COMMUNITIES OF TRANSFORMATION AND THEIR WORK SCALING STEM REFORM

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Thanks to the leaders of four communities of practice (CoPs) - Project Kaleidoscope (PKAL), SENCER, BioQUEST, and the POGIL Project for allowing us to participate and learn from their communities.

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Table of Contents

Executive Summary

This mixed-methods study examined four STEM communities (BioQUEST, Project Kaleidoscope, the POGIL Project, and SENCER) in order to better understand the roles of these communities in advancing the goals of scaling STEM education reform. The project explored three key questions:

- How do members and leaders of communities of practice (CoPs[1]) perceive CoP design (membership, structure, communication, activities, and organization to support new knowledge development and action) shapes the ability to achieve goals (around undergraduate STEM pedagogical change and diffusion)?
- What are the perceived benefits of participation in a STEM reform community of practice or network for the individual participants and for their campuses?
- How do communities of practice and networks form, and how are they sustained in ways that help them to achieve their goals?

The following are the key findings related to these questions:

1 The study identified a novel approach to improving STEM education, which we have called *communities of transformation.*

This study identified a unique variant of communities of practice, called communities of transformation (CoTs) that are present in the STEM reform area. The defining feature of these newly identified entities is their focus on exploring philosophically, in deep and fundamental ways, how science is taught. This can lead to more substantive changes that have the potential to address the problems described in national reports around underrepresentation of women and underserved minorities, persistence rates, and success among students. These communities of transformation create innovative spaces that have the potential to shift institutional and disciplinary norms. We identify how these differ from more traditional professional development models, including campus-based professional development and disciplinary meetings.

2 Communities of transformation address both individual faculty and broader systemic change.

Much of the early work to improve STEM education has focused on altering individual faculty behavior through faculty development and dissemination of best practices. Some more recent efforts (e.g., Association of American Universities' STEM reform initiative) focus on changing broader systemic and institutional norms. Communities of transformation provide support for individual faculty change, but they also simultaneously work (to varying degrees) to shift departmental cultures, institutional norms, and disciplinary values. In this report, we describe work that these communities conducted to alter the conversation around teaching within disciplines, as well as evidence of broader impact achieved through service on national committees and task forces aimed at improving STEM education. Their unique work to address both the individual faculty and the broader system is a compelling strategy for change. We found that the strength of these efforts lies in working from the ground up, with individual faculty buy-in, motivation, and support for improving practice. Additionally, in general, institutional type, discipline, and rank/appointment status were not significantly associated with the outcomes we measured, when accounting for our other engagement, design, and motivation variables. We think this points to the potential for CoTs resembling those in our study to contribute to overcoming typical barriers to reform such as reward structures, disciplinary cultures, and a lack of institutional leadership.

1 A community of practice is a group of people who share a concern or a passion for something they do and learn how to do it as they interact regularly (Allee, 2000; Lave, 1988; Wenger, 1998 and 2007).

3 Benefits of these communities accrue to both individual faculty and to their institutions.

Participants reported that the greatest benefits of involvement in these communities came in the form of learning and improving in their teaching, reenergizing them in their sense of satisfaction and fulfillment in their work, and gaining credibility for their work related to STEM reform. Additionally, nearly 35% of participants indicated that engagement in these communities contributed to changes related to STEM reform in their departments, while more than one in five participants indicated that some sort of institutional change had come about as a result of involvement in these communities. We also identified how involvement of several individuals from a single institution increased departmental and institutional benefits. In fact, one of the largest effect sizes we observed to predict departmental and institutional benefits came from having more peers from the same institution involved together in the community. In general, it is also important to recognize that the longer faculty remained involved with these groups, the more benefits they reported.

4 Communities of transformation provide significant benefits for women faculty and for faculty of color.

For nearly all of the individual benefits we studied (except for involvement leading to publications), female faculty members reported statistically significantly greater benefits resulting from their participation in these communities than their male counterparts. Faculty of color indicated greater benefits than White faculty members in several key areas: networking, being afforded the opportunity to pursue new grants or projects, gaining credibility for their approach to professional work, and gaining skills to make the transition from faculty work to administration.

5 Positive outcomes follow from an engaging philosophy that is lived in programmatic activities and fostered through a supportive and mentoring community.

Faculty report that they make gains, such as improved teaching, becoming leaders for change, and renewed enthusiasm for their careers, as a result of the engaging philosophies that are part of these four communities of transformation. Survey results and interviews both suggest that embedding the philosophy in events, workshops, newsletters, and other key communications made faculty better able to adopt new approaches to teaching/learning. Faculty also appreciated role modeling by leaders in these communities. The communities of transformation had a system for bringing new faculty along by first brainstorming changes and ideas with them, then helping them address challenges on their campuses, and then providing more formal mentoring. Further, leadership that espouses and models the philosophy, fostering a supportive culture, further contributes to achieving outcomes.

6 Communities of transformation follow similar trajectories as they evolve from an idea to a community.

The lifecycles of these communities of transformation follow a similar trajectory that moves from showing potential (testing out initial ideas, obtaining initial grants, coming together for discussion over years of gestation), to coalescing (naming the problem, forming cultures), to maturing (building communities, obtaining new grants, developing leadership), to stewardship (creating leadership succession plans, putting into place a viable financial model, hiring professional staff, creating and deploying a framework of research, feedback, and assessment, following a focused yet

flexible strategy). The importance of this similar trajectory demonstrates that future communities of transformation can follow the steps of these groups to successfully evolve and navigate challenges.

7 Communities of transformation face common challenges and must develop particular strategies to navigate them.

A common set of challenges emerged that provides clear direction for future groups in terms of obstacles to anticipate in their work. These challenges include: funding, shifting focus, community leadership too much identified with an individual leader, project-focused versus community-focused decisions, staleness, legitimacy, the dominant culture of science education, maintaining community integrity, focus on general faculty improvement versus a specific pedagogical approach, and increasing and changing demands on faculty. This report articulates these challenges and offers advice for navigating them.

8 Communities of transformation rely on a specific set of avenues for expanding impact.

In order to expand membership and impact, the communities studied took six different avenues, all of which show promise for use by future communities of transformation. We have categorized these avenues as disciplinary, institutional, sector-focused, constituent-based, national, and international approaches. The study identified that communities can be more successful when they expand in areas where they have some existing strengths or assets. For example, two communities studied had connections to leaders in disciplinary societies, while two others had connections to administrators to leverage for an institutional approach to expansion. This report also documents challenges for expansion.

9 Future communities of transformation can draw on the sustainability model identified and developed through this study.

Since communities of practice are typically organic organizations that can come and go, the communities of transformation engaged in the important work that was the focus of this study must have plans for sustainability. Such plans are critical to the expansion, success, and impact of communities of transformation. This report offers a sustainability model that includes the following elements: creating leadership succession plans, putting into place a viable financial model, hiring professional staff, creating and deploying a framework of research, feedback, and assessment, and following a focused yet flexible strategy.

10 There are further ways that communities of transformation can extend their impact.

The study also identified some key ways that these communities of transformation can increase their already significant impact, through working with centers for teaching and learning on campuses, helping faculty create professional learning communities on their own campuses, inviting teams from campuses to maximize impact, and working even more deeply with disciplinary societies, among other recommendations.

I. Background and Overview of Project

For the past 20 years, countless reports have been issued calling for reform of undergraduate STEM education to improve student learning and success for both majors and non-majors. Recent reports describe the need to focus on creating more student-centered learning environments that use the most effective research-based teaching, learning, and assessment strategies (American Association for Advancement of Science, 2011; Howard Hughes Medical Institute, 2009; National Academies, 2010; National Science Foundation, 2010). All of these reports call attention to a set of problems in undergraduate STEM education: 1. Few students choose to be STEM majors; 2. Traditionally underrepresented groups have extremely low participation in STEM fields; 3. STEM majors face low graduation rates; and, 4. There are broad skills that graduates lack as they complete STEM majors (e.g., teamwork, writing) and non-STEM majors (e.g., quantitative reasoning, analytical thinking), making it difficult for them to meet workplace needs in our technology-based knowledge economy. While experts across the country generally agree on the nature of the problems and on some of the interventions needed, there is less agreement about how to create widespread change. Some emerging evidence suggests that current approaches are ineffective (Fairweather, 2009).

Systemic change in higher education has proven difficult. Isolated efforts, such as funding short, one-time faculty innovations, have not been effective at yielding the kind of widespread change articulated in national reports. This is due to the fact that colleges and universities are complex systems in which multiple factors influence educators' actions, values, and behaviors. Given the size and scale of higher education, changing individual faculty members or even isolated departments will have minimal impact. Fairweather (2009) notes, in his report to the National Academies Research Council Board of Science Education, that the presumption that funding individual innovations will lead to widespread changes is spurious, and it is not born out by the evidence. Instead, he advocates for engaging institutional leaders on campus to overcome a set of existing hurdles, such as reward structures, and he notes the importance of professional networks as avenues to scale up change. He observes that networks systematically engage large numbers of faculty on an ongoing and sustained basis, which is more likely to lead to change.

In a review article commissioned by the National Academies, Ann Austin outlines the factors that need to be addressed in order to promulgate more evidence-based teaching practices. Among the top factors is professional development that involves communities of practice (CoPs) that "provide opportunities for faculty members to interact with others as they explore new assumptions and try out new approaches to teaching…in an environment that simultaneously provides challenge and support." Over the years, National Science Foundation (NSF) has funded networks and CoPs (see the important distinction between these below) as means for disseminating innovations and creating change; in more recent years, this has become an even more prominent strategy.

Institutional, regional, and national CoPs and networks that are focused on providing knowledge, support, and exemplary models for STEM education have been identified in reports as important vehicles for creating change, yet there is little systematic research on how to best structure them, nor are there any data about their outcomes or impact. The use of networks in such projects is motivated by solid social science research. Over the last fifty years researchers such as Everett Rogers have identified how social networks are the primary vehicles for the dissemination of innovations. Yet, this research on social networks has focused on changes quite different from those required by educational reform, and it has focused on other types of contexts, such as farming or medical practice[2]. More recent research on communities of practice identifies how social networks that foster conversation and learning within educational contexts are effective vehicles for peer professional development and adaptation of innovative strategies that result in change (Daly, 2010). However, while we know many such CoPs lead to change, we do not know how they can be best designed to achieve their goals. In particular, we have little information about STEM faculty networks, and about whether they require any unique design features to help stimulate reform.

In summary, while networking efforts have emerged as critical strategies for creating innovation in higher education, we know very little about such networks beyond the fact that they are positively linked to facilitating change. From the existing research, we know that CoPs and social networks offer certain advantages within change processes—for example, communication systems, knowledge transfer, and access to expertise (Tsai, 2002; Valente, 1995). Yet, having worked with several networks in STEM undergraduate education, we sense that there are other less well documented benefits, such as leadership development, that need to be identified and cultivated. Further, we also need to seek more specific explanations for how STEM CoPs and networks can be designed to create change and how their dynamics differ from those of the more organic networks that have been the focus of most social science research over the past fifty years. This report begins to answer the question of how STEM CoPs and networks can be best designed to maximize innovation. We explore what leadership and management is needed to support them, and how they can become sustainable. By understanding more about these features of communities of practice, we can design programs that better harness the power of such communities to bring about change.

The project examined and compared four undergraduate STEM reform CoPs/networks that each have different designs, but share the common purpose of undergraduate STEM reform. The research sought to understand how such communities can be most effectively designed to spread innovations among network members, as well as on the campuses where those members are employed.

A quick note about terminology. Social networks are defined in the literature as people loosely connected through some form of interdependencies, such as values, preferences, goals, or ideas (Wasserman & Faust, 1994). A community of practice (CoP) is a group of people who share a concern or a passion for something they do and learn how to do it as they interact regularly (Allee, 2000; Lave, 1988; Wenger, 1998 and 2007). A CoP has a greater sense of shared mission and purpose than a network, and it is often structured in a more intentional manner.

