of college instruction. Despite the progress evident in *Vision and Change*, forward momentum will likely be limited, because we lack evidence-based, reliable models for actually realizing the desired "change."

> *All* members of the biology academic community should be committed to creating, using, assessing, and disseminating effective practices in teaching and learning and in building a true community of scholars. (American Association for the Advancement of Science [AAAS], 2011, p. 49)

Realizing the "vision" in *Vision and Change in Undergraduate Biology Education* (*Vision and Change*; AAAS, 2011) is an enormous undertaking for the biology education community, and the scale and critical importance of this challenge prompts us to ask fundamental questions about widespread transformation of college biology teaching and learning. For example, *Vision and Change* reflects the consensus that active teaching enhances the learning of biology. However, what is known about widespread application of effective active-teaching pedagogy and how it may differ across institutional and classroom settings or with the depth of pedagogical understanding a biology faculty member may have? More broadly, what is the research base concerning higher education biology faculty–development programs, especially designs that lead to real change in classroom teaching? Has the develop-and-disseminate approach favored by the National Science Foundation's (NSF) Division of Undergraduate Education (Dancy and Henderson, 2007) been generally effective? Can we directly apply outcomes from faculty-development programs in other science, technology, engineering, and mathematics (STEM) disciplines or is teaching college biology unique in important ways? In other words, if we intend to use *Vision and Change* as the basis for widespread transformation of biology instruction, is there a good deal of scholarly literature about how to help faculty make the endorsed changes or is this research base lacking?

In the context of *Vision and Change*, in this essay I focus on a few key topics relevant to broad-scale faculty development, highlighting the extent and quality of the research base for it. My intention is to reveal numerous issues that may well inhibit forward momentum toward real transformation of college-level biology teaching and learning. Some are

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quite fundamental, such as ongoing dependence on less reliable assessment approaches for professional-development programs and mixed success of active-learning pedagogy by broad populations of biology faculty. I also offer specific suggestions to improve and build on identified issues.

At the center of my inquiry is the faculty member. Following the definition used by the Professional and Organizational Development Network in Higher Education (www.podnetwork.org), I use "faculty development" to indicate programs that emphasize the individual faculty member as teacher (e.g., his or her skill in the classroom), scholar/professional (publishing, college/university service), and person (time constraints, self-confidence). Of course, faculty members work within particular departments and institutions, and these environments are clearly critical as well (Stark *et al.*, 2002). Consequently, in addition to focusing on the individual, faculty-development programs may also consider organizational structure (such as administrators and criteria for reappointment and tenure) and instructional development (the overall curriculum, who teaches particular courses). In fact, Diamond (2002) emphasizes that the three areas of effort (individual, organizational, instructional) should complement one another in faculty-development programs. The scope of the numerous factors impacting higher education biology instruction is a realistic reminder about the complexity and challenge of the second half of the *Vision and Change* endeavor.

This essay is organized around specific topics meant to be representative and to illustrate the state of the art of widespread (beyond a limited number of courses and institutions) professional development for biology faculty. The first two sections focus on active teaching and biology students' conceptual understanding, respectively. The third section concerns important elements that have been identified as critical for effective STEM faculty-development programs.

ACTIVE TEACHING AND LEARNING

Is There Evidence That Active Teaching Can Be Broadly Applied across Faculty-Development Programs?

The third chapter of *Vision and Change* promotes student-centered classrooms that are "interactive, inquiry driven, cooperative, collaborative, and relevant" (p. 22) and incorporate the constructivist literature supporting this pedagogy. This emphasis reflects general acceptance that active teaching helps students learn biology more effectively than passive, lecture-based approaches. Indeed, Dirks (2011, p. 12) says that active learning ". . . should no longer be referred to as a pedagogical practice . . .but rather the central dogma of science education."

