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Bridging the Gap

Assessing How Science Faculty Learning Communities Promote Scientific Teaching

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Although there is a need for continued pedagogical advancement in science undergraduate education, what is needed more urgently is more widespread adaptation of pedagogical practices that research has already shown to promote learning. Those practices include interactive engagement pedagogies such as active learning and inquiry-based learning. The need now is to find ways to integrate and institutionalize these evidence-based strategies for teaching science and to help science faculty learn about and implement them. Scientific Teaching Learning Communities (STLCs) create a culture that values scholarly teaching within science departments, important for bridging the gap between science and education and for improving undergraduate science learning. Evidence for the impact of STLCs on the student-learning environment was obtained through the development and use of the Participant Assessment of Learning Gains survey, an adaptation of the online Student Assessment of Learning Gains survey originally developed by Seymour *et al*. (Available at: http://www.wcer.wisc.edu/salgains/instructor/SALGains.asp, 1997 and Paper presented at the National Meeting of the American Chemical Society, 2000). Data reveal how STLCs are transforming faculty behavior and directly affecting what they do in their science classrooms.

Keywords: Science education reform, scientific teaching, instructional development, faculty learning community.

Science education reforms followed by efforts to teach scientifically [1] foreshadow the desired undergraduate science-learning environment of the future, but to get there, important changes are needed. Consider that the most common reason that academically prepared students give for leaving a science, engineering, or math major in the first 2 years of college for a nonscience major (40–60% retention) is pedagogical. These students, from a wide range of different types of institutions, are unwilling to put up with the poor teaching, emphasis on memorization of large bodies of facts, and the "weed out" objectives and culture of these disciplines [2]. Reform efforts must address these issues, and although the dominant mode of teaching in the undergraduate science classroom today may still be lecturing [3], science faculty are becoming more familiar with interactive engagement (IE) pedagogies [1] including peer instruction, active, problem-based, cooperative, and collaborative learning, methods that have proven to be superior to the traditional lecture format in promoting learning in general [4] and in the sciences [5]. Indeed, the science education literature has many examples of successful science education approaches; however, there is still much to be done to get these practices more wide spread and institutionalized. Establishing a new paradigm for undergraduate science education that focuses on the concept of scientific literacy is of great importance and an obvious place to begin is with faculty development, particularly instructional improvement for faculty in science departments.

The information and resources for science teaching are growing; however, the pace at which these innovations are adapted, implemented, and adopted by science departments needs to be improved within the science education reform movement. Scientists do not conduct their research without collaboration at many levels, yet collaborating and even talking about teaching are not routinely done in many science departments and, in fact, can be perceived as taboo in some research oriented departments [6]. This phenomenon limits the growth of a science faculty instructional development culture, where ideas about teaching and learning in the sciences can be discussed and shared. There are some institutes and workshops which faculty may be able to attend to learn more about how to create positive learning environments, such as the National Academies Summer Institute on Undergraduate Education in Biology [7] and Project Kaleidoscope events [8], but these are just not enough and those that do exist do not allow attendance by enough faculty to impact widespread reforms for science education at all institutions. Additionally, support is diffi-

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cult to sustain once participants return to their home institutions. Therefore, increasing faculty development opportunities for greater numbers of faculty members in a department, making them accessible to scientists in higher education, making them acceptable to scientists, as well as affordable and not too time consuming, are all necessary steps to ultimately promote increased student science learning, especially in research focused institutions.

A critical step has to do with transforming the culture in a science research-based department to one in which faculty begin to see the value of teaching as scholarship and where faculty become more aware of the research on learning. That means we need science faculty to value talking about teaching and learning. With this goal in mind and over the last 4 years, we have developed discipline-specific Scientific Teaching Learning Communities (STLCs), a variation on the traditional multidisciplinary Faculty Learning Community (FLC) as pioneered and defined by Cox [9], to help science faculty to use their science skills to consider, design, and implement teaching strategies and learning environments that best promote learning. Like many FLCs, the STLCs are year-long, biweekly, 90 minute, structured, facilitated discussions of teaching and learning issues, but because they are discipline specific, topics include ideas about science education reforms, with a focus on educating faculty regarding best practices in science education and supporting them as they begin to implement new teaching strategies in their traditional lecture-based classrooms. In STLCs, participants approach their teaching as they would their research, that is scientifically, based on the evidence in the literature about how people learn. The STLC group works together to provide feedback and support to each other as they design and implement new, non lecture-based, interactive teaching strategies based on the science teaching and learning research. The details of the design and implementation of the STLCs, including the specific topics addressed, the STLC activities, and the resources used, are reported elsewhere [10]. Briefly, sessions involved modeling interactive teaching strategies through activities, discussions, and sharing of ideas in a format that takes advantage of the collective knowledge of the participants, who include both tenured, tenure-track, and nontenured faculty members with a wide range of classroom experience. In this article, we describe how we are assessing the impact of the STLC experience on what faculty do in their classrooms, and the role of the STLC experience in promoting sustained change in science faculty teaching behaviors and attitudes.