While we entered the study considering that the four groups examined could operate either as networks, as communities of practice, or as some hybrid of the two, by the end our research suggested that they are best understood as a particular variant of communities of practice, which we called "communities of transformation." We will use this term to refer to the groups studied in this research, and in section 4 we will describe the important distinctions that define these communities.

2 A few exceptions exist with the work of Mort at Columbia University in the 1950s.

This project addressed three main questions:

1. How do members and leaders of communities of practice (CoPs) perceive CoP design (membership, structure, communication, activities, and organization to support new knowledge development and action) shapes the ability to achieve goals (around undergraduate STEM pedagogical change and diffusion)?

   Sample sub-questions addressed:
   a) How can active engagement be obtained among members?
   b) What knowledge is best transmitted through networks, and through which media vehicles (online, in person workshops, etc.)?

2. What are the perceived benefits of participation in a STEM reform community of practice or network for the individual participants and for their campuses?*

3. How do communities of practice and networks form, and how are they sustained in ways that help them to achieve their goals?

   Sample sub-questions addressed:
   (a) What leadership and management is needed to form and sustain these communities?
   (b) What barriers are there to formation and sustainability?
   (c) What strategies work best for overcoming barriers?

* We conceptualized benefits throughout the research process in many ways, including benefits for individuals and institutions, outcomes of participation, and impact of these communities on individuals and institutions. As a result, we use the terms benefits, outcomes, and impacts interchangeably throughout this report.

The Four Communities of Transformation

What follows is a brief overview of the communities of transformation (CoTs) studied, and why they were chosen. A chart comparing these four communities is provided in the supplementary materials, and further details can be found on websites noted in the text. The four CoTs chosen for this project were Project Kaleidoscope (PKAL), the Process Oriented Guided Inquiry Learning Project (the POGIL Project), Science Education for New Civic Engagements and Responsibilities (SENCER), and the BioQUEST Curriculum Consortium. The study selected these particular groups rather than others in order to focus on communities with the following key features:

1. Focus on reform of undergraduate STEM education;
2. Large-scale membership and wide dissemination of best practices;
3. Higher education community and focus on reform within the context of postsecondary education;
4. Long enough history to allow study not just of formation but also of outcomes and sustainability;

5. Ability to survey members[3]

These four communities met these criteria and also were different enough in key dimensions around design, organization, and activities to enable us to explore meaningful differences and to identify key patterns that can help future STEM networks as they form (or reform) to aid in STEM efforts.

PKAL

Project Kaleidoscope (PKAL) is an umbrella network of STEM faculty across the country that focuses on creating innovation among faculty to enable changes in their practices. The national PKAL community has nearly 7,000 members at over 1,000 colleges, universities, and organizations. Formed in 1989, PKAL was one of the earliest undergraduate science reform networks, and it continues to operate as one of the few networks to be sustained over time. More information about PKAL is available at http://www.aacu.org/pkal. PKAL was chosen because it has several long-standing networks within it, and research that is limited to new or emergent networks is difficult and often does not yield as much data about long-term benefits or strategies for sustainability. Furthermore, PKAL includes several different types of networks, which lends itself well to comparative studies and to examining design differences and their effects on goals. This study focused on two ongoing networks within PKAL. The first is the Faculty for the 21st century (F21) network, which has been in existence for fifteen years. This is a loose network of nearly 1,500 STEM colleagues, of which nearly 200 have participated in PKAL summer leadership institutes. The second sub-community at the center of this study is the more recently formed family of regional networks that engage over 650 STEM faculty at 100 institutions. The regional networks develop and share effective models for transferring STEM education best practices and innovations among peers in order to increase the number of faculty members in each region who are using proven, research-based pedagogies. These regional networks are tighter and denser than the national network, and they have more regular interaction built into their structure. PKAL was chosen based on its long history, broad reach, advocating of several different pedagogical practices, and involvement of several different disciplines.

THE POGIL PROJECT

The Process Oriented Guided Inquiry Learning Project (the POGIL Project) is a national professional development and curriculum reform effort whose mission is to connect and support educators from all disciplines interested in implementing, improving, and studying student-centered pedagogies and learning environments. It involves approximately 6,500 faculty across a range of disciplines. The POGIL Project began in 2003 with support from the National Science Foundation. It works to disseminate specially designed activities that express its instructional philosophy, and it provides professional development to faculty who are interested in implementing group-learning approaches and developing new instructional activities. It originated in the discipline of chemistry, but its approach has been disseminated into other STEM fields. While the network has long been based out of Franklin and Marshall College, the POGIL Project continues to grow each year. The POGIL Project has recently become an independent 501(c)(3) as a strategy to sustain activity in the future. It has many subgroups and projects that have developed within the overarching framework, and it boasts a strong set of regional networks. More information about the POGIL Project

3 We also want to note why we did not choose other types of networks or communities. There are many networks that focus on the link between K-12 and higher education (e.g. ISTEM) to improve teaching of STEM in high school and to ease transition into college. These partnerships, while important, involve a different sort of network that crosses different communities. These types of partnerships are not comparable to the networks in this study. Additionally, they are the one type of STEM reform community that has received some study and attention—less so as networks but as partnerships. There are also networks represented in disciplinary societies, but these focus mostly on scholarship, rather than teaching. Lastly, there are smaller communities of only a few dozen educators, such as the National Numeracy Network, but these groups are intimate and have limited reach.

is available at http://pogil.org/. The POGIL Project was chosen for this research because of its stature as a long-standing network working toward a plan of sustainability in STEM reform. As an example of a community of practice, it offers unique resources and varying forms of communication among its members. It was also selected because of its targeted focus on a particular pedagogy and a particular community of participant faculty, a strategy that differs from the broader-reaching approach exemplified by PKAL.

SENCER

Science Education for New Civic Engagements and Responsibilities (SENCER) is a faculty development and STEM education reform initiative launched in 2001 under the National Science Foundation's CCLI national dissemination track. SENCER is an approach to STEM education that teaches rough complex, capacious, contemporary, and contested civic challenges to basic canonical STEM knowledge and methods. It strives to use context to engage interest, to make science real and relevant, and to stimulate memorable learning. The project has expanded from focusing on single courses to smaller course modules, course intersections, learning communities, major curricular reforms, pre-medical and graduate education, new certificates, and degree granting programs. The SENCER community includes thousands of faculty members, academic leaders, and students from more than 400 two- and four-year colleges and universities in 46 states and nine countries. The organization's goals are to:

1. Get more students interested and engaged in learning in STEM courses;
2. Help students connect STEM learning to their other studies;
3. Strengthen students' understanding of science and their capacity for responsible work and citizenship

SENCER was selected because it involves several different science disciplines like PKAL, has a broader range of pedagogical practices it advocates, and uses unique approaches to engage members such as team participation.

BioQUEST

The BioQUEST Curriculum Consortium has a 25-year history of supporting undergraduate biology education reform. It supports international and interdisciplinary collaborations among faculty, with the overarching goal of creating learning experiences that more accurately reflect biological science practices. The BioQUEST approach emphasizes student engagement in problem-posing, problem-solving, and peer persuasion. BioQUEST uses modern information and communications technologies as a means to increase student access to scientific data, tools, literature, and communities. Many BioQUEST projects involve partnerships with scientific and educational organizations to provide professional development and innovative curriculum resources. The BioQUEST Curriculum Consortium includes a large network of faculty who have contributed materials and collaborated in the exploration of innovative biology education. BioQUEST was chosen because of its long history, reach to many members, advocating for a more targeted set of pedagogical strategies, and focus in a particular discipline.

We now turn in section 2 to the literature related to networks and communities of practice that framed and informed our study of these communities.

II. Framing: Social Networks and Communities of Practice

We drew primarily on two bodies of literature when designing this study: social network analysis and literature on communities of practice (CoPs). Here we review the literature that informed the study design, as well as pushed us forward in our analyses.

Benefits of Networks

Social network analysis focuses more on outcomes, as compared to the literature on communities of practice; thus we used social network analysis to frame our understanding of outcomes (described in section 5). Social networks are defined in the literature as people loosely connected through some form of interdependencies, such as values, preferences, goals, or ideas (Wasserman & Faust, 1994). In general, outcomes are the most commonly studied aspect of networks. Since we had so much rich data in this area, this study focused on a narrower question: How might STEM networks be unique in terms of outcomes that promote change?

Diffusion of innovation or change has emerged as an outcome in many different studies of social networks, which is why social network analysis has been applied to the study of change processes in more recent years (Rogers, 2003; Valente, 1995). Three specific outcomes of social networks have been related to change: *learning, social capital, and risk-taking* (Borgatti & Foster, 2003; Burt, 2000; Kilduff & Tsai, 2003; Tenkasi & Chesmore, 2003). Many researchers have found a strong linkage between learning and changes in behavior, showing that as people interact with others in networks they are more likely to experience schema changes allowing openness to new approaches (Tenkasi & Chesmore, 2003). Networks also provide social capital that facilitates the change process by providing access to relationships and knowledge about how to overcome barriers (Burt, 2000). While different definitions of social capital exist, most of the theoretical discussions operate under a definition of social capital as the resources embedded in social relations and social structure which can be mobilized by an actor to increase the likelihood of success in purposive action (Daly & Finnigan, 2009). These resources can vary to include knowledge about how organizations work, influence possessed by particular people, or access to financial resources. Finally, achieving long-term change often requires risk-taking that can be less problematic if it is done collectively rather than individually (Valente, 1995). If a person knows that many of her peers are going to join her in an activity or behavior, she is more likely to feel empowered to engage in this behavior (Rogers, 1962; Valente, 1995). While there are other important components in the efficacy of networks, these three—learning, social capital, and risk-taking—are the ones most commonly identified that demonstrate the importance of social networks in achieving long-term transformations. There are of course many other individual and organizational outcomes of networks, but these three are the most often associated with change.

As noted earlier, these outcomes identified in the literature have been drawn from studies of change initiatives in contexts that are quite different from that of STEM reform. Thus, as we examined learning, social capital, and risk-taking within this specific context, it was important to see which components were most salient in STEM professional networks, and whether other outcomes emerged as similarly important for change. As we studied the four STEM reform communities described in section 1, we paid close attention to how learning, social capital, and mediating risk-taking served to facilitate change in this particular environment. We also took into account the broader literature on outcomes[4] , and we drew on this literature as we studied those outcomes that emerged as pivotal to change within the networks.

While we knew much about outcomes of networks and benefits to members, we knew much less about how the design of these networks shaped these various outcomes. This study set out to draw connections between design principles and the achievement of the outcomes described above that foster lasting change. The limited data that exist on this topic come mostly from the social networks literature, and we now turn to a review of that material.

Various studies have identified how the design of social networks impacts outcomes such as achievement of goals and change. This literature, as well as the literature on design in communities of practice (described below) informed our data collection (section 3) and analyses related to design, described more fully in section 6. The most commonly identified design characteristics were: strong and weak ties, heterophily and homophily, subgroups, connectedness, and opinion leaders. We discuss each of these design attributes briefly below.

STRONG TIES

Strong ties are most useful for the communication of tacit, non-routine, and complex knowledge; in contrast, *weak ties*—present in networks said to be "less dense"—are better suited for communication of simple and routine information (Nelson, 1989; Tenkasi & Chesmore, 2003). Strong ties are characterized by three defining characteristics: frequent interaction, an extended history, and intimacy or mutual confiding between parties (Kraatz, 1998). Most studies of change find strong ties to be more conducive to deep or complex changes (Balkundi & Harrison, 2006; Tenkasi & Chesmore, 2003). Strong ties are more likely to promote in-depth, two-way communication and exchange of detailed information. Because pedagogical and curricular reform efforts require a deep and complex kind of change, we anticipated that it was likely that strong ties would be important for undergraduate STEM reform networks. While they can be designed to create frequent interaction, networks that are created for the purpose of innovation may be less likely to have extended histories or intimacy among members. Weak ties, on the other hand, are characterized by distance and infrequent relationships that may be casual, less intimate, and non-reciprocal in nature. However, for the dissemination of ideas and public information, weak ties can be extremely helpful. Weak links can also provide exposure to important external ideas that may promote the development of a more robust change idea. Thus, there may be times and circumstances where weak links are important for creating specific types of change, especially in certain phases of the change process. This study examined the degree to which networks can promote strong ties—those that have been found in the literature to be more useful for scaling up change. Also, the study examined when weak ties might be helpful in some aspects of network activity.