In college biology, there is rich literature concerning effects of active teaching on student learning. For instance, a recent (March 2013) Education Resources Information Center search using the abstract search terms "active, learning, and biology" in peer-reviewed journals since 1979 yielded 80 articles. In one study, Freeman *et al.* (2007) found that highly structured active teaching, such as groups working on exam and clicker questions that reinforce specific reading assignments, was especially helpful for high-risk students in an introductory biology class. At a more advanced level, Knight and Wood (2005) measured significant learning gains and improved conceptual understanding in courses emphasizing classroom discussion of carefully conceived and conceptually based clicker questions, and homework groups, among other related approaches. Udovic *et al.* (2002), Ebert-May *et al.* (1997), and Armbruster *et al.* (2009) also showed that student-centered pedagogy and interactive approaches increased student performance in biology courses. The powerful evidence from these and numerous other studies has prompted several national biology faculty–development programs to strongly promote active-learning approaches (e.g., Wood and Gentile, 2003).

While there is ample evidence that designers of professional-development programs for biology faculty should include active teaching and learning as a cornerstone, the literature also includes notes of caution. Importantly, the papers referred to above are all written by highly experienced biology faculty. What do we know about effective use of active teaching by more typical biology instructors? Some research suggests less success here. Andrews *et al.* (2011) randomly selected introductory biology courses to examine use of active teaching by a broad population of faculty. These researchers found no association between learning gains concerning natural selection and active-teaching pedagogy and conclude that some faculty members superficially apply active-teaching approaches but do not understand constructivist foundations for this pedagogy. Similarly, in physics, Henderson and Dancy (2009) warn that dissemination of research-based practices such as active teaching will have limited impact unless faculty members thoughtfully consider the theoretical basis for them.

There are other important take-home messages with regard to incorporation of active teaching in far-reaching biology faculty–development programs. First, in my experience, active teaching for many instructors is a pedagogy that requires repeated practice, feedback about efficacy, and ongoing discussion about theoretical underpinnings in the context of a faculty member's own experiences. In addition, some faculty members face students' active opposition to active teaching and learning (Dembo and Seli, 2004), which can be quite difficult to understand and address. Therefore, many biology teachers may not be ready to participate in programs aiming at fundamental transformation (the ultimate goal of *Vision and Change*), because they are struggling with the active-teaching component by itself. In addition, active teaching is a means to an end in fundamental reform of biology instruction and therefore should be carefully paired with other effective approaches, such as the Blooming Biology Tool (BBT; Crowe *et al.*, 2008), data analysis by students, or use of concept inventories. In this way, the active-learning exercises are explicitly designed to improve understanding of specific concepts or data analysis skills. This is what Haak *et al.* (2011) mean by highly structured active teaching. Finally, using active teaching to help students improve conceptual understanding in biology may be more difficult than in other STEM fields. For instance, Michael (2006) reminds us that underlying student misconceptions about biological concepts are alternative conceptions about chemistry and physics (see also Hartley *et al.*, 2012), making design of effective active-teaching approaches to improve conceptual understanding in biology especially challenging.

All of this indicates that incorporation of active-teaching pedagogy into widespread biology faculty–development programs is going to be very challenging. Especially problematic is the dearth of research on strategies for incorporating active teaching in biology in particular. This is an area that deserves targeted grant support.

Are There Approaches Solidly Based on Active Learning That Have Effective, Large-Scale Faculty-Development Programs?

Several programs that emphasize active learning in the context of social constructivism—problem-based learning (PBL), process-oriented guided-inquiry learning (POGIL), and case-based teaching—deserve special attention due to their impact on STEM education and the scale of their professional-development component.

Medical educators developed PBL as an alternative to traditional lectures in large lecture halls (Prince and Felder, 2007). PBL students work in structured teams on open-ended, real-world puzzles; students must define the problem precisely, identify what they need to know to address it, and develop and assess alterative hypotheses with data and information, some provided by the instructor (Allen, 1997). As they attempt to solve the problem, students are motivated to find and then apply what they are learning. PBL has been widely adapted in chemistry, physics, biochemistry, and biology courses, as well as in other areas (Duch *et al*., 2001). An impressively large number of faculty members have participated in PBL workshops nationally and internationally. To date, in the case of just one PBL professional-development institute open to faculty in all disciplines, more than 700 faculty members from 95 higher education institutions in the United States and 40 institutions in other countries have attended (D. Allen, personal communication). In a meta-analysis of 43 empirical studies with data on both knowledge and skills, Dochy *et al*. (2003) found a robust positive effect of PBL on skills such as problem solving and working in groups. It is interesting that students in this study gained slightly less knowledge in PBL classrooms compared with traditional ones but retained more of their acquired knowledge. In another meta-analysis, Gijbels *et al*. (2005) reported positive effects of PBL on students' understanding of principles that link concepts; the authors also emphasized the importance of matching assessment to a faculty-development programs' goals. There is a rich literature about effective designs of PBL professional-development programs, with emphasis on medical and dental students. Some of these studies support the use of role-playing followed by discussion, for example (Dalrymple *et al*., 2007).