We provide an analysis of why discipline-specific STLCs are effective and we provide the details of a new assessment approach for STLCs that can be adapted to other instructional development programs. The assessment instrument that we developed for use with STLC participants, by modifying the Student Assessment of Learning Gains Survey (SALG) originally described by Seymour *et al.* [11, 12], is called the Participant Assessment of Learning Gains Survey (PALG). PALG survey results reveal that STLC participants are engaging with colleagues to talk about teaching. In addition, it provides evidence that STLCs have a direct impact on what faculty members actually do in their classrooms, and it reveals how these activities may be impacting student learning.

BACKGROUND AND SIGNIFICANCE: SCIENCE FACULTY INSTRUCTIONAL DEVELOPMENT

Many universities and colleges are confronting issues of how to address a new paradigm for undergraduate science education that is consistent with what is known about how students learn [13, 14], the teaching strategies that promote learning, and the goals of science education [3] including initiatives, which target the department as the unit of change necessary to achieve undergraduate reforms in the sciences [15]. Of course, it is the faculty members in those departments that are best suited to initiate lasting and effective classroom reforms, and they play a critical role in the development of this new science education paradigm. In other words, in order for reforms to take hold in the classrooms of a given department, buy-in from as many department faculty members as possible is critical so that there is sustained interest in changing teaching behaviors to be consistent with the new paradigm. Achieving this buy-in is one of the most important challenges an institution and department faces and careful consideration should be given to the value, in this regard, of some of the more common efforts for instructional development.

One way department level reform efforts often begin is through faculty committees. Yet, committee work on curriculum reform tends to be an elected body that serves to promote a particular topic or investigate a topic for the purpose of producing a report. By itself, such reports do little to support individual faculty motivation and commitment to a transformative pedagogy that is important for curricular change. Instructional improvement workshops may offer a better solution for science education reforms, especially ones that address scientists and their discipline. For example, the NAS Summer Institute offers a series of workshops over a period of days where science faculty members from across the country work together to develop interactive lessons for their courses [16]. Such types of workshops are designed to meet the needs and interests of both individual faculty participants and small teams of faculty from a given institution who have shown an interest in enhancing their teaching despite other demands on their time.

NAS Summer Institute participants return to their home institutions with a national network of new colleagues with which to talk about teaching and to implement changes and to help spread the word about the need for reforms among their colleagues [17]. However, in order for workshops to be most successful, in terms of impact, they must address the stages of change that workshop participants undergo as they learn new ideas and seek to make changes in how they teach [18–20]. The elements and activities of the workshop need to be crafted to move the participants toward changing their instructional behaviors. The first stage of change, called “unfreezing,” is getting the participant to challenge previously held beliefs about the effectiveness of their instructional behaviors within their current paradigm. Most of the time, this unfreezing occurs before the workshop

starts, as participants come to the workshop with a desire to learn about and adopt the workshop strategies [18]. The second stage is referred to as "cognitive restructuring" and describes the process whereby the participant learns about alternative approaches to instruction that fit with their new views about what is effective in promoting learning. Most workshops are aimed at participants in this stage. In order for changes to be lasting, however, workshops need to address participants in the third stage, which involves participants' sustained application of what they learned such that "refreezing" and the adoption of a new instructional paradigm occurs instead of refreezing and backsliding to former beliefs and attitudes. Programs that best address this third stage provide participants with the opportunity to transform their beliefs, behaviors, and practice over time and in a supportive learning environment [18]. It can be challenging for the typical workshop to provide this type of support after participants return to their home institutions and begin implementation efforts on their own.