HETEROPHILY AND HOMOPHILY

Another area of design found to shape outcomes is diversity or homogeneity of ties. Diversity of ties, or *heterophily*, can lead to more complex thinking about change processes, but homogeneous ties, or *homophily*, can lead to quicker adoption of change and to stronger relationship development, ultimately encouraging strong ties (Borgatti & Foster, 2003; Moody & White, 2003). Homophily might also lead to greater engagement and participation of network members. We can examine the degree of heterophily or homophily in the structure of social networks and draw conclusions on how those dimensions impact networks as they try to meet their goals.

SUBGROUPS

The development of *subgroups* (cliques) within networks has also been identified as a strong lever for moving changes forward (Freeman, 1979; Reagans & McEvily, 2003). Within the networks in our study, we examined the types of subgroups that form to facilitate change, and the structural properties that might govern this process.

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4 In terms of individual outcomes, the following have been identified: social support, sense of belonging, information sharing, community, more meaningful participation, enjoyment of work, confidence, help with challenges, expansion of skills, enhanced professional reputation, increased employability, and stronger sense of professional identity (Rogers, 2003; Valente, 1995). In terms of organizational outcomes, networks have been shown to help execute strategic plan, increase retention of talent, increase capacity for knowledge, allow for more alliances with external groups, foresee technological developments, improve quality of decisions, improve problem-solving, increase coordination across units, provide additional resources for implementing strategy, and strengthen quality assurance (Wenger, McDermott, & Snyder, 2002).

CONNECTEDNESS

Another concept, *connectedness*, provides a measure of how much exposure each individual receives to the innovation (Borgatti & Foster, 2003; Valente, 1995). Individuals can be influenced to alter their behavior when they are surrounded by many people that have adopted a change, even if others throughout the campus or profession as a whole have not done so. This study tests the notion of connectedness by examining individuals who have more exposure to innovations than others within the networks. This approach yields insights on structural considerations for development of leadership and pervasiveness.

OPINION LEADERS

The presence of *opinion leaders* within social networks can help speed up adoption of innovations (Cross & Parker, 2004; Freeman, 1979; Valente, 1995). We examined the way key opinion leaders from STEM are brought into networks and helped to effect change.

These five design features are discussed in the literature, but their treatment is typically constrained to the more organic forms of social networks. While we examined each of these features in our study of STEM networks, we aimed to address a lack in the research in the question of how more constructed networks, like communities of practice, can be designed intentionally to achieve these outcomes. Thus, in addition to testing out some of the existing findings from social network theory about how design can shape outcomes, we explored new areas where little research exists, such as the type of leadership needed within networks, the way that formal organizations can support networks, and the way to create sustainable networks.

Our approach expands upon the organic focus of social network analysis, which limits what we know about the role that can be played by leadership, organizational structures, and intentional support; this is a major gap in the literature, noted by most social network scholars as a critical area for future studies (Mullen & Kochan, 2000; Spillane, Healey, & Kim, 2010). This gap is the reason there is so little literature about fostering and sustaining networks, a progression seen primarily as an organic series of events, rather than as a structured process. It is also important to note that social network analysis is primarily a survey-based, quantitative approach, which does not lend itself to the study of evolution of communities over time. Thus, we turned to the literature on communities of practice (CoPs) in order to partially remedy these limitations. CoPs have been studied through qualitative methods that better capture processes, and these studies have provided insight into the formation and sustainability of networks. There is also an existing body of research, albeit less well defined, about designing CoPs for engagement.

Defining Characteristics of Communities of Practice

A community of practice (CoP) is a group of people who share a concern or a passion for something they do and learn how to do it as they interact regularly (Allee, 2000; Lave, 1988; Wenger, 1998 and 2007). CoPs operate similarly to traditional social networks in that they connect people with a similar interest or value, and they similarly may cross organizational boundaries and be more loosely connected. CoPs are defined by three of characteristics: 1) a *domain*—a common ground of purpose and value; 2) a *community*—a set of individuals connected; and 3) a *practice*—ideas, frameworks, tools, or documents that the community members share. Without these three areas, an entity cannot be defined as a community of practice. CoPs take on many forms: they can be co-located or distributed (i.e., centralized in the same location or not); short-term or long term; homogenous or heterogeneous (focused on the same field or area or more diverse); small or big; housed within a unit or organization or spread across multiple such units; spontaneous or intentional; unrecognized or institutionalized. While their forms can differ, CoPs often emerge within organizations, and they often involve people working day-to-day with one another.

Because most research has focused on local CoPs within a single organization or unit, the principles identified in the literature on CoPs must be used with caution. Nonetheless, this research did provide direction for our methodological approaches, and it introduced some key insights—related to design, formation, and sustaining communities—that were valuable for shaping this study. In what follows, we review the defining characteristics of CoPs, as well as a

variant of CoPs known as professional learning communities (PLCs). These definitions helped us frame our understanding of the communities in our study—communities of transformation—which are examined in more detail in section 4. What are these Entities? Communities of Transformation

In the literature, CoPs tend to be organic, developing naturally from a need shared among people. Most of the early work on CoPs examined the tacit learning that happened while people worked together through apprenticeship practices. Lave (1988) and Wenger (1998), who originated the concept, philosophically disagree about whether CoPs can be intentionally created or structured and whether they are truly organic entities. Even Wenger, McDermott, & Snyder (2002), who went on to examine "non-organic" CoPs, feel that CoPs are defined by a more organic state, and that they can only be nurtured, not created. The community or social aspect of learning is central in this phenomenon; thus, interaction and the relationships that are developed as part of the community are seen as essential to the CoPs existence.

The key activity of a CoP is to develop the domain that is at the center of the community. This becomes the identity of the community, and it serves as a focus for developing the shared repertoire of resources for the practice. The community operates through learning by problem-solving, sharing information, seeking expertise, visiting others, and using other similar approaches (Wenger et al., 2002). The literature describes challenges that emerge over the lifecycle or stages of a CoP. Given the organic nature of a CoP, it tends to go through a natural cycle (potential, coalescing, maturing, stewardship, transformation) in response to challenges that result from growth. In the course of this cycle, a CoP refines its identity and membership, and it incorporates new members and new purposes (Wenger et al., 2002).

Professional learning communities (PLCs) are a particular type of structured and organizationally located CoP that is commonly found in the education sector. PLCs are built on the principle that community is central to learning. PLCs can be considered a type of CoP because each PLC involves a *community*, has a *domain*, and involves a set of *practices* (e.g., the socially defined practices that enable one to become a strong teacher or principal). PLCs are distinctive, however, because they have several facets that are not part of the definition of CoPs. For example, PLCs are always intentionally created and tend to be heavily structured. This is less typical of CoPs. Additionally, the leadership of a PLC usually defines the membership, and a PLC typically includes people based on their roles, rather than on their organic interest in the domain (Stoll et al., 2006). While PLCs entail the exchange of information, expertise, and problem-solving, the character of these interactions in a PLC are often less peer-to-peer than in typical CoPs. While some institutions have set up peer-oriented PLCs with teachers only, these communities are always created and sanctioned by the institution's administrative leadership (Bond & Lockee, 2014; Stoll et al., 2006). In addition, the nature of the work of PLCs tends to be more narrowly defined around a set of issues, such as student success or teaching broadly understood (DuFour, 2004; DuFour, DuFour, & Eaker, 2008). The model for such cases is more structured and hierarchical than that of CoPs (see, for example Roberts, 1998, in which PLCs are led by school principals). Domain, membership, and community operate differently in PLCs than they do in the other CoPs typically described in the literature. We now turn to the literature on design of CoPs.

Designing Communities of Practice

As with the limited literature on design of networks, the literature on design of CoPs informed our data collection and analyses, especially on the challenge of designing communities for engagement and the achievement of outcomes (see section 6). One of the major findings in the literature on CoPs is that design varies greatly based on the identified goals. There are many different types of CoPs, so there is no single design that guarantees efficacy. While the social network literature emphasizes basic designs and structures that support certain outcomes, CoPs tend to exhibit a less direct connection between design and outcomes. There is not a single best design, but various design principles that can enable a community to meet its specific goals. Several such general principles and practices were identified in Wenger, McDermott, & Snyder (2002) as important for creating learning that leads to change:

1. *Design the community to evolve naturally*. Because a CoP is dynamic by nature, in that its interests, goals, and membership are subject to change, it should be designed to support shifts in focus.

2. *Create opportunities for open dialog not only among members, but also with those bringing in outside perspectives.* While members and their knowledge are the most valuable resource of a CoP, it is also beneficial to look outside the community to understand other possibilities for achieving learning goals.
3. *Welcome and allow different levels of participation.* Wenger identifies three main levels of participation in a CoP. First, there is the core group of members who participate intensely in the community through discussions and projects. This group typically takes on leadership roles in guiding the community. Second, there is the active group of members who attend and participate regularly, but not at the same level as the leaders. Third, there is the peripheral group of members who, while they are passive participants in the community, still learn from their involvement. Wenger notes that the third group typically includes the majority of the community.
4. *Develop both public and private community spaces.* While CoPs typically operate in public spaces where all members share, discuss, and explore ideas, a CoP should also offer opportunity for private exchanges. A CoP designed in this way can coordinate relationships among members and access to resources through an individualized approach that is based on specific needs.
5. *Focus on the value of the community.* A CoP should create opportunities for participants to explicitly discuss the value and productivity of their participation in the group.
6. *Combine familiarity and excitement.* A CoP should offer the expected learning experiences as part of its structure, but there should also be opportunities for members to shape their learning experience together by brainstorming and by examining both the conventional and the radical wisdoms related to their topic.
7. *Find and nurture a regular rhythm for the community.* A CoP should coordinate a thriving cycle of activities and events that allows for the members to regularly meet, reflect, and evolve. The rhythm, or pace, should maintain an anticipated level of engagement to sustain the vibrancy of the community, yet not be so rapid that it becomes unwieldy and overwhelming in its intensity.

Lifecycle of Communities of Practice: Formation and Sustaining

The literature on CoPs has developed a framework that examines formation, design, and sustaining of CoPs and is an expansion of the principles above, connecting them to how networks evolve over time. These various concepts were used to inform this study. The best-known framework for the lifecycle of CoPs was offered by Wenger et al. (2002), who created a five-stage community development model based on empirical studies of CoPs. We present this model here as a precursor to our description of the lifecycles of these communities in sections 7, 9, and 10.

The lifecycle model includes the following stages: 1. *potential*; 2. *coalescing*; 3. *maturing*; 4. *stewardship*; and 5. *transformation* (Wenger et al., 2002). Wenger and colleagues also outlined specific challenges or tensions for each stage, represented here in Table 2.1. These challenges indicate areas that might impact the viability or growth of CoPs. We briefly review the elements of the model that guide our exploration into higher education CoPs.

POTENTIAL

The first phase, *potential*, is the phase where an important topic attracts an informal group of people who are interested in beginning to work together. Wenger et al. (2002) note that at some point the "idea of forming a community is introduced into [a] loose network, and this prospect starts to redirect people's attention. They start to see their own issues and interests as communal fodder and the relationships in a new light of a potential community" (p. 71). As the sense of this shared domain develops, more systemic planning and activities begin. So the beginning work at the potential stage is to define the scope of the domain that brings people together, to find people who see the value in increased networking and sharing of ideas, and to identify what common knowledge is needed to further the community. Through this stage the emerging community creates a vision and sense of mission.