Like PBL, POGIL emphasizes self-managed student teams and materials that guide students through discovery as they construct understanding. POGIL is based on constructivism (metacognition, prior experience) and a three-phase learning cycle of exploration (students find trends and patterns in data), concept invention (they develop a new concept or idea), and application (the concept is applied to new contexts; Murphy *et al*., 2010). Students work in teams that may report findings to the class; teams also self-reflect on their learning. A scripted activity guides students through this process via leading questions. Implementation of POGIL is flexible in that not all lectures need be replaced (Moog *et al*., 2006). Dissemination is through the NSF-supported POGIL Project (www.pogil.org). At present, peer-reviewed POGIL publications on student learning focus on one or a few courses for this relatively new program (e.g., Murphy *et al*., 2010), although the number of students reached overall is large. In one study, for example, Brown (2010) found significantly higher scores for the comprehensive final plus overall grade in POGIL sections of an anatomy and physiology course compared with scores reported for lecture-only sections. Availability of a validated instrument designed to measure student achievement in POGIL classrooms (Bunce *et al*., 2010) is critical, because the instrument can provide research-based evidence of student learning in POGIL courses. Bunce *et al*. (2008) also applied stage-of-readiness research (Rogers, 2003) to evaluation of POGIL workshops. Their intriguing finding that postworkshop self-reports of readiness were lower than preworkshop reports indicates the importance of workshops for accurate self-assessment of this innovation. It is encouraging that POGIL, less than a decade old, reflects advances in evaluation and research on STEM reform and faculty development (e.g., validated instruments, quantitative comparison with traditional teaching, and change research).

In contrast with POGIL, dissemination of case-based teaching began in the early 1990s (Herreid, 1994). In this approach, students are presented with hypothetical or historical cases that are often dilemmas needing solutions. Science students typically work cooperatively with data and background information, learn content and concepts, and come to understand the process of science as they consider solutions and consequences of particular actions. Cases may be used with discussions, debates, public hearing formats, and mock trials, among other approaches, which increases the approach's appeal to faculty (Herreid, 1994). Another value of case-based teaching is the large and readily available number of peer-reviewed cases and accompanying resources (see http://sciencecases.lib.buffalo.edu/cs) and faculty-development programs. The National Center for Case Teaching in Science provides a large list of publications on STEM case-based teaching (http://sciencecases.lib.buffalo.edu/cs/teaching/publications). A number of qualitative studies address the value of case-based approaches in biology using students' comments, for instance, but there are fewer based on quantitative approaches. As an example of the latter, Rybarczyk *et al*. (2007) found that students in courses that included cases concerning cellular respiration achieved significantly higher learning gains on multiple-choice questions targeting known misconceptions about this process. In addition, Lundeberg *et al*. (2011) found that, across multiple institutions, introductory biology students' understanding was higher in courses emphasizing clicker cases compared with ones relying only on PowerPoint lectures. Cased-based teaching professional-development studies, mainly focusing on K–12 teachers, point to the importance of feedback and reflection, classroom observation, and several years of practice, among other factors (e.g., Dori and Orit, 2005).

Recently, NSF has supported research coordination networks to integrate potentially complementary reform efforts in biology. The case study and PBL network (http://sciencecasenet.org/rcn) is designed to bring together the resources, experience, and expertise of the two communities to stimulate new projects and research. In the context of *Vision and Change*, steps toward additional analysis of the effectiveness of these programs for faculty development would be a useful outcome of this network. Especially important topics include "what works" in medical/dental PBL professional development, research-based instruments to assess student learning and faculty progress, and the value of flexible versus more structured pedagogical approaches.

CONCEPTUAL UNDERSTANDING

Is There Evidence That Particular Faculty-Development Programs Lead to Improved Student Understanding of Core Biology Concepts?