In view of the gap most workshops leave in supporting faculty members in a department in this refreezing stage, we saw the potential of establishing faculty learning communities (FLCs) in the sciences, where ideas about teaching and learning would be introduced, implementation strategies would be modeled, and support and formative feedback would occur over a year-long experience. Over the past several years, traditional FLCs have enjoyed significant growth, as undergraduate education and excellent teaching have become a renewed focus for colleges and universities. Cox defines FLCs as both cohort-based and topic-based groups of cross-disciplinary faculty where, among other things, new ideas about teaching and learning are exchanged, course projects are realized, and where faculty engage in community building [9]. The science FLCs that we describe are based upon the principals of a successful FLCs that Cox and most others subscribe to, including the important concept of community building, but there is one notable difference: the science FLCs are discipline-specific. The result is that these STLCs have the ability to significantly affect the beliefs, practices, and behaviors of faculty within science departments. Whereas cross-disciplinary FLCs have many documented benefits [9], there are also limitations because department instructional goals may vary greatly, topics may be generalized to account for experts in a variety of disciplines, and constructive feedback from group members may be hampered by lack of conceptual understanding of a discipline's subject matter. For example, we observed that science faculty members were noticeably absent from the cross-disciplinary FLCs and workshops on topics offered on our campus that related to instructional improvement, and the few science faculty members that did attend often expressed frustration that the conversations were not specific to their discipline. They needed to work more closely with science colleagues to create an environment where collective knowledge is generated and shared as a common practice. A group of content area experts can together brainstorm ideas for classroom activities, assessments, and learning outcomes for example, by using the collective knowledge of the group [10].

Discipline-focused STLCs provide an important means for cultivating cultural change within science departments. Whereas most workshops may not be sustained over a long enough time period to prevent the refreezing of former beliefs and behaviors, and the impact on the department as a whole may be limited, the STLCs met bi-weekly over an academic year to provide support and motivation to engage in instructional improvement over time. This model reduces the threat of refreezing of previous beliefs and increases the promise of refreezing the new paradigm of scientific teaching because the cohort groups interact with each other on a regular basis within the environment where they research, teach, socialize, and perform many of their daily professional duties as science faculty.

STLCs IN INSTRUCTIONAL DEVELOPMENT

A disciplinary approach to FLC's is not entirely unique as there are few other discipline-specific nonscience FLCs for curriculum reform that have been identified in institutions of higher education [21]. But, the lack of science FLCs in the literature is notable. In this work, we provide evidence that STLCs can lead not only to collegial discussions about teaching and learning on a consistent basis but also to faculty instructional behavior changes. This means that there are more faculty members in a science department that are inclined to speak about teaching and learning and to act on needs in these areas, such as creating an environment where teaching is valued, supporting curriculum reforms, and ultimately increasing student learning and retention of science majors.

The STLCs differ in other important ways from the typical FLC goals described elsewhere [9]. For example, a group product such as a revised course or a highly individual product such as a teaching portfolio is not emphasized, nor it is a specific type of interactive teaching (peer instruction, the case method, problem-based learning, etc.), prescribed as the focus, as is the case in many topic-based multidisciplinary FLCs [9]. Rather, our STLC's focus was on applying general IE teaching ideas and strategies to the science classroom and on the process of scientific teaching—a term originally used by Handelsman *et al*. [1], which describes and reflects the way scientists approach their teaching as they do their research, based on evidence and the research literature. Thus, the STLC is about promoting and supporting classroom behavioral changes, departmental culture change, and an awareness of the literature on teaching and learning.

We built upon the initial successful 1-year life science STLC with nine members described by Sirum *et al.* [10] to establish, over a 3-year period, five 1-year-long STLCs at a new institution. The first of these three involved 10 biology faculty members from a department of about 30 tenured or tenure track faculty members. The goal of the group was to learn about and begin to implement IE teaching strategies. In our 2nd year, this STLC continued with six original participants returning and five new members from the biology department. The initial goal of the group had evolved to begin addressing curriculum and pedagogical issues beyond each participant's individual

classroom, but based on the needs and desires of the group, much of the focus remained on design and implementation of specific IE activities for each participant's course or courses. In the 3rd year, this group continued with three new and six returning members. In addition, a new STLC was formed, and this time was aimed at faculty in all of the Natural Sciences. This STLC had 12 members in the 1st year, eight new, and three returning members in the 2nd year, and the goal was to help participants learn about design and implement interactive activities in their classrooms. All five of the STLCs included pretenure and tenured faculty members of all ranks, and combined had 53 participants.