COALESCING

During the second stage, *coalescing*, people come together and launch the community, and they find value in engaging

TABLE 2.1: STAGES OF COMMUNITY DEVELOPMENT AND KEY CHALLENGES/TENSIONS FOR DEVELOPING COMMUNITIES OF PRACTICE (WENGER ET AL., 2002)

Stage	Challenge/Tension
Potential: Community starts as a loose network of connections with potential for growing and developing more connections	**Discover or Imagine**: Build on what is present, or explore where potential could lead
Coalescing: More connections are built, coalescing into a community	**Incubate or Deliver Immediate Value**: Allow connections to form and build trust slowly, or immediately try to show the value of the community
Maturing: Membership and depth of knowledge in the community grows	**Focus or Expand**: Direct energy toward internal interests of core members, or expand to meet interests of new members
Stewardship: Actively share and develop knowledge formed through community	**Ownership or Openness**: Balance ownership over community domain with the need to bring in new ideas
Transformation: Community evolves as new members enter and/or initial energy wanes	**Let Go or Live On**: Either let the community wane, or transform it in order to sustain the progress made toward goals

in learning activities together. At this stage leaders in the CoP facilitate dialogue, create informal meetings, develop initial community support and communications, and develop organizational supports for the long run. Within this phase, the focus is on creating enough interest that people continue to participate. Part of creating this interest in continued involvement is achieved by establishing the value of the domain. The community needs to develop trust and strong relationships to get through philosophical challenges and other issues that emerge. The community also needs to develop key avenues for sharing information and creating information-rich resources.

MATURING

In stage three, *maturing*, the community begins to take charge of activities, and it grows in size. At this time, the community is involved in many joint activities together. Active learning is taking place, and the growing community develops standards for how its members interact over the long run. In the maturing stage, the community needs to clarify and focus its roles and boundaries. As the community grows, new ideas are brought in that might expand or change the domain of its focus. New members can disrupt the patterns of interaction that the core members of the community have developed. The community needs to find ways to stay focused on its core purpose and mission while it includes greater numbers of individuals. A key issue related to practice focuses on organizing resources and knowledge for the long haul; the community needs to systematize its practices and create a rhythm of activities that community members can count on. Also, the community identifies gaps in knowledge, especially as the community grows. One challenge is to keep creating additional resources to meet the needs of new members. The tension between focus and expansion is palpable in this phase.

STEWARDSHIP

In stage four, *stewardship*, the community is well established and needs to find ways to sustain energy, to renew interest, and to continue to gain new members. At this point community leaders address organizational issues that may hinder their ongoing development, and they often forge linkages with other groups. In this stewardship phase, the community strives to sustain its momentum as continued new members join, as energies decline over time among longtime leaders, and as the original ideas of the community can fade in urgency and become less intellectually interesting. Stewardship is a balance between creating ongoing ways to bring in new ideas and remaining focused. Communities in this phase work to bring in new energy and new people, while supporting long-time leaders. Wenger et. al. (2002) describe the maturing and stewardship phases under the same broad label of maturing, and they see these two phases as hard to separate distinctly.

TRANSFORMATION

The last stage is *transformation*. Wenger et al. (2002) note that a tension exists in this phase, between the community's sense of ownership and its openness to new ideas—an openness that is never fully resolved and often results in crisis. As the community widens its boundaries, it risks diluting its focus. If the community stays closed, on the other hand, it can suffocate itself. It is a natural feature of the lifecycle of a CoP that these events should occur, and sometimes the influx of new members in the transformation stage creates a new focus for the community; this leads it to transform. Other times the community may cease to exist, because members no longer feel that its purpose is relevant or needed.

Localized and Distributed Communities of Practice

Most of the literature reviewed to this point applies to more localized communities of practice. The STEM groups in this study, however, fall into what is called a "distributed community of practice" that cannot rely on regular face-to-face meetings and interactions as the primary vehicle for connecting members. Many communities of practice entail daily interactions among members, but distributed communities of practice have particular challenges that need to be considered in the design, formation and sustaining aspects: the distance that separates their members, the size of the community, and the need to work together across cultural differences (Wenger, McDermott, & Snyder, 2002). Because of the distance they cover, distributed communities must connect members more intentionally, and their design must think through challenges such as different time zones and the lack of spontaneous interactions among members. Second, distributed communities are often much larger in size than local communities of practice, with sometimes hundreds or thousands of members. Because people are unlikely to know each other well, or to have much face-to-face interaction, the community must wrestle with the question of the right size, and it must recognize when becoming too large impacts its viability. Thus, structures need to be created to adapt to growth. Third, distributed communities often run into issues related to the different cultures represented by their members. When people from across the country and world collaborate, they may not understand each other's languages, customs, or styles of interaction, and this can create communication barriers that eventually lead to problems within the community. This study acknowledges and takes into consideration these factors connected to distributed CoPs, which have not as yet been studied in depth.

Summary

This study was informed by the literature on networks and communities of practice. The network literature informed our original thinking about outcomes of community involvement and design, while the CoP literature informed our thinking about how these communities form and evolve, how they are sustained, and how they can and should be designed to maximize engagement. While both of these literature bases (social networks and communities of practice) were informative, neither was a direct fit for the undergraduate STEM groups that were the focus of this study. These STEM reform groups are not organic, as is typically assumed in social network analysis, nor are they as tightly developed and structured as communities of practice. Instead, most STEM reform groups are semi-structured and fluid, and they best fit the model of a distributed community of practice—a model that has not yet been the object of much research. Therefore, a study of these unique STEM groups was needed to identify the outcomes, design, formation, and sustainability issues that pertain to their work. We drew on the earlier research described above for concepts, theories, and framing, but, because we knew that the STEM groups in our study did not match the literature, we were open to new concepts and principles that emerged as we strove to understand their formation, design, and sustainability. We now turn in section 3 to the methodology we employed for this study.

III. Overview of Methods

The overall study employed an exploratory mixed-methods approach, including interviews, observations, document analysis, and surveys. Studies of communities of practice (CoPs) typically utilize both quantitative and qualitative methods to identify trends and examine underlying mechanisms within the communities (Fontaine & Millen, 2004). In line with exploratory mixed-methods studies (Creswell & Plano Clark, 2011), we began with qualitative data collection of participant interviews of leaders and staff from each community, observations of signature community events, and document analyses for key documents from the four communities that we studied. This allowed us to better understand the design principles of and the nature of involvement in these communities as a means to explore this topic. We utilized findings from this phase of data collection in order to inform the survey design for the second phase.

Data Collection

OBSERVATIONS AND DOCUMENT ANALYSIS

The study began with a review of documents in order to develop a context for these four STEM reform communities. Samples of the types of items we collected include: notes from meetings, planning documents, advisory board correspondence, descriptions of their missions, philosophies, and values, key correspondence between leaders, grant applications, reporting on grants, reports for advisory boards and other key groups, as well as on-going correspondence with the community via newsletters. Later, as part of interviews, we collected key documents that they identified that might help us to better understand what was engaging to them, such as publications, web-blogs, or newsletters.

We observed a signature event for each community, visited each community's main office (where we also went through their archives), joined their listservs, visited their websites on an on-going basis, and attended other key events about which they informed us. Observation took place over 2 and a half years. During observations, our researchers took fieldnotes about the activities, using the literature on communities of practice and professional learning communities to develop observation protocols. Observation notes from key events were taken in each case by more than one researcher, and then they were compared for validity. Fieldnotes from events were typically quite long, 30 to 35 single-spaced pages for each event. As Rogers (2003) has noted, we can learn a tremendous amount from real-time studies that follow networks and communities of practice, and from watching their activities.

INTERVIEWS

After initial review of documents and of data from site visits, we interviewed 112 people—between 26 and 30 people within each community (including both organization staff and faculty leaders). Each community studied is supported by an organization that includes leaders and staff that have worked extensively with the communities, both in their current forms and in the past. The communities each have longstanding members and leaders that have helped sustain them; for this study, we drew on interviews with faculty leaders in particular. We also asked to speak with faculty who had less involvement in these communities in order to get a sense of their experiences as well. Interviews lasted between one and two hours, and they followed a common protocol that asked about impacts or outcomes from participating in the community, level of involvement, what they found most engaging in the community, what they perceived shaped the outcomes they noted, and other areas related to their engagement and involvement. The communities of practice literature informed the interview protocol. All interviews were recorded digitally and transcribed. Interviews were used to inform items for the survey and to build on the literature we brought to the study.

For the interview portion of the study, our sample (n=112) consisted of 75% current faculty members (n=84)—60.7% of whom were professors (n=51) and 29.8% associate professors (n=25). The remaining 25% of participants (n=28)

were either former faculty members, current administrators, or staff members of the four reform communities. When asked to indicate their primary job responsibilities, 42% of the sample indicated teaching (n=47), 33.9% indicated administration (n=38), 3.6% indicated research (n=4), and 20.5% indicated other responsibilities (n=23). As for personal demographics, 57% of participants identified as female (n=64) and 92% identified as White (n=103).

SURVEY

The survey was conducted last, and the survey design was informed by the interviews, documents, and observations. The survey invitation was sent to 17,868 e-mail addresses.[5] The survey was custom designed for each community's particular structures (e.g., activities, communication vehicles), but it followed a common survey design to allow for comparison across the four communities. It addressed the following areas: participants' involvement in the community over time; perceptions of community activities; perceived outcomes of community involvement for individuals, their departments, and their institutions; perceptions of the importance of community design elements on their participants' practice; and individual and professional characteristics. Survey design was informed by the information gathered in the first phase of data collection, as well as by the literature pertaining to design and outcomes of networks and communities of practice. This allowed us to identify the design aspects and involvement opportunities that characterized these communities.

A total of 3,927 participants responded to the survey invitation, indicating a 22% initial response rate. This response rate is similar to the response rates of other surveys administered to national samples of STEM faculty (e.g., Hurtado, Eagan, Pryor, Whang, & Tran, 2012). The final sample for this study consists of 2,503 participants who completed the entire survey; these participants were distributed amongst 997 institutions (ranging from 1 to 28 observations per institution) and four communities (ranging from 235 to 1,102 observations per community). The survey sample consisted of 36.7% professors (n=919), 27.9% associate professors (n=699), 9.2% assistant professors (n=231), 20.2% non-tenure-track faculty or faculty working in institutions without tenure (n=506), and 5.9% individuals with no academic rank (n=148). The mean length of time spent teaching undergraduate students was 16.8 years (SD = 8.67). More than half of the participants worked in public institutions (n=1320, 52.7%), and 21.2% worked in doctoral institutions (n=530), 32.6% in master's institutions (n=816), 27.8% in baccalaureate institutions (n=695), 13.7% in associates institutions (n=342), with the remaining portion working in other organizations or types of higher education institutions (n=120; 4.8%). As for personal demographics of the survey sample, 54.3% identified as female (n=1359), 82.4% as White (n=2062), and the average age of participants was 49.9 years (*SD* = 10.5).

Data Analysis

The qualitative data were coded and analyzed using Boyatzis' (1998) thematic approach. This approach involved first going through the data for new or emerging inductive codes. Second, deductive codes derived from the literature on communities of practice and learning communities was then applied. Deductive codes included items reviewed in the literature related to stages of CoP development and design principles, as well as items from the literature on learning communities. The qualitative data were analyzed using HyperRESEARCH, a qualitative software program that helps manage and analyze large amounts of qualitative data and eases the coding process. All forms of qualitative data including interviews, observation fieldnotes, and documents were inputted into the software.