Programs That Focus on Concept Inventories. *Vision and Change* identifies five core concepts for biological literacy: evolution; structure and function; information flow, exchange, and storage; pathways and transformations of energy and matter; and systems. Following Labov *et al.* (2009) and Seymour (2001), who emphasize linking evidence to specific learning goals in STEM reform, are there biology faculty–development programs that provide convincing evidence about gains in student understanding in one or more of the five conceptual areas? An example of such evidence outside biology is the large database on pre–post instruction gains for Force Concept Inventory questions (Hestenes *et al.*, 1992; Hake, 1998). As validated concept inventories by their nature can provide reliable data on conceptual change (Smith and Tanner, 2010), it makes sense to ask whether there are programs designed to help faculty members use the numerous biology concept inventories now available (D'Avanzo, 2008; Fisher and Williams, 2011) to assess students in their courses. Such an approach is particularly powerful, because faculty members use data from tested inventories to inform their practice and therefore engage in scientific teaching and formative evaluation; both have been identified as critical to effective STEM teaching reform (Handelsman *et al*., 2005).

While there certainly are biology faculty–development programs that introduce faculty to concept inventories (e.g. Faculty Institutes for Reforming Science Teaching [FIRST] IV, 2013), few appear to rely on these tools as primary evidence of program efficacy. One that does is the Host–Pathogen Inventory (HPI) developed by Marbach-Ad *et al.* (2007) to track growth in student understanding as students moved through nine courses in a single institution's biology program. The *Vision and Change* concepts emphasized by the HPI are structure/function and information. Marbach-Ad *et al.* (2009) found that HPI precourse scores in upper-level courses demonstrated retention of conceptual understanding emphasized in a lower-level microbiology course. In the HPI program, 19 faculty members—from assistant to full professors, tenure-track teachers to instructors—worked together over several years to shape and improve the HPI. As discussed below, this lengthy process was critical, as faculty members came to a shared insight about what deep conceptual understanding in biology means and the pedagogies that help students gain this understanding.

Research-based conceptual inventories were also central to the Diagnostic Question Cluster (DQC) program, but in this case, faculty members came from universities, four-year colleges, and community colleges nationally, and the questions (concerning energy and matter transformations across biological scales of organization) are generally applicable to biology instruction (D'Avanzo *et al.*, 2012; http://biodqc.org). As in the HPI program, DQC faculty development focuses on a small number of faculty members who work closely together over several years to use the inventory questions in their courses, examine the data, and use and modify active-learning approaches that target diagnosed misunderstandings. Each faculty member in the DQC program saw significant gains in student understanding of processes concerning photosynthesis, respiration, digestion, growth, and other related misconceptions (D'Avanzo *et al.*, 2012). Hartley *et al.* (2011) report that, across institutions, students' ability to apply expert reasoning to the novel application questions doubled postinstruction, although 16% still relied on classic alternative conceptions at the end of the course or module ($n =$ 525 students).

Thus, there are several faculty-development models based on use of conceptual inventories with validated evidence on student understanding of key biological ideas. Of course, the inventories alone cannot be the basis for course transformation; both the HPI and DQC programs emphasize other critical elements, such as collaborative groups of faculty members working together on issues they care deeply about (Rogan and Anderson, 2011), regarding faculty as part of the solution and not as problems that need to be fixed (Henderson *et al*., 2010), and active teaching and learning.

It is challenging and expensive to conduct faculty-development programs, and there is much we can learn from studies on students' conceptual gains with Conceptual Assessments in Biology (CABs) in a single or a few courses. CABs have been developed and used to examine student understanding of genetics (e.g., Bowling *et al.*, 2008; Smith *et al.*, 2008), natural selection (Anderson *et al.*, 2002), osmosis and diffusion (Fisher *et al.*, 2011), randomness (Garvin-Doxas and Klymkowsky, 2008), energy and matter in biological systems (Hartley *et al.*, 2011), and photosynthesis and respiration (Haslam and Treagust, 1987), among other topics (D'Avanzo, 2008). An important lesson from this work is the persistence of some students' alternative conceptions in the face of experienced and dedicated teachers' explicit efforts to expose and change these incorrect ideas. Thus, in addition to helping faculty members select appropriate inventories, faculty developers who design programs with CABs as a key assessment tool will need to help faculty members interpret their own students' responses and then select or design and assess appropriate active-learning approaches to help students improve.