The STLCs were facilitated based on best practices in teaching and learning: sessions were active, engaged, collaborative, and provided opportunities for participants to get feedback. Sessions continued for one academic year, biweekly for 90 minutes, and sessions were organized around the basic concepts and strategies for IE teaching (e.g., peer instruction and cooperative learning) as well as specific topics dictated by the interests and concerns of the participants (student motivation, large classes, getting students to read). In the STLCs, participants explored all the best practices in IE teaching strategies as they apply to the sciences, and they looked at specific science examples to see how others applied these strategies with success [10]. The STLC became a place where faculty could get feedback on how to apply IE to their specific courses, topics, and concepts; discover ideas about teaching and learning and resources that they had not come across on their own; and use the ideas from the group to modify their activities to be more effective.

ASSESSMENT OF THE IMPACT OF STLCs

STLCs enable a change in culture [10] but can this change be measured? Previously, in a life science STLC case report, the six faculty participants in a year-long life science STLC describe, through narrative statements, changes in their awareness about the best practices in teaching and learning and report that the STLC experience has empowered them to take risks and try new things in the classroom [10]. As we expanded our STLC program to include more participants, it provided us with an opportunity to gather more data on the effects of the STLC. In the past, others have assessed FLC effectiveness through surveys of participants [22], by observation of participants' classrooms to record authentic implementation of the teaching strategy studied in a topic-based multidisciplinary instructional development FLC [23], and even by attempts to measure student learning [18]. The ultimate desire is to determine whether these instructional interventions and programs increase student learning, as that is their goal.

Actually measuring student learning as a result of instructor participation in a STLC would be ideal, but in most cases, it is neither practical nor possible to do properly. For one, valid and reliable measures of student learning would need to be available for comparison of student learning in different courses. For another, even if such an instrument were available, such as the Force Concept Inventory used in physics [24], there are too many confounding variables that may impact student learning to attribute any gains directly to participation in the STLC. The next best level to assess the impact of an instructional development program is at the application level [18]. This means that if faculty members are actually doing the things intended as a result of the STLC then the STLC is having a positive impact. There is a large body of evidence about what types of learning environments are most effective and as these learning environments become more pervasive in a classroom, it is reasonable to predict that there is an increased likelihood that student learning will increase as well.

Connolly and Millar [18] propose five possible levels of assessment of instructional development programs or workshops. These workshop assessment levels are 1) participation, 2) satisfaction, 3) learning, 4) application, and 5) impact/student learning. With the problems associated with measuring student learning, they propose that measuring impact of programs focused on pedagogical reform is usually limited to Stages 1–4, the highest level being 4, the application stage. In fact, typical assessments of workshops and programs involve questions primarily pertaining to the first 3 levels: surveys of number of participants in the workshop, participants' satisfaction with the workshop, and what the participants said they learned from the workshop. But more important to student learning is if these participants actually apply what they have learned in their classrooms. Therefore, assessment at the application stage provides better evidence for the effectiveness of an instructional development program [18].

Application was assessed in the STLC participants where the participants learned about many teaching strategies and with the realization that one size does not fit all faculty members [25], all students, and all courses. So instead of measuring application by observing and judging authentic implementation, we asked the participants to report on how many "new to them" IE activities they ran in their classrooms instead of lecturing. As the goal is culture change, to move toward getting faculty to consider teaching, getting it in the open as something valuable to think and talk about in the sciences, then assessing whether faculty simply tried to implement a new IE strategy reflects positively on the influence of the STLC, even if the faculty member was not initially successful with the new approach. The point is to focus on individual attitude changes and department level cultural changes that move toward faculty viewing teaching as an iterative process of experimentation with teaching strategies, assessment of student learning, and refining the teaching strategies to improve student learning, in other words, scientific teaching.