We utilized several quantitative analytical procedures to analyze quantitative data. Scale scores for our outcome variables were calculated by averaging the individual items in each scale, rather than by summing the items, in order to

5 The administrative staff of the four STEM reform communities provided us with contact information for each individual on their e-mail lists in order to send personalized invitations and to track responses. All four organizations acknowledged the existence of out-of-date contact information for participants and individuals who do not identify as faculty (i.e., members of other organizations) on their contact lists. Additionally, one community has a high-school arm of their initiative, and they were unable to separate those addresses from the larger list. So, while the population in the study was approximately 18,000, there is no way for us to know the true population size.

contribute to the ease of interpretation and comparison with other outcome items (Furr, 2011). We utilized descriptive statistics of our outcomes and design variables to identify trends in the data.

We then utilized ordinary least squares (OLS) regression to examine the extent to which participants' perceptions of CoP design characteristics and engagement are associated with the three dependent variables in our study. Prior to utilizing OLS regression, we examined the unconditional intraclass correlations (ICCs) for three individual outcome variables (learning and improving practice, skills for leadership and change, and networking) and two organizational outcome variables (departmental change and institutional change) because our participants exhibited clustering by institution and reform community. We opted to utilize OLS regression rather than multi-level modeling for two reasons. First, the majority of the variance in our dependent variables was within institutions rather than between institutions or communities. Second, our sample contained a large proportion of singletons in institutions, as well as institutions with only two participants (35.2%), threatening the estimates and validity of utilizing multi-level modeling with these data (Rabe-Hesketh & Skrondal, 2012).

Prior to running the regression models, we calculated descriptive statistics and examined histograms for each continuous variable in the study to ensure approximately normal distributions. We also calculated multicollinearity statistics for all variables. Variance inflation factor (VIF) values were low (ranging from 1.04 to 3.42) and well within the acceptable range to indicate no issues with multicollinearity in the analyses (Meyers, Gams, & Guarino, 2006). We ran regression models that included focal variables (design characteristics and engagement behavior) and control variables (personal demographics, professional characteristics and motivations, and institutional characteristics). All continuous variables (including the dependent variables) were standardized (i.e., grand-mean centered) prior to their inclusion in the models.

Trustworthiness and Validity

We utilized multiple forms of trustworthiness, including outside experts and auditors, member checks, triangulation, piloting, and multiple coders. We had two advisory boards that informed the study design and reviewed results: an external board comprised of national STEM experts and an internal board comprised of members from each of the four initiatives studied. We presented data collection protocols and instruments, as well as findings, to each board for input. The internal board was able to serve as a member check and to register whether the findings seemed to reflect their insights and experience. We piloted the interview and observation protocols. We triangulated data from multiple sources—documents, observations, and interviews. For the focus on sustainability, the key data were examining alignment or any discrepancies between interviews and archival data about development and sustainability. Lastly, we had three different coders of data that compared their interpretation of the emerging trends and coding of deductive codes within HyperRESEARCH. Coding was conducted separately and then compared.

Summary

The exploratory mixed-methods nature of this study addressed a set of research questions that spanned outcomes, engagement to lifecycle of the CoPs. The qualitative work allowed us to understand the ways in which the communities operate or engage faculty, how they formed, and how they have been sustained over time. This information contributed to our ability to design a survey to community members in order to best understand the outcomes of participating in these communities, and to identify how engagement (often in terms of design principles) in these communities contributes to individual and broader outcomes in members' departments and campuses. We now turn to the key findings from our study, beginning first with the finding that these communities can be identified and understood as a variant of communities of practice. This model, which we call a "community of transformation," encapsulates how we think these communities work scaling STEM reform.

IV. What are These Entities? Communities of Transformation

As we described in section 2, we originally framed the study using the literatures on social networks and communities of practice (CoPs). As we studied these four groups, however, it became clear that they did not share many of the characteristics of social networks. They had more structure than most networks, they were more formal, they had stronger shared purposes and goals, and their members had closer ties. We did find that individuals in these communities formed their own informal networks of connections through their involvement. However, we also found that the ways in which members engaged with their communities were heavily influenced by the ways in which the communities themselves were fostered by the leadership and by shared philosophies. Thus, community members participated according to organizational structures, rather than according to the informal relationships that were developed through involvement. In other words, network concepts failed to explain the workings of these groups.

STEM Reform Communities in Relation to the Communities of Practice Literature

In comparison to the literature on networks, the community of practice literature was much more relevant for understanding these STEM reform communities' characteristics. The groups each had a clear domain—a type of teaching innovation—on which they were focused. This domain created a strong identity for members, which was common in CoPs. There was also a sense of care for domain and work that is common of CoPs—not just a sense of shared interest that characterizes social networks. The communities were well formed and nurtured, additional attributes that are characteristic of CoPs. The sense of community served as a strong social fabric in each group, and it was essential to fostering the domain. Further, each community focused on a practice: teaching and developing resources and sharing relevant information. In our interviews, it became clear that participants in these groups described themselves as members of communities, and that the language of networks was foreign and did not resonate with their experiences.

The literature on CoPs was very helpful for explaining the formation of these groups and their common lifecycles and challenges. The basic design principles from the literature on CoPs were relevant for engaging members in these groups, although, as we highlight in this report, the most important design aspects we found at work to facilitate engagement were not reflected in the CoP literature. The outcomes of these groups were also similar to those found for other CoPs related to learning, leadership, networking, and re-energizing people. Thus, we found much resonance between the findings of our research and the existing literature of CoPs; the literature can be a helpful base to draw on to inform future efforts at scaling STEM reform among faculty communities.

However, the literature on CoPs did not fully describe the phenomena that we recorded in our research. For example, while communities are structured in many ways, most empirical studies tend to document CoPs that are located within organizations. CoPs in the literature thus tend to exist within a company, hospital, or government agency and be supported with space, resources, materials, staffing, and leadership through the sponsoring organization, whether formal or informal. Each of the STEM reform communities we studied was not situated in this way, which led us to describe them as *non-organizationally located communities*. By non-organizationally located, we mean that there is not an organization providing resources (human and financial) or other infrastructure to the communities. This position presented specific challenges to the communities studied—particularly challenges around sustainability. Perhaps as a result of this difference, the communities in this study had a divergent approach to issues of expansion, as compared to that described in the CoP literature. Therefore, we found their non-organizational status to be an important dis-

tinction for the entities we were studying—a distinction that significantly influenced results, as we examine in more detail in the ensuing sections.

Additionally, in the entities studied, we also found some meaningful differences related to engagement and design that were not captured in the CoP literature. As a result of these differences, which we describe in detail below, we labeled the groups we studied a variant or subtype of communities of practice, called *communities of transformation* (CoTs). In this section, we describe how the CoTs in this study resemble CoPs, but they also bring some unique features that made our results different from the more general CoP literature. A comparison of CoTs with other communities we described in section 2—CoPs and professional learning communities (PLCs)—can be found in Table 4.1.

Communities of Transformation

In this study, we believe that we have identified empirical data to support another variant of communities of practice called communities of transformation, or CoTs. To best understand CoTs, it is helpful to compare and contrast them with CoPs.

Traditional CoPs tend to work within the value system of their organizational settings to improve those settings. The practices that they put forward are not seen as entailing a dramatic departure from the status quo; rather, they offer improvements on existing efforts that can be understood within the philosophy or paradigm of existing practices. What we found in our interviews and through observing events and activities is that a CoT departs significantly from existing practices and values to create an innovative culture and reality. When people participate in these communities, they are introduced to and over time begin to live new practices that dramatically depart from the practices currently used within their institutions. Traditional CoPs also often operate in more organic, gradual ways, as people learn from each other through day-to-day practice. In the distributed communities that were the focus of this study, however, participants did not have such daily interactions to drive their learning, and they only experienced intermittent contact with the broader communities. In this setting, specific learning mechanisms were established by these communities that engaged individuals across isolated locations. This was an important design feature for the success of these CoTs.

We found three defining elements crucial for creating new or innovative cultures in CoTs, distinctive from CoPs and PLCs:

1. A compelling philosophy;
2. Living integration of the philosophy throughout activities and communications, creating a new

APPENDIX 4A: Sample of Philosophy in a Guiding Document

Directly quoted from SENCER website (SENCER, 2015):

The SENCER Ideals illustrate the principles and philosophies that guide SENCER's approach to educational practice:

- SENCER robustly connects science and civic engagement by teaching "through" complex, contested, capacious, current, and unresolved public issues "to" basic science.
- SENCER invites students to put scientific knowledge and the scientific method to immediate use on matters of immediate interest to students.
- SENCER helps reveal the limits of science by identifying the elements of public issues where science does not offer a clear resolution.
- SENCER shows the power of science by identifying the dimensions of a public issue that can be better understood with certain mathematical and scientific ways of knowing.
- SENCER conceives the intellectual project as practical and engaged from the start, as opposed to science education models that view the mind as a kind of "storage shed" where abstract knowledge may be secreted for vague potential uses.
- SENCER seeks to extract from the immediate issues the larger, common lessons about scientific processes and methods.
- SENCER locates the responsibilities (the burdens and the pleasures) of discovery as the work of the student.
- SENCER, by focusing on contested issues, encourages student engagement with "multidisciplinary trouble" and with civic questions that require attention now. By doing so, SENCER hopes to help students overcome both unfounded fears and unquestioning awe of science.

world of practice;

3. A network of peers to break the isolation, brainstorm revising practices, and help sustain changes once an individual returns to the status quo environment

The overall elements of CoTs are mapped onto a chart (Table 4.1) that also compares them to CoPs and PLCs. We will refer to this chart more specifically in the discussion, and it also captures elements presented in the findings.

PHILOSOPHY

First, having an engaging, well-articulated, and clear philosophy is important to ground people in a new value system and to guide novel behavior, especially when educators are in isolation, trying to learn and practice alone at their institutions. This philosophy provides an anchor for learning. In the interviews, faculty discussed how the philosophies of these four communities were the most compelling and engaging aspect of their involvement, and the survey results of these four organizations also reinforce this point (Kezar & Gehrke, 2015a). An example of one of these guiding philosophies is provided in Appendix 4A: the *SENCER Ideals*. Importantly, the underlying philosophies of these four CoTs challenge traditional ideas of science, not only teaching practices. For example, SENCER's focus on relevant social problems, civic education, and interdisciplinarity is a departure from more traditional, disciplinary views of science. Similarly, BioQUEST has brought philosophers into its community and encourages creativity and interdisciplinary thinking, and PKAL examines the cultural and social underpinnings of science and the importance of being culturally relevant and student centered. By challenging traditional notions of science, these groups advance entirely novel approaches, not just the limited practice of tweaking science curriculum.

Three defining elements of communities of transformation are: 1. A compelling philosophy; 2. Living integration of the philosophy throughout activities and communications, creating a new world of practice; and 3. A network of peers to break the isolation, brainstorm revising practices, and help sustain changes once an individual returns to the status quo environment.

LIVING INTEGRATION OF PHILOSOPHY

Second, in order to help members to embrace new practices that depart from the status quo within their own institutions, it is critical that communities provide members with opportunities to live or embody their values in practice. CoTs help individuals to inhabit new possibilities by creating this novel, philosophically driven world of practice. Thus, we found it to be another core characteristic of CoTs that their philosophies be embodied through a number of activities and events. For a CoT to embody its philosophy means that its signature events operate according to the philosophy, that the leadership of the community exemplifies the philosophy in all communications (e.g., listserv, websites), and that materials (e.g., resources, texts) reflect the philosophy. As community members articulated the influence of these different areas—activities, leadership, and resources—they noted how each area distinctly contributed to the eventual transformation that the community made possible.