Gains in student understanding as measured by validated conceptual questions is a high bar, and numerous analyses note how few STEM professional-development programs rely on such measures (e.g., Henderson *et al.*, 2008). However, given the large and growing number of conceptual inventories in biology (D'Avanzo, 2008; Fisher and Williams, 2011) and their future availability on the ci-HUB (a community for concept inventory developers, researchers, faculty, and students; http://cihub.org), use of research-based CABs as a centerpiece of faculty-development programs, perhaps through professional societies, deserves particular attention by the biology education community.

Other Approaches That Emphasize Conceptual Understanding in Biology. Biology faculty developers may also incorporate several other established approaches that help students better comprehend key concepts. For example, test questions can be specifically designed to assess higher-level thinking skills; this pedagogy emphasizes deep conceptual understanding in biology and the active teaching supporting this learning. For example, Crowe *et al.* (2008) developed and used the BBT in three different teaching environments in a university and a liberal arts college. The BBT, based on Bloom's taxonomy of cognitive domains, was also paired with Bloom's-based Learning Activities for Students (BLASts). Importantly, the authors found that the process of developing the BBT itself led to fundamental changes in faculty members' courses. These included more teaching approaches that emphasized analysis or synthesis, for instance, and giving students opportunities to rank their own test answers with a Bloom's-based rubric and thereby develop metacognitive skills. There is evidence that emphasis on higher-level Bloom's questions improves biology student performance on final exams (e.g., Stanger-Hall, 2012). BBT-type approaches have influenced numerous college biology teaching reform efforts (e.g., Wu, 2009). However, Bloom's taxonomy has been available for more than 50 yr (Bloom, 1956), and it is therefore discouraging that Momsen *et al*. (2010) found test questions in more than 70 biology courses targeted lower cognitive levels.

A second approach, use of concept maps, has also been available for decades to examine students' conceptual comprehension in biology (e.g., Novak, 1980). Concept maps are potentially useful, because in constructing their maps students must link new ideas and information to what they already know; therefore, faculty members literally have a picture depicting students' understanding of key processes and players and how this may develop over time. There are numerous studies about use of concept maps in biology courses in single institutions. For instance, Markam *et al.* (1994) found that concept maps of biology majors were structurally more complex than those of nonmajors and concluded that such maps can be used to assess students' conceptual change in biology courses. Songer and Mintzes (1994) found that pairing concepts maps with student interviews helped faculty members appreciate students' alternative conceptions about cellular respiration. Concepts maps have been a central focus in medical and allied health faculty–development programs (e.g., All and Havens, 1997) but less so in biology faculty–development programs. Perhaps this is because applying interpretation of students' maps to course reform is particularly difficult in biology courses, especially at the introductory level (Kinchin, 2001).

ESSENTIAL ELEMENTS OF BIOLOGY FACULTY–DEVELOPMENT PROGRAMS

In Widespread Transformation of Biology Courses, What Elements of Effective Faculty-Development Programs Are Especially Important?

It is critical for designers and funders of biology faculty–development programs to recognize that research on effective STEM teaching practice in one or a few courses is very different from research on effective widespread transmission of these practices across college-level biology courses. The impressive advances achieved by biology faculty and educators over the past decade, many outlined above, may well have limited impact, because we have not also rigorously examined how to successfully disseminate these findings and ideas. Henderson and Dancy (2011, p. 1) put it this way: "The biggest barrier to improving undergraduate STEM education is that we lack the knowledge of how to effectively spread the use of currently available and tested research-based instructional ideas and strategies." In particular, Charles Henderson and colleagues critique the "develop and disseminate" approach of the NSF in the Course Curriculum and Laboratory Improvement (CCLI) program (Henderson and Dancy, 2011). CCLI has expanded into the Transforming Undergraduate Education in Science, Technology, Engineering, and Mathematics (TUES) CCLI program. While the new solicitation includes language about "dissemination," "transferability," and "widespread adaptation," it does not specifically mention research on any of this.

Despite the limited research base concerning widespread expansion of well-studied pedagogies and approaches in the sciences, what follows are recommendations useful to designers of biology faculty–development programs that reoccur in numerous reviews of STEM faculty–development programs. Table 1 illustrates emphasis of several key elements in five biology faculty–development programs.