As the STLC was based on best practice regarding how people learn, so should we base our evaluations and assessments on these same best practices. Many faculty development programs use surveys to probe the effectiveness of their programs. Cox describes a survey used for probing participants of FLCs for learning gains in their students [22]. However, although this survey

probes faculty-reported student learning gains, it lacks questions regarding feedback on elements of the FLC experience that participants found useful, what the faculty participant learned, the new skills and attitudes the faculty members acquired as a result of participation in the FLC, and the participants' report on the utility of their new learning. Therefore, we developed an instrument to address these questions.

The online SALG survey, a Likert-scale survey originally designed by Seymour *et al.* in 1997 [11, 12], allows instructors to ask students questions about which elements of the class promote learning and probes student self reported changes in attitude and learning. The PALG survey is an adaptation of the SALG we designed for use with faculty to assess the impact of faculty participation in professional and instructional development programs. Like many post-professional development program participation surveys, the goal was to learn from faculty participants about the effectiveness of the program, in this case year-long Scientific Teaching faculty Learning Communities. The unique features of this survey are that it can be adapted to apply to many different types of professional development programs, it easily and thoroughly probes faculty self-reported learning gains and classroom behavioral changes, as well as faculty reports of student learning gains, and it compiles the evidence for changes in faculty and student learning in an easy to customize, administer, analyze, and tabulate online-format.

Modeled after best practices in student evaluation of teaching and learning, the PALG was generated from the SALG template that has five types of questions that can be customized to the professional development program. These include questions about:

1) Which elements of the program facilitated the participant's learning?
2) How well the participant now understands the concepts presented?
3) How well the program has added to a participant's skills?
4) How the program influenced the participant's attitude towards the subject?
5) How much of what they learned the participant will use in the future?

Importantly, there are additional questions about how many new activities the participant tried in their classroom(s), to what degree student learning has increased as a result, and how the faculty member knows that student learning has increased, some adapted from Cox's FLC survey [22].

The SALG web site allows the author of a modified survey to make the survey instrument available to other users of the web site. Therefore, the PALG survey is readily available for others to use as we have designed or to modify to address the goals of a specific program. If WWW access and computers are available during your program, faculty members can be asked to complete the survey online before leaving the session, as was done for most of our STLCs leading to a very high-response rate. Additionally, the tabulated data are available immediately, the respondent's anonymity is preserved, and there is space for participants to add their own open-ended comments.

STLC PALG DATA

Over a 3-year period, we facilitated five 1-year-long STLCs. The PALG was used to document learning gains in faculty participants and their reports of changes in student learning as a result of their STLC participation. The data for each PALG main question numbered 1–5 are shown in corresponding Tables I–V. Participants can choose to respond to each numbered question sub item from the following five categories: 1) is neutral or nothing, corresponding to "not at all," 2) is "a little," 3) is "somewhat," 4) is "a lot," and 5) is the maximum, "a great deal." Therefore, 3 represents moderate gains, the sum of 4 and 5 indicates gains greater than moderate and subtracting the sum of 3, 4, and 5 from 100% would yield the % of 1 and 2 responses selected.

STLC participants reveal the importance of discipline-specific STLCs, as they report that they value most sharing ideas and activities about science teaching and learning with colleagues (see Question 1 responses in Table I). Data from the PALG also indicate the positive effects of the STLC experience on faculty members in several other key areas as follows:

Concepts

As a result of participation in the learning community, faculty indicate increased understanding of the concepts discussed over the year (Question 2, Item numbers 1–11 in Table II), especially the concepts pertaining to IE pedagogy and creating a positive learning environment at the level of their own classrooms, with 61–71% reporting more than moderate gains (Items 3–7 and 10 in Table II). We observed that while gains in overall understanding of larger scale transformation at the departmental curriculum level were not as great (29% report more than moderate gains in Table II, Item 12), 83% of respondents nonetheless report that the STLC helped somewhat, a lot, or a great deal with understanding curriculum reform.

Skills

Faculty report gains not only on their conceptual understanding of various IE pedagogical approaches but also gains in skills in applying these methods to their own classrooms as a result of STLC participation (Question 3, Item numbers 1–12 in Table III). Greater than 60% indicate that they have made more than moderate gains in the design and implementation of interactive learning activities (Items 4 and 5) their understanding and use of the research literature in teaching (Item 10), and in their overall teaching effectiveness (Item 12), and 83% made more than moderate gains in their skills in talking about teaching with colleagues (Item 10). Gains in the challenging areas of curriculum design (Item 2), motivating students (Item 3), design and implementation of formative assessment strategies (Items 6 and 7), and teaching as research (Item 11) were more modest with 32–41% of respondents indicating more than moderate gains.