NETWORK OF PEERS

Third, the relationships faculty formed in the communities helped them to maintain their new practices when they returned to their campuses, in part by allowing them to brainstorm uses for the practices on their own campuses. This feature of these CoTs is similar to common designs of CoPs in general, and of PLCs in particular, but it also introduces a different approach to mentorship and support. All communities of practice are based on the premise that interpersonal support for change and innovation in practice is important; thus, it is typical to see the importance of community and relationships within any derivative of a CoP. Yet, in traditional CoPs, relationships are often tacit,

6 Parallel to this effective structure of mentorship and community building, participants also discussed regional networks that were created by each of these CoTs. Participants said that such sub-networks typically did not represent the CoT well, because the regional communities lacked the key leaders to embody the philosophy, did not have an infrastructure where the philosophy was built into the design, and did not have enough of a cadre of dedicated volunteers. While all those interviewed recognized that the regional networks could perhaps one day themselves become communities of transformation, at present they fell short of what the more central efforts were able to create. It is these elements that proved crucial to the success

occurring naturally as people work with one another. In contrast, within PLCs, considered in this study to be a subset of CoPs, community development and learning are highly structured; it is the role of learning community leaders to arrange regular sessions for group brainstorming and sharing of information. Within the CoTs studied, however, this process has unfolded in a way unique from these two alternatives. Each CoT has developed a core of individual volunteers that provide mentorship and ongoing communication with individuals who attend events. At all times, these four communities have a group of individuals—usually 100 to 150 people—that are willing to communicate with and mentor a set of members as they begin to live the new practice. Usually these relationships develop organically based on shared or similar disciplines, institutional types, backgrounds, or concerns. At other times, these pairings can be assigned, such as when an individual member appears not to be making organic connections. These relationships are not highly structured as in PLCs, nor are they tacit as in CoPs—rather, relationships are more loosely connected and not formally dictated by overall structures. The faculty that are mentored then in turn become mentors for the next group. Each STEM reform CoT used this type of multi-generational approach, ensuring that new professionals are constantly recruited, that a middle generation is continually being mentored into more advanced roles, and that a senior group reliably works in leadership roles. Because these CoTs have been around for many years, they have reiterated this core group of individuals many different times, and they are constantly rejuvenating each group. We identify not only the importance of mentorship and relationships related to transformation, but the vehicles that emerged for developing and sustaining these volunteers over time.[6]

CoTs are similar to traditional CoPs in many aspects: they are organic, they share the underlying characteristics identified in the literature (domain, community, and practice), and they nurture membership and a community that mirrors that of CoPs. Yet, communities of transformation are distinctive in several key characteristics:

1. They focus on creating and fostering an innovative space that does not exist;
2. They rely on philosophy more than practice as they work to define the domain;
3. The philosophy is central to their community adhesion, engagement, and action

See Table 4.1 for a summary of the qualities of CoTs and a comparison with the characteristics CoPs and PLCs. While communities of practice are typically focused on improving specific practices (e.g., improving customer service or dental hygiene), they are not often engaged in radically rethinking or altering that practice. In contrast, innovation across theory and practice—not simply modification of practice alone—is a defining feature of communities of transformation. A philosophy is the coalescing feature that serves to embed innovation. Within CoTs, the domain is more than an interest area; it is distinctly defined by a philosophy and underlying values. The community supports this philosophy by living it through various interactions and through the work that is carried out both internally in the community and externally on members' campuses. Events, communications, and all community-related activities are defined by the task of living this philosophy. We believe that philosophy played such an important role to these communities because the practices they espoused were innovative and challenged the existing status quo. Thus, the practical innovation required a clear rationale and articulation.

In terms of community, CoTs have similar activities to traditional CoPs. Each shares information, establishes mentors, seeks and fosters expertise, and solves problems. However, we saw a unique quality of CoTs in the way these community activities were all defined by enacting the philosophy to engage the community. This was reflected in the descriptions given by community members that described the philosophy as the most salient feature. Also, the community relationships were neither tacit/organic (as in traditional CoPs) nor highly structured (as in PLCs). Instead, they were intentionally designed using organic elements. This design included the emergence of leaders through several avenues, as well as the creation of structures such as key annual events, communication channels, websites, and ways to link various faculty together to brainstorm and mentor one another.

of the core communities that we capture in the narratives below. Note that PKAL was an exception to this finding, and its regional networks were stronger and more successful compared to those of the other communities studied.

Table 4.1: Comparison of Core Characteristics of Communities of Practice, Professional Learning Communities, and Communities of Transformation

Characteristic	Community of Practice	Professional Learning Community	Community of Transformation
Definition	Group of individuals who share a concern or a passion for something they do and learn how to do it better as they interact regularly.	Group of individuals committed to working collaboratively in ongoing processes of collective inquiry and action research to achieve better results.	Distributed community of individuals that uses a core philosophy to create and foster new practices that can be integrated into the various institutions in which individuals work.
Underlying characteristics	A domain, a community, and a practice that is shared across participants.	A well-defined domain, a hierarchical and structured community, and often not a clear, shared practice.	An innovation that is lived (domain), a distributed community, and a practice (e.g., teaching STEM).
Membership and domain	Identity is defined by a shared domain of interest in current practices. Membership implies a commitment to the domain, and a shared competence that distinguishes members from others. Members are practitioners who develop a shared repertoire of resources: experiences, stories, tools, ways of addressing recurring problems, etc.	Membership is defined often by a leader who created the community; thus, the identity of the PLC comes jointly from the domain as well as from the leader. In education PLCs, the domain is typically student success. The notion of a shared practice may not be a prevalent part of this model.	Shared interest or domain is an innovation that does not currently exist in practice in a substantial way; members are organized around the task of bringing this vision into practice. Membership is organic, as in CoPs, and there is a shared practice (i.e.. teaching).
Community	Members engage in joint activities and discussions, help each other, and share information. They build relationships that enable them to learn from one another. The focus is on improvement of the domain. Traditionally, CoPs have been physically located in one place and have expanded over time.	Membership is steered toward the explicit task of bringing together teachers and administrators, or other hierarchically defined practitioners. Across this hierarchy, a sense of collective work is emphasized, such as efforts toward renewal or improvement of a school.	Members engage in joint activities and helpful discussions mostly shared at a distance. Their relationships enable them to learn or share from each other. The focus is on engagement and absorption of a novel practice. Communities rely on a hybrid structure with some in-person encounters, relying mostly on distance interactions. These communities are less organic than CoPs and less structured than PLCs.
Actions	Problem-solve, share information, seek and foster expertise, visit others, map knowledge.	Discuss teacher work, discuss student work, discuss student data, discuss the professional literature.	Hold signature events that demonstrate the new innovations; develop leadership that embodies this new goal; develop a guiding philosophy that helps support the new practices; create a guiding document.
Research background	Lave and Wenger's concept of situated learning, developed while studying apprenticeship as a learning mode.	Evolution of Lave and Wenger into a highly structured, constructed, and hierarchical form of situated learning.	Further evolution of Lave and Wenger, not situated in day-to-day practice, but in a distributed community. Development of idea of community that is neither fully organic nor highly constructed.
Where applied	CoPs have been adopted most readily in business due to the recognition that knowledge is a critical asset that needs to be managed strategically. Also seen across multiple sectors (government, non-profit) and professions like academe and law.	PLCs are mostly used in schools and in other more hierarchical institutions. Also found in other professions.	To date, CoTs have only been identified in higher education, but they are likely to exist in other places. They are most likely to be useful in settings or domains where a deep or fundamental change in practice is needed or already taking place.

It is also striking that the four CoTs we studied were distributed (located in a network, not in a single organization) and hybrid communities. By hybrid communities, we mean that they employed a combination of virtual and in-person connections; we describe this feature under future research, as we did not have evidence that it constitutes an essential quality. The distributed nature of these CoTs, however, seems to be an essential characteristic of such communities; CoTs function through the power of a distributed community to support people in isolated status quo locations.

The findings regarding distributed structure of communities of transformation should be treated with caution, however. While we describe this characteristic as a unique aspect of CoTs, it may also be a result of the fact that traditional communities of practice have historically been studied only within organizational settings; thus, much of the empirical literature reflects this form. CoPs typically have been seen to be organizationally situated and working to modify existing practices, but largely not challenging the existing order of the organizations that support them. Thus, we would like to acknowledge that the broad definition of CoPs indeed allows for the possibility of more radically altering practice, even if this function has so far not been documented in empirical research. By elaborating on the radical innovations fostered by communities of transformation, we hope to bring to light a variant empirical example of communities of practice that has not been identified in the literature to date and to articulate and define its key characteristics.

While we identified communities of transformation within higher education settings, we imagine they may be common across many sectors, both within non-organizational settings and among more networked groups. We also imagine that philosophy may be more relevant to certain types of practices, such as teaching, that are particularly imbued with complex beliefs that define them. For example, medical practitioners might form a community of transformation to introduce a radical variation into their complex practice, such as embedding acupuncture into traditional medical practice, which would entail a dramatic departure from status quo practice in many institutions. A group that formed around this issue may also be defined as a CoT. In light of this expansive applicability, we imagine that there are other CoTs that exist in various fields that have simply not been identified to date. Our research can be instructive to such CoTs, whereas the existing research on CoPs may be misaligned for outlining the best ways to engage participants, for understanding lifecycles and challenges faced, or for best understanding the outcomes possible for such groups.

Summary

In summary, through this study we have identified a new variant of communities of practice, which we have termed communities of transformation (CoT). These communities have three distinguishing characteristics that differentiate them from CoPs. They exhibit:

1. A compelling philosophy;
2. Living integration of the philosophy to create a new world of practice;
3. A network of peers to break the isolation and brainstorm revising practices

This approach to STEM reform holds promise in the ways that it can engage faculty and contribute to relevant benefits and outcomes for STEM education. In section 5, we describe these outcomes and benefits.

V. Outcomes and Benefits from Participation

One of the goals of our research was to identify outcomes and benefits of participation in communities of transformation (CoTs) as perceived by community members. This was in line with our second research question: What are the perceived benefits of participation in a STEM reform community of practice or network for the individual participants and for their campuses? In this section, we describe the outcomes we identified through our research, as well as some trends in the data regarding these outcomes. Later, in section 6, we look in more depth at the ways that engagement and community design are associated with these outcomes.

We asked participants to assess the extent to which their involvement in their communities contributed to meeting 26 individual-oriented benefits and 13 outcomes related to their organizations. Based on the literature on communities of practice (CoPs), we had an idea of the kinds of outcomes that might be met through involvement in the four communities of transformation. The outcomes we settled on were informed by this literature, as well as by qualitative data gathered through interviews and observations. As you can see in Tables 5.1 and 5.2, we performed exploratory factor analysis on these items and uncovered five broader constructs on which 30 items could be grouped. Three of these outcomes relate to the individual, including learning and improving teaching practice, skills for leadership and change, and networking, while the other two pertain to departmental and institutional outcomes. The remaining items that did not load on a construct represent other important outcomes that contribute to STEM reform (see Table 5.3). [7]

Table 5.1: Scale Scores and Factor Loadings for Individual Outcomes Scales

Individual Outcome – Scales [a]	Factor Loading	Cronbach α	M (SD) [b]
Learning and Improving Practice		0.95	3.33 (1.05)
-Led to changes in teaching practice	0.90		
-Motivated me to be innovative in practice	0.89		
-Led to professional growth to improve practice	0.82		
-Gained access to new curricular/pedagogical resources	0.79		
-Contributed to intellectual growth	0.77		
-Provided examples to model work after	0.68		
-Contributed to understanding big picture of STEM reform	0.57		

NOTE: [a] Factor loadings and Cronbach α's calculated for total sample only. [b] Five-point scale with 1=Not at all, 3=To some extent, and 5=To a great extent.

7 Tables 5.1 and 5.2 list the factor loadings and Cronbach α values for each scale. The factor loadings for each item represent the extent to which each item is correlated with the underlying factor, with a value of 1 being the strongest possible relationship to the factor. For example, the item most strongly correlated with our first individual outcome Learning and Improving Practice is the item "Led to changes in teaching practice." The Cronbach α value represents the internal reliability of the items within the scales, again with 1 representing the strongest internal consistency of each scale.