Concerning Participating Faculty

1. Give Faculty a Central Role in Critical Aspects of the Professional-Development Program. While the independent-minded science professor may be viewed as an obstacle to course and curriculum reform, this trait can be an advantage when faculty members are seen as colleagues and not simply participants. For instance, the Modeling Physics program was designed to treat teachers as partners who develop curricular materials (Jackson *et al.*, 2008). Similarly, in the DQC program, conceptual questions were modified based on faculty input over time (D'Avanzo *et al.*, 2012), and the HPI was developed, used, and modified by a group of faculty members (Table 1; Marbach-Ad *et al.*, 2007). Other roles faculty could play include mentoring new participants (a train-the-trainer approach), assuming leadership in the home institution, and organizing sessions at professional meetings.

2. Embed Rewards in the Program That Faculty Value. Lack of rewards supporting STEM teaching reform is an ongoing issue in faculty development. Laursen and Rocque (2009) interviewed 44 faculty members from the NSF-supported Leadership Education for Advancement and Promotion (LEAP) program; in the educational system category, half of the comments concerned challenges with meaningful recognition of reform efforts. It is discouraging that more than 20 yr after Boyer's *Scholarship Reconsidered* (1990), a National Research Council (NRC) report notes the ongoing positive relationship between pay and traditional scholarship, with pay and time in the classroom showing the opposite trend (Fairweather, 2008).

One way to address this disparity is to make recognized scholarship (what "counts" for reappointment and promotion at a particular institution) of evidence-based reforms a central part of a faculty-development program, a tactic the Carnegie Foundation for the Advancement of Teaching has long promoted (e.g., Hutchings *et al.*, 2011). This approach is challenging in biology faculty development, because most STEM faculty members are not familiar with the literature and theories underlying particular reforms or with

Table 1. Elements emphasized in five biology faculty–development programs

Program	Active learning	Central role for faculty	Rewards embedded	Cooperative teams	Reference
HPI	X	X	X	X	Marbach-Ad *et al.*, 2007
DQC	X	X	X	X	D'Avanzo *et al.*, 2012
STLC	X			X	Sirum and Madigan, 2010
FIRST IV	X		X	X	FIRST IV, 2013
HHMI Summer Institutes	X			X	Wood and Gentile, 2003

appropriate dissemination venues; therefore, presenting posters, giving talks, and publishing their findings in the area of educational research is difficult for them. The American Society of Microbiology developed the Biology Scholars Program to address this problem, with 150 faculty participants since 2005 (www.biologyscholars.org). Similarly, the scholarship of teaching and learning (SoTL) would need to be an explicit part of any program promoting such a faculty-reward outcome. There is evidence that SoTL from a faculty-development program has been valuable in reappointment and promotion decisions for some biology faculty, especially on campuses that encourage multiple forms of scholarship (O'Meara, 2005; Sorcinelli *et al.*, 2006; D'Avanzo *et al.*, 2012). In addition to scholarship, other rewards include outstanding teacher awards and recognition by deans and department chairs in special lecture series (Rogan and Anderson, 2011). Of course, such rewards require a high degree of top-down involvement within institutions and/or departments. A final point is that rewards should be included in a professional-development program from the beginning and not added on later. Rewards emphasized in several biology faculty–development programs (Table 1) include group research (HPI), SoTL (DQC), and postdoctoral fellows' enhanced job prospects (FIRST IV).

3. Include Strategies to Address Forces—Both Positive and Negative—Particular to Individual Faculty Members *and Their Institutional Settings.* Some overviews concerning course and curriculum reform discuss social, personal, and institutional influences on individual faculty members (Diamond, 1989), but effectively addressing these is far from easy, especially in programs that span institutions. There are factors at every college and university that can advance the reform process (e.g., science faculty members with educational specialties who can facilitate efforts) and inhibit change (expectations about content coverage). In addition, individual faculty members have helpful/constraining attributes, such as willingness/lack of confidence to try new ideas. Rogan and Anderson (2011) recommend that professional-development programs include explicit recognition and discussion of such opposing and supporting forces for each participant and also specific change strategies to address these forces (such as rewards from upper management). However, few biology faculty–development programs do this (Table 1). Both Henderson and Dancy (2007) and Rogan (2007) present models characterizing these positive and negative forces that may be useful in design of professional-development programs. In the former paper, individual traits (such as a teacher's beliefs or knowledge about active pedagogy) and situational ones (outside the faculty member's control) are presented visually to show conditions under which change is most likely. Similarly, Rogan (2007) describes a "zone of feasible innovation" with an upper boundary depicting changes feasible at a given time that shifts upward as new practices take hold. The emphasis here is to view change as a long-term process with some reforms possible now and others more likely in the future.