TABLE I
Aspects of the STLC that helped participants' learning

Q1: How much did each of the following help your learning?	% Responding much or very much help (4 + 5)	% Responding moderate, much or very much help (3 + 4 + 5)
A. The way in which the material was approached	71	95
B. How the STLC activities fit together	66	93
C. The pace at which we worked	63	88
D. STLC activities		
D1. Presentation and discussion of topics and readings brought by facilitator	88	95
D2. Presentations and discussion of topics brought by individual group members during assigned session	73	95
D3. Spontaneous group discussions	85	100
D4. Exchange of ideas with colleagues	95	100
D5. Troubleshooting classroom issues	63	80
D6. Demonstrations or videos	39	63
F. Resources:		
F1. Assigned readings	63	93
F2. Minutes of the sessions	56	83
F3. E-mail communications	61	85
F4. Supplemental resources offered (web sites, readings, etc.)	76	85
H. Individual support as a learner:		
H1. Quality of contact with group members/learning from other participants	83	95
H2. Quality of contact with facilitator	80	98
H3. Feedback from group on your ideas	78	95
K. The way this STLC was taught overall	88	100

Summary of Participant Assessment of their Learning Gains (PALG) Survey results from five one-year long Scientific Teaching faculty Learning Communities (STLCs) with 53 combined participants, $N = 41$. The survey was administered online at the end of each final STLC session of the academic year. A five-point Likert scale was used: (1) No help/Not at all, (2) A little help/A little, (3) Moderate help/Somewhat, (4) Much help/A lot, (5) Very much help/A great deal.

Attitude

With these increases in conceptual understanding and skills, come gains in interest in, attitudes toward, and confidence in teaching (Question 4, items 1–10 in Table IV, and Question 5, items 1–5 in Table V). Participants report that while pursuing teaching as an additional area of their research is not the highest priority for them (39% indicate more than moderate gains, item 4, Table IV, and item 4, Table V), they do think that they will seek out teaching resources on their own in the future and pursue course and curriculum reforms (>60% more than moderate gains, items 2 and 5, Table V). Importantly, 68% of participants report more than moderate gains in courage to take risks and try new things in the classroom (Item 2, Table IV) and 83% report that the STLC contributed a lot or a great deal to continuing with critical reflection and continuous improvement of their teaching practice (Item 1, Table V).

Impact on Student Learning

The Additional Questions sections of the survey include questions that were written or modified to focus on the impact of the STLC on student learning by prob-

TABLE II
Degree of STLC participants' understanding of the concepts

Q2: As a result of your work in this STLC how well do you think that you now understand each of the following?	% Responding a lot or a great deal (4 + 5)	% Responding somewhat, a lot, or a great deal (3 + 4 + 5)
1. Student motivation issues	56	96
2. Development of students' higher order thinking skills	44	85
3. Active learning	76	95
4. Characteristics of a positive learning environment	68	95
5. Identification of learning goals	61	95
6. Peer instruction strategies (e.g. "think-pair-share", "clickers")	71	93
7. Issues regarding student preparedness for class	71	93
8. Assessment of learning	56	93
9. Role of technology in the classroom	49	85
10. Group learning strategies	68	93
11. Issues regarding large enrollment courses	46	76
12. Curriculum reform	29	83

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TABLE III

Degree of STLC participants' change in skills

Q3: How much has this STLC added to your skills in each of the following?	% Responding a lot or a great deal (4 + 5)	% Responding somewhat, a lot, or a great deal (3 + 4 + 5)
1. Identification and prioritization of learning outcomes	56	88
2. Curriculum design	41	83
3. Motivating students	39	93
4. Design of interactive learning activities	66	95
5. Implementation of interactive learning activities	61	93
6. Design of formative assessment strategies	33	78
7. Implementation of formative assessment strategies	32	76
8. Evaluation of the role of technology in the classroom	46	71
9. Talking about teaching with colleagues	83	95
10. Understanding and using the research literature in teaching and learning	63	80
11. Teaching scientifically (teaching as research)	37	73
12. Your overall effectiveness as a teacher /Ability to create a positive learning environments	63	93