Table 5.1: Scale Scores and Factor Loadings for Individual Outcomes Scales

Individual Outcome – Scales [a]	Factor Loading	Cronbach α	M (SD) [b]
Leadership/Change		0.94	2.63 (1.13)
d-Gained skills to overcome barriers to change	0.85		
-Empowered to influence change on campus	0.76		
-Helped develop skills to be a leader	0.72		
-Motivated me to overcome barriers at home institution	0.72		
-Gained ideas for contributing to change on campus	0.60		
Networking		0.91	2.54 (1.11)
-Expanded personal support network	0.87		
-Connected to people who share personal interests	0.86		
-Connected to people who share professional interests	0.77		
-Expanded professional support network	0.73		
-Connected to a local (i.e., geographic proximity) network	0.67		

NOTE: [a] Factor loadings and Cronbach α's calculated for total sample only. [b] Five-point scale with 1=Not at all, 3=To some extent, and 5=To a great extent.

Table 5.2: Scale Scores and Factor Loadings for Organizational Outcomes Scales

Organizational Outcomes – Scales [a]	Factor Loading	Cronbach α	M (SD) [b]
Departmental Change		0.92	2.39 (1.09)
-Led to changes in teaching practices in my department	0.90		
-Led to curricular changes in my department	0.93		
-Led to changes in educational values in my department	0.90		
-Informed departmental strategic planning	0.80		
Institutional Change	0.77	0.95	2.05 (0.97)
-Led to developing communities of practice at institution	0.96		
-Led to developing campus network for STEM reform	0.95		
-Led to curricular changes in other departments	0.91		
-Led to emergence of new campus leaders for change	0.82		
-Led to changes in teaching in other departments	0.80		
-Led to changes in educational values in other departments	0.74		
-Informed campus strategic planning	0.68		
-Led to campus workshops and professional development	0.66		

NOTE: [a] Factor loadings and Cronbach α's calculated for total sample only. [b] Five-point scale with 1=Not at all, 3=To some extent, and 5=To a great extent.

Table 5.3: Scores for Individual Outcomes

Individual Outcomes – Individual Items	M (SD) [a]
Recharged and/or energized in work	3.27 (1.25)
Allowed to have fun in professional environment	3.10 (1.28)
Lent credibility for approach to teaching	3.01 (1.33)
Lent credibility for approach to professional work	2.84 (1.34)
Afforded opportunities to collaborate on projects	2.58 (1.35)
Assisted in career advancement	2.30 (1.30)
Gave opportunity to pursue new grants or major projects	2.28 (1.33)
Led to publications	1.72 (1.15)
Gave skills to make transition from faculty to administration	1.88 (1.26)
NOTE: [a] Five-point scale with 1=Not at all, 3=To some extent, and 5=To a great extent.	

Individual Benefits

Figure 5.1 shows the frequency of benefits through community involvement cited by the participants. In general, our participants reported the greatest benefits of involvement in these communities coming in the form of learning and improving their practice, reenergizing them in their satisfaction and fulfillment in their work, and gaining credibility for their work related to STEM reform. These individual benefits are important for different reasons among faculty engaging in STEM reform, and we delve deeper into these outcomes below.

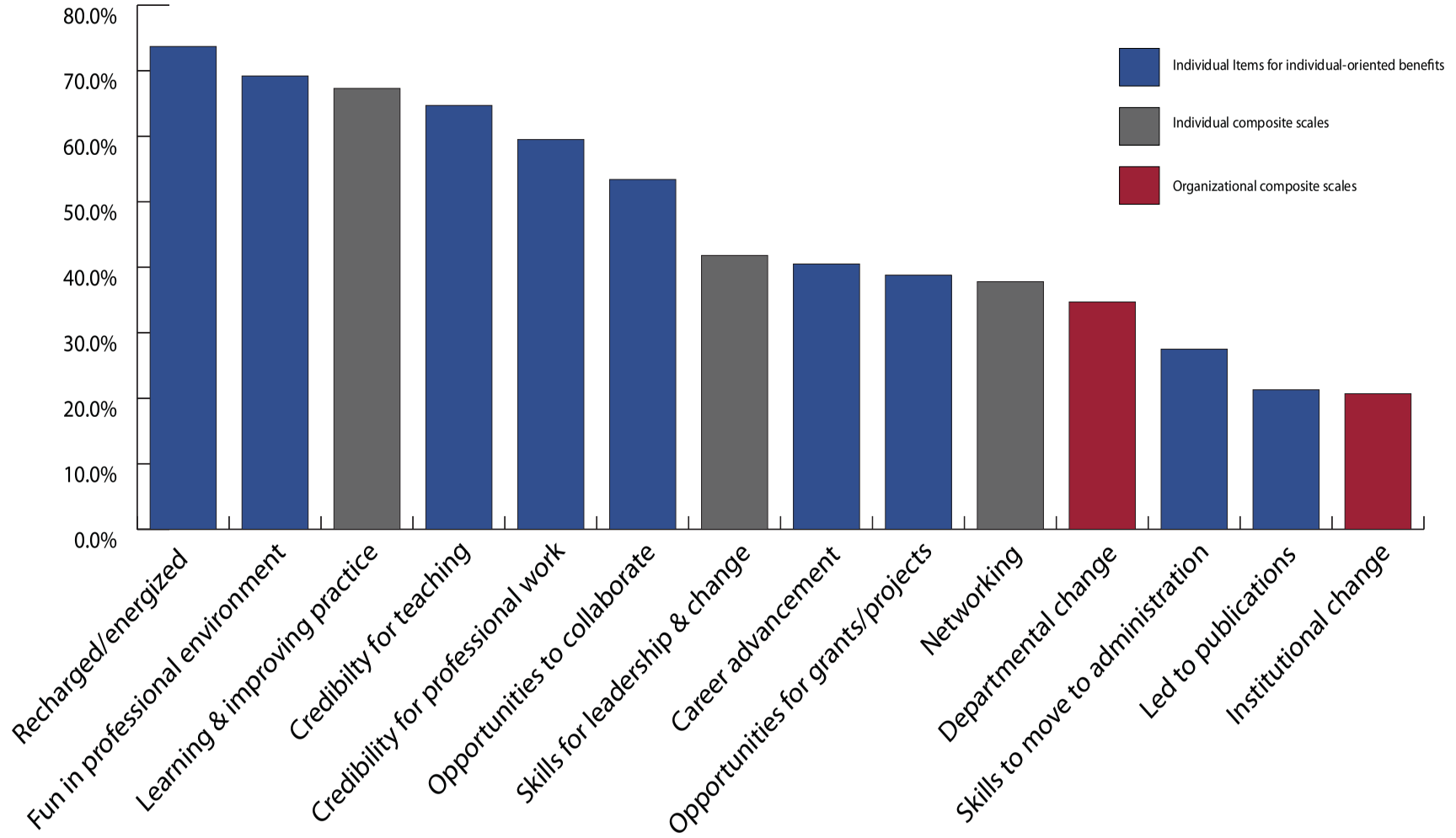
LEARNING AND IMPROVING PRACTICE

Of the three broad outcomes we mentioned above, learning and improving practice was the most frequently cited benefit of community involvement (67.3%). This is encouraging for the work of STEM reformers, as more than two in three community members indicated that they changed their teaching and improved in practice as a result of their involvement in these communities. Much of the work of these communities is focuses on pedagogical reform, which comes in the form of applying specific methods in the classroom (such as process-oriented, guided-inquiry learning) or adopting a new perspective or approach to science education (such as studying science through complex issues like HIV and climate change). When we asked participants in our interviews to identify the most important aspect of their community involvement, faculty would often cite the pedagogical approach to science education in their community. As one of the primary foci of STEM reform remains getting faculty to adopt evidence-based teaching practices (Dancy & Henderson, 2008), this finding points to the value of these communities in these efforts. However, effective STEM reform requires more than simply engaging faculty in improving teaching; the other frequently cited benefits in this study highlight other ways in which these communities contribute to STEM reform.

REENERGIZING FACULTY IN THEIR WORK

Feeling reenergized and having fun in a professional environment are the two most frequently cited benefits of community involvement (73.7% and 69.2%, respectively). STEM reform can be difficult work, especially for faculty seeking to change their teaching practice. They face many barriers to making meaningful changes, including institutional reward structures that undervalue innovation in teaching, disciplinary cultures that place more emphasis on research, and a lack of institutional leadership that fosters a culture that values teaching (Austin, 2011; Henderson, Beach, & Finkelstein, 2011). Faculty who value teaching and are interested in student learning may reach a point where they lack the energy or motivation to keep pursuing this work in the face of these barriers. Our interviews and observations revealed that faculty felt renewed in their efforts due to the supportive and innovative spaces of these communi-

Figure 5.1
Frequency of Participants Indicating Benefits from Involvement in STEM Communities of Transformation



NOTE: Benefits of involvement were measured on a 5-point scale, with 1 = Not at all; 3 = To some extent; 5 = To a great extent. Values in chart indicate the frequency of participants who indicated at least a score of 3 for these benefits.

ties. Many spoke of the difficulties of engaging in reform in institutions that were less supportive, and they were able not only to develop or regain a passion for this work, but they also looked forward to the chance to let loose and have fun. The role these communities play in helping faculty tap into this passion and sense of fun is vital to their success.

LENDING CREDIBILITY TO FACULTY AND THEIR REFORM WORK

Faculty participants also indicated that they gained credibility for their approaches to teaching (64.7%) and professional work (59.5%) due to their community involvement. As we mentioned above, institutional and departmental structures in which STEM faculty often find themselves can tend to focus on research over teaching and student outcomes. Faculty who are interested in such educational aspects of their work may feel that they are seen as less credible due to these interests. The communities in our study work hard to engage faculty members in this meaningful work, and they also are attuned to the structures that can inhibit faculty in these pursuits. Leaders of these communities play key roles in supporting faculty members who are actively involved, even going so far as writing letters of support for tenure and promotions and communicating with community members' institutions about their accomplishments and how their work contributes to broader progress in STEM reform. These communities also serve as the primary home for professional development for many faculty in our study, and the nature of the work and value communicated by the leadership of these communities go a long way in supporting faculty in pursing these efforts.

Organizational Outcomes

While less prevalent, we found that participants also indicated some organizational benefits from their involvement in these communities. Nearly 35% of participants indicated that engagement in these communities contributed to some extent to changes related to STEM reform in their departments, while more than one in five of the participants indicated that some sort of institutional change had come about as a result of their involvement in these communities. We interviewed several individuals from a variety of institutions who were able to infuse the practices from one of the communities into their departments on campus. This often occurred when multiple members from an institution were engaged in the community, especially when this included administrative leadership (e.g., department chairs, deans). We found that departments and even small institutions or schools of science utilized the principles of the communities to guide curricular and strategic planning for their science education efforts. The United States Military Academy at West Point and Brigham Young University Idaho are two good examples of institutions that utilized the *SENCER Ideals* (reproduced in Appendix 4A) as a guide for science courses throughout their curricula.

We have seen how the broad aggregate results of our research point to the benefits that communities of transformation can provide to STEM reform. We will now highlight several findings from our multivariate analyses that suggest particular reasons why administrators and faculty might gain from engagement with communities of transformation such as the ones in our study.

Multiple Benefits of Ongoing Involvement

For faculty members who pursue ongoing support for teaching and professional development, these communities of transformation offer a highly meaningful experience. Our analyses showed that faculty who were more continuously involved in these communities (i.e., attended more events and engaged more frequently with the community) exhibited greater benefits related to learning to improve practice, leadership skills, and networking (See Table 6.3). Our interviews and observations revealed that faculty who continuously engaged with these communities enjoyed ongoing support from the leadership of the CoTs and often reconnected with their own passion for teaching and for their disciplinary work.

This dovetails with the fact that feeling reenergized in one's work was the most prevalent benefit cited by faculty in

our surveys.