4. Emphasize Cooperative Teams of Faculty Members Who Work Together Effectively to Transform Their Teaching. Cooperative group work is usually considered in the context of student learning, but the benefits of this approach apply to faculty as well. Many medical schools recognized this in the 1990s and included social constructivism (learning within a knowledge community) in faculty-development programs (Wilkerson and Irby, 1998). Rogan and Anderson (2011) describe three critical elements of such communities of practice: they 1) are joint enterprises understood and revisited frequently, 2) bind faculty members together into a social unit, and 3) produce a shared set of resources (such as materials and approaches) over time. Numerous biology faculty–development programs demonstrate the efficacy of different types of learning communities (Table 1). For example, Sirum and Madigan (2010) provide evidence for changes in classroom teaching as a result of year-long bimonthly discussion groups called discipline-specific scientific teaching learning communities (STLCs). Similarly, faculty members who developed the HPI worked in teams to better understand students' responses to interview questions (Marbach-Ad *et al.*, 2009). Communities of practice within biology faculty–development programs can take many forms; teams may include instructors from single departments, similar-type institutions, or faculty members attempting to use the same type of concept inventory, for instance. As with students, the incentive for faculty members to work together must be very strong; that is, they must have clear group goals and perceive the communal effort, combined expertise, and mutual support as worth the considerable time and effort. Many biology faculty–development programs use cooperative teams (Table 1).

Concerning Program Design

1. Base Design and Evaluation of the Program on Research and Theory, Including Literature on Change, How Students Learn, Faculty Motivation and Barriers, and Institutional Reform. There is a large and disparate literature on faculty development written by professionals with very different training and expertise. In an analysis of nearly 200 articles, Henderson *et al.* (2011) discovered little overlap in assumptions and referenced literature by three STEM research communities—disciplinary-based, faculty-development, and higher education researchers. Such compartmentalization limits transfer of lessons learned and evidence for transformation of STEM courses that can inform design of new programs. As a first step, a faculty developer should recognize the distinctions between these communities. As described by Henderson *et al*. (2011), discipline-specific STEM education researchers (SER) often focus on student learning and specific curricular or course reforms within their own discipline. In contrast, faculty-development researchers (FDR), typically in centers for teaching, may be more concerned with helping faculty members in general improve as teachers, while higher education researchers (HER) may focus on institutions nationally.

Each of the three communities provides important lessons for biology faculty developers. Rutz *et al.* (2012), an FDR example, provides quantitative data showing that "more faculty development focused directly on improved teaching and learning results in higher performance from students" (p. 44). This study supports the critical conclusion that genuine transformation of biology instruction, the goal of *Vision and Change*, will necessitate repeated or sustained engagement by faculty in one or more programs over numerous years. The LEAP project takes a HER approach; in this context, Laursen and Rocque (2009) include data from interviews about skills needed at different career stages common across institutions. In contrast, the concept inventory research discussed above is more typical of a SER perspective, in that the efforts concern students' alternative conceptions and conceptual challenges within specific subdisciplines of biology. Mulnix's (2012) critique of a lecture-based biology pedagogy workshop organized by a well-known national organization points to the need for blended approaches; research on student learning (SER) and from teaching centers (FDR) clearly shows the value of student-centered approaches in such workshops.