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TABLE IV

Degree of STLC participants' change in attitudes

Q4: To what extent did you make gains in any of the following as a result of what you did in this STLC?	% Responding a lot or a great deal (4 + 5)	% responding somewhat, a lot, or a great deal (3 + 4 + 5)
1. Overall confidence in teaching	46	83
2. Courage to take risks and try new things in the classroom	68	90
3. Enthusiasm for teaching and learning	51	85
4. Confidence in viewing classroom as a site for teaching-as-research	39	71
5. Interest in the teaching process	61	83
6. Interest in the teaching and learning research and literature	44	83
7. Perception of yourself as a teacher	49	85
8. Enjoyment of teaching	49	85
9. Awareness of who our students are	39	88
10. Valuing teaching as an important form of scholarship	54	78

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TABLE V

Amount STLC participants will carry with them into the future

Q5: How much of the following do you think you will remember and carry with you into other classes or aspects of your life?	% Responding a lot or a great deal (4 + 5)	% Responding somewhat, a lot, or a great deal (3 + 4 + 5)
1. Critical reflection and continuous improvement	83	98
2. Seeking out teaching resources on your own	61	93
3. Participation in future learning communities	71	93
4. Pursuing teaching as research	39	71
5. Pursuing course and curriculum reforms	63	95

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ing the degree of application of what the faculty member learned and the faculty member's perception of how the classroom environment and student learning may have changed as a result (Tables VI and VII). The 41 faculty members responding report that combined they taught more than 8,400 students since becoming a STLC participant and in these classes they tried 136 new interactive activities. Importantly, 98% of responding STLC participants report increases in student learning ranging from "a little" to "a great deal" as a result of their participation in the STLC. Their evidence for this learning includes quantitative measures such as better grades and test scores, attendance, and retention as well as qualitative evidence such as better student engagement/class discussion, student interest, motivation, class atmosphere, and deeper learning (see percentage of respondents selecting each item in Table VII). In 2004, the NAS Summer Institute reported that 20 universities were represented by 40 participants and combined they taught 22,000 students [17], whereas with this STLC approach,

TABLE VI

Additional Questions. The additional questions omitted from this table to save space include background questions regarding number of years of teaching experience, number of years at the institution, and typical class size taught (see SALG web site for complete survey [24])

What do you value most about your FLC experience?	29 of 39 respondents indicated interaction with colleagues
What is the approximate total enrollment of your class(es) since you became a FLC participant?	8,420 students combined for all respondents
What is the approximate number of new "interactive activities" you tried in your class(es) since becoming a FLC participant?	33 participants report having tried 136 new activities: # Activities Tried: 0 / 1–3 / 4–6 / 7–20 # participants: 4 / 12 / 11 / 16
What is the degree that student learning has changed as a result of your participation in the FLC?	98% indicate that student learning increased as a result of their FLC participation: % responding a lot or a great deal (4+5): 38 % responding somewhat, a lot, or a great deal (3+4+5): 79 responding a little, somewhat, a lot, or a great deal (2+3+4+5): 98
If there were an opportunity to participate in next year's STLC, would you be willing to participate?	86% of respondents indicate yes

Summary of Participant Assessment of their Learning Gains (PALG) Survey results from five one-year long Scientific Teaching faculty Learning Communities (STLCs) with 53 combined participants, $N = 41$. The survey was administered online at the end of each final STLC session of the academic year. A five-point Likert scale was used: (1) No help/ Not at all, (2) A little help/A little, (3) Moderate help/Somewhat, (4) Much help/A lot, (5) Very much help/A great deal.

in 3 years, we had 53 participants from one university, and 41 report impacting >8,400 students out of a total enrollment of ~18,000 on one campus. With a higher percentage of the faculty members participating at one institution and even in one department, a paradigm or cultural shift is likely to occur more rapidly and a foothold for institutionalization of science education reforms is fostered.

IMPLICATIONS FOR SCIENCE EDUCATION REFORM

Our data show that STLCs are effective programs for helping faculty learn about, develop skills and interests in, and apply research-based pedagogies in their science classrooms, thus affecting student learning. By adapting the SALG to STLC participants to create the PALG, we were able to effectively measure gains at the application level of instructional development program assessment. In addition, we asked science faculty to report on changes in student learning both qualitatively and quantitatively, giving a broad picture of the most important elements of a teaching reform STLC.