The benefits from community involvement we examined—leadership skills, improving practice, networking, grant opportunities, opportunities for career advancement, and others—are likely attractive to many faculty members. When we examined motivations for faculty to become involved in these communities, we identified some important patterns. Faculty in our study cited a host of reasons that motivated them to join these communities. While some of these faculty were oriented toward a specific kind of benefit, such as the desire to improve teaching, we found that participants benefited in several outcomes even when they were not seeking those particular benefits. For example, faculty seeking to improve their teaching practices (the most oft-cited motivation for involvement) not only reported greater benefits in learning and improving practice, but also reported greater benefits relating to leadership development and networking. In fact, higher scores for all five of our broad benefit constructs resulted among participants who identified any of the following motivations for involvement: support for change on campus, strategies to involve peers in change, opportunities for grant funding, and connecting to like-minded colleagues. This suggests that participation can lead to multiple benefits beyond one's initial reasons for engaging in these communities.

Our qualitative interviews provided a good example of these expanding benefits of involvement. One faculty member described entering a community initially because she was interested in improving an introductory course, but through her involvement she began to engage colleagues in rethinking the departmental curriculum. As a result of her passion for improving teaching and her knowledge gained through involvement in the community, she moved into a role in the Center for Teaching and Learning. The initial benefits pushed her into new and more effective areas over time. This story is an example of a common narrative arc within our interviews, which was mirrored broadly in our survey results.

Who Benefits? Gains for Women and Faculty of Color

By comparing reported benefits according to two characteristics particularly important to STEM reform—gender and race/ethnicity—we uncovered some significant trends (see Table 5.4). For nearly all of the individual benefits we studied (except for involvement leading to publications), female faculty members reported statistically significantly greater benefits resulting from their participation in these communities as compared to their male counterparts. While all such disproportionate benefits are notable, we are especially drawn to the difference between men and women reporting improvement in skills for leadership and change, gaining skills to transition from faculty to administration, and contributing to career advancement. In a similar fashion, faculty of color indicated greater benefits than White faculty members in several key benefits—networking, being afforded the opportunity to pursue new grants or projects, gaining the opportunity to collaborate with others on projects, gaining credibility for their approach to professional work and teaching, and gaining skills to make the transition from faculty work to administration—as a result of their involvement with these communities.

These pronounced benefits for women and faculty of color suggest the importance of communities of transformation for these traditionally marginalized populations in STEM fields. With increasing efforts to diversify STEM fields and disciplines, these communities seem to provide increased support for these groups of STEM faculty than may exist on their home campuses. This is certainly reinforced by our interviews and participant observations throughout the project. We observed and were told repeatedly of faculty members feeling supported by both leaders and fellow participants in the communities, which frequently served as their main professional communities outside of their institutions. Often faculty members expressed much more colleagueship with people in the community than at their own institutions, which helped them remain in faculty positions despite the fact that they may have otherwise left academe without this support. For faculty of color in particular, the key benefits mentioned above point not only to the connections that can be made but also to the benefits that can accrue from these connections through involvement in these communities. Faculty of color gain significant social capital that provides access to grant and research opportunities, presentations that provide visibility, and networking/personal connections for letters and promotion.

Table 5.4: Outcome Variable Mean Comparisons by Gender and Race/Ethnicity

Individual Outcomes – Individual Items	Female M (SD)[a]	Male M (SD)	*t* Statistic	Effect Size Cohen's d
Learning and Improving Practice Scale	3.47 (1.00)	3.18 (1.08)	6.50***	0.28
Leadership/Change Scale	2.72 (1.14)	2.53 (1.11)	3.61***	0.16
Networking	2.64 (1.09	2.43 (1.12)	4.35***	0.19
Departmental Change	2.44 (1.09)	2.34 (1.10)	2.07*	0.09
Institutional Change	2.08 (1.09)	2.02 (0.96)	1.16	
Recharged and/or energized in work	3.45 (1.20)	3.05 (1.27)	7.78***	0.33
Allowed to have fun in professional environment	3.26 (1.24)	2.90 (1.30)	6.61***	0.28
Lent credibility for approach to teaching	3.16 (1.32)	2.83 (1.32)	5.81***	0.25
Lent credibility for approach to professional work	3.00 (1.32)	2.67 (1.33)	5.74***	0.25
Afforded opportunities to collaborate on projects	2.68 (1.36)	2.48 (1.32)	3.52***	0.15
Assisted in career advancement	2.39 (1.34)	2.20 (1.25)	3.46**	0.15
Gave opportunity to pursue new grants or major projects	2.38 (1.35)	2.17 (1.28)	3.75***	0.15
Led to publications	1.74 (1.18)	1.69 (1.12)	0.97	
Gave skills to make transition from faculty to administration	1.95 (1.30)	1.81 (1.22)	2.26*	0.11
	White M (SD)	**FOC[b] M (SD)**	***t* Statistic**	**Effect Size Cohen's d**
Learning and Improving Practice Scale	3.32 (1.05)	3.39 (1.04)	1.11	
Leadership/Change Scale	2.62 (1.13)	2.72 (1.17)	1.31	
Networking	2.51 (1.09)	2.73 (1.15)	3.19**	0.14
Departmental Change	2.38 (1.08)	2.44 (1.14)	0.90	
Institutional Change	2.04 (0.95)	2.13 (1.05)	1.32	
Recharged and/or energized in work	3.26 (1.25)	3.29 (1.24)	0.31	
Allowed to have fun in professional environment	3.11 (1.28)	3.07 (1.30)	0.54	
Lent credibility for approach to teaching	3.00 (1.33)	3.13 (1.33)	1.68+	0.07
Lent credibility for approach to professional work	2.82 (1.34)	3.00 (1.33)	2.32*	0.10
Afforded opportunities to collaborate on projects	2.57 (1.34)	2.71 (1.36)	1.78+	0.08
Assisted in career advancement	2.29 (1.29)	2.40 (1.35)	1.48	
Gave opportunity to pursue new grants or major projects	2.24 (1.32)	2.51 (1.36)	3.36**	0.15
Led to publications	1.71 (1.15)	1.80 (1.18)	1.24	
Gave skills to make transition from faculty to administration	1.85 (1.25)	2.07 (1.29)	2.48*	0.12

*NOTE:+p < .10; *p < .05; **p < .01; ***p < .001; [a] Five-point scale with 1=Not at all, 3=To some extent, and 5=To a great extent; [b] FOC=Faculty of Color*

Team Involvement for Organizational Change and Leadership Development

We also identified how the involvement of several individuals from a single institution increased departmental and institutional benefits, as well as boosting reported individual benefits for developing skills for leadership and change (See Table 6.3). In fact, one of the largest effect sizes we observed in our analyses in predicting departmental and institutional benefits came from having more peers from a single institution also involved in the community. Some of the communities of transformation in our study intentionally harness this effect through a campus team structure, in which campuses are encouraged to send teams of faculty and administrators to events to engage in group learning and reform. Yet, even in the communities that are not based on this team structure, we still observed benefits of involvement of multiple faculty members from the same institution.

By encouraging multiple faculty members from the same institution to pursue engagement in the same community of transformation, administrators can foster a common language and strategy of reform among their faculty members, which our findings suggest contribute to greater departmental and institutional change. These team members can learn together from other members of the community and gain ideas for strategies to apply to their home campuses. Additionally, faculty reported greater individual benefits in leadership and change skills when more of their peers were involved in the community, suggesting that being able to engage with one's colleagues in these reform communities increases the ability to lead on their home campuses.

Additional Strategies for Broader Impact/Outcomes

While our study focused on the effects on individuals and how individuals influenced their departments and institutions, our qualitative data demonstrated further impact that we were not able to capture on the survey. In this section, we describe some of these important strategies/impacts that can result from supporting large scale CoPs. Section 9, in which we elaborate on the maturing phase of the CoP lifecycle and the focus on community expansion, also demonstrates some of the broader impacts that can be achieved by reshaping disciplinary groups, influencing larger institutional environments and whole sectors, targeting regional areas through regional networks, and even increasing international efforts through work and partnerships abroad. In this section we continue to describe the significant impacts of these CoPs that are often overlooked.

CREATING OTHER NETWORKS OR COMMUNITIES OF PRACTICE

Some of the communities in this study have fostered the development or creation of other networks or CoPs for improving STEM education. PKAL in particular was responsible for establishing many other networks and communities of practice such as the Faculty for Undergraduate Neuroscience (FUN), the National Numeracy Network (NNN), and Quantitative Inquiry, Reasoning, and Knowledge (QuIRK). SENCER similarly works to create a network of informal educators focused on making science education more relevant.

WORKING ACROSS AND BETWEEN COMMUNITIES OF TRANSFORMATION

Over time, the four communities of transformation have each co-hosted events with other STEM reform groups in an effort to broaden their impact by having more individuals attend. PKAL and BioQUEST have hosted several events together, including the BioQUEST summer workshop that we attended, which was hosted in conjunction with a PKAL regional meeting.

NATIONAL REPORTS AND ACTIVITIES

These CoTs were also very involved with the creation of national reports and activities aimed at STEM reform. BioQUEST's involvement with *BIO 2010* (National Research Council, 2003) is an example of working with national organizations on a report aimed at creating large-scale pedagogical and curricular changes. Leaders in BioQUEST

served on the planning groups, and they were instrumental in providing ideas stemming from their own philosophy and curricular materials. BioQUEST was also instrumental in revising the MCAT.

A CADRE OF LEADERS

PKAL's Faculty for the 21st Century (F21) program was directly aimed at creating a set of leaders among STEM faculty that would advance into department chair, dean, and other leadership roles on campuses that would help to propel needed reforms over time. Recognizing that many STEM faculty neither aspire nor are prepared to play leadership roles, the program helped inspire and train these individuals. They were able to explore their passions in order to identify areas in which they might want to take leadership. These faculty were also provided training on how to manage departmental politics, how to create a shared vision, how to overcome challenges to creating change, and other skills important to implementing these important STEM reforms.

SERVICE AS CONVENERS ACROSS GROUPS

Particularly in the early years, there was little communication among different STEM reform efforts; the CoTs in our study played a pivotal role in convening related efforts and bringing together intermediary groups that could synergize their shared work. On numerous occasions, PKAL served as a convener by hosting science education groups across disciplines and associations.

CONSULTANCIES

Each of these CoTs offered different types of consultancies over the course of their histories to support other institutions or groups in STEM reform efforts. PKAL offered consultancies, supported by the Keck Foundation, that helped institutions pursue particular STEM reform projects, ranging from facilities reform to faculty and leadership development. SENCER offered "house calls" where SENCER leaders went out to campuses to help with curricular reform efforts and to coalesce faculty to work across different departments in support of new curricula. The POGIL Project provided consultancies for campuses that were interested in integrating the POGIL Project activities across a department or a set of departments.

Our study did not examine the relationship between certain design features and these broader educational impacts, but these CoTs seem to offer compelling examples for motivating this kind of change. PKAL, for example, appeared to be involved in activities that related to some of these broader impacts to their work on leadership development, to the creation of networks, and to the importance of convening. These areas all suggest directions that other future CoTs might want to explore if they seek to have these broader, enterprise impacts.

Summary

This section describes the outcomes and benefits of participation in STEM reform CoTs, while also highlighting additional strategies for achieving broader outcomes for STEM reform. Our findings reveal that these communities contribute most frequently to individual outcomes related to feeling reenergized in one's work, learning and improving practice, and gaining credibility for one's work, yet they also contribute to broader outcomes for faculty members' departments and institutions in terms of broader curricular and pedagogical uptake. These communities have also contributed to broader change through other strategies we highlight, although it is hard to capture these impacts empirically. We turn in section 6 to the ways in which these communities are designed to contribute to these outcomes and benefits.

VI. Design for Engagement & Outcomes

One of our central research questions was: How do members and leaders