A recent report on the status of discipline-based STEM education research (NRC, 2012) can serve as a guidepost for designers and funders of professional development for biology faculty. The following recommendations from that report are solidly based in SER and FDR theory and research. First, effective programs are sustained and long-lasting. One that emphasizes communities of practice and SoTL, as described above, will likely require several years of sustained effort. Second, faculty members need ongoing feedback about the efficacy of their efforts. An example of feedback discussed earlier is iterative use of pre–post assessments with validated instruments accompanied by careful application of findings to course revision. A third and related recommendation is that genuine transformation of classroom teaching necessitates deep conceptual change in teaching and learning for faculty. Henderson and colleagues also repeatedly emphasize this point (e.g., Henderson and Dancy, 2011), as do other SERs (e.g., Gess-Newsome *et al*., 2003). Both persuasive feedback and sustained programs that give faculty members the opportunity to reflect on their experiences with other instructors are helpful here. Faculty developers would also require reliable ways to assess such conceptual change.

2. The Design of Faculty-Development Programs Should Include Rigorous Evaluation Documenting Effectiveness. The research base concerning effective STEM faculty development, including for biologists, is not robust. For instance, some studies rely on less reliable assessments such as self-reporting by faculty and students (Desimone *et al*., 2010). Typical is a recent study of the Howard Hughes Medical Institute's (HHMI) Summer Institutes claiming to be "a model for transforming professional development" based only on participants' self-reporting of outcomes (Adams *et al*., 2012). In their random selection of more than 100 faculty-development models and approaches, Henderson *et al*. (2008) found very few with even moderate evidence concerning success or lack thereof.

Faculty development–program efficacy can be studied with quantitative or qualitative approaches, or both (e.g., D'Avanzo *et al*., 2012). Quantitative student data include pre–post gains for matched, conceptually based questions and scores for higher Bloom's-type questions. A group of biology faculty members at James Madison University developed a multiple-choice assessment to examine graduating biology students' skills in quantitative and scientific reasoning; these faculty members then "closed the assessment loop" by using these data to modify their teaching (Hurney *et al*., 2011). Qualitative evidence, which includes findings from interviews or focus groups, is used alone or can help evaluators better understand particular quantitative results. Concept inventory questions are often validated with student interviews (e.g., Hartley *et al*., 2011).

Effectively researching effects of biology course reforms within a single institution is unquestionably difficult and across institutions for large numbers of faculty members even more so. Anyone who has attempted ongoing assessment of biology courses in a university appreciates the challenge of frenetically collecting and promptly returning biology exams several times during the semester. The difficulty is compounded by the need for triangulation—use of multiple approaches and data sources—a well-known strategy that can increase the validity of evaluation and research findings (Creswell, 2009). Despite the challenges, faculty developers need reliable evidence—positive or not—solidly based on program goals when they design new biology professional-development programs. The value of negative findings cannot be overlooked. For example, Ebert-May *et al*. (2011) used the Reformed Teacher Observation Protocol to show that for biology faculty in two national professional-development programs, active-teaching frequency self-reports were significantly higher than actual classroom measures. This study is a valuable reminder that faculty developers must be cautious about overly optimistic self-reporting by faculty members, a well-known phenomenon (e.g., Tschannen-Moran *et al*., 1998). It also supports the claim that biology educators lack effective professional-development models.

TRANSFORMATION OF BIOLOGY TEACHING AND LEARNING

Vision and Change emphasizes transformation of college biology education. What does this mean? Mezirow (1997) describes transformative learning as a process leading to radical change in the learner's frame of reference. In the context of social constructivism, this change occurs within a group setting. Thus, biology faculty members engaged in transformation would work within a learning community to dramatically revise their assumptions about teaching and learning through honest, critical reflection on their own experiences in the classroom. They would be willing and able to question their basic beliefs about themselves as teachers and about their students, departments, and schools. Brownell and Tanner (2012) emphasize the same point when they ask biologists to challenge their most basic assumptions about what it means to be a university or college professor. According to Servage (2008), application of transformative learning theory to professional development for teachers has been problematic, because the focus tends to be on acquisition of technical skills and not on genuine transformation. Therefore, if we as biology educators seek genuine "transformation" of biology teaching and learning, we must understand what this means and then apply research on transformative learning to our faculty-development endeavors.

CONCLUSION

Biology educators are justly proud of the many advances related to college-level biology teaching and learning in recent decades. *Vision and Change* alone is evidence of that. I suggest, however, that fundamental change will be limited, because we lack theory-based and evidence-based, realistic models for actually achieving the desired "change" broadly.

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