Although faculty report having tried new classroom activities, we do not have any independent measures concerning whether the implementation or application was effective. However, given that the goals of these STLCs are classroom reforms and changes in faculty attitudes regarding teaching and learning, the PALG provides evidence that faculty may indeed be persisting with new models for teaching, critical reflection, and paying more attention to the research on learning (Question 5, Items 1–5 in Table V), all reasonable predictions of increased student learning. Long-term goals involve

TABLE VII

Evidence for student learning

Please indicate how you know student learning has changed by checking the appropriate responses	% of STLC survey respondents indicating agreement
Achievement of more and/or new learning outcomes	44
Better performance on tests	49
Better performance on writing assignments	29
Better class discussion/engagement	73
Better classroom atmosphere	68
Better attendance	41
Students more motivated	46
Students more interested	61
Better student evaluation comments (note: PALG survey given prior to dept. required student evaluations)	20
Better student evaluation numbers (note: PALG survey given prior to dept. required student evaluations)	15
Greater "coverage"	12
"Deeper" learning	46
Increased beneficial contact with students outside of classroom	37
Better retention/less drops	29

Summary of Participant Assessment of their Learning Gains (PALG) Survey results from five one-year long Scientific Teaching faculty Learning Communities (STLCs) with 53 combined participants, $N = 41$. The survey was administered online at the end of each final STLC session of the academic year. The percentage of respondents indicating agreement with each item is indicated in the table.

department level assessment of student learning and these data might provide some direct measures of STLC impact on student learning.

STLC assessment at the application level allows us to find out how the STLC is addressing the three stages of change [18]. We saw that the last stage, refreezing to get faculty to adopt and persist with a new view of how to approach their teaching scientifically, was a challenge that the STLCs met well. Faculty had the sustained support of the group for feedback and specific ideas regarding design and implementation of their classroom activities and this support encouraged them to pursue further applications and attempts, even when their first attempts may not have gone so well. In addition, faculty members report that they will continue to reflect and pursue classroom reforms beyond the STLC experience (Question 5, Items 1–5 in Table V). Beyond the data that support this notion of a cultural change and a pedagogical shift in attitude, Life Science STLC members, who make up almost half of the department, have reported dynamic, spontaneous conversations about teaching and learning with members of the department who have yet to participate in a STLC: as one faculty member put it "I have been here for twenty years and this is the first time we have had "hallway" conversations about teaching!"

CONCLUSIONS

Our PALG survey data show that STLCs can promote changes in faculty members' behavior that can lead to increased student learning. Direct assessment of student learning as a result of participation in an instructional development program may be something to aspire to and, in some cases, may follow. In the meantime, the PALG survey offers a way to approach assessment of the impact of professional and instructional development programs that is easy to use and modify, and the survey can provide data about the impact of the program or workshop for purposes of program assessment and justification.

The discipline-specific character of the STLC offers distinct advantages in the sciences, namely maximal support for faculty as they pursue application of what they learned and increased dissemination of the ideas discussed in the STLCs, leading to changes in the culture of a science department toward teaching scientifically and talking about teaching. STLCs require minimal resources and can be established at any institution. For example, in our case, the Provost's office, through our Center for Teaching, Learning, and Technology, provided for each participant $500 in professional development funds for year-long participation and $3000 for the facilitator, as well as light lunch fare during the sessions. In initiating a STLC, it is important to start with a facilitator (or co-facilitators) who helps to guide the group in setting the agenda for sessions and who keeps the sessions interactive so that participants can share their collective knowledge and experience. Sessions that are inviting, inclusive, and supportive are the key to successful STLCs [10]. Perhaps in the future, participants in workshops such as the NAS Summer Institute could receive training on how to initiate and facilitate a STLC at their home institutions to support their dissemination efforts [17]. Similarly, as the number of new faculty with education positions in science departments such as science faculty with education specialties (SFES) increases [26], these faculty members could initiate and lead a STLC as a way to establish connections with their science colleagues. The STLC would help with the science education specialist's isolation, a result of what is often a unique faculty position within a department [27] and help bridge the gap between the science and education cultures [28].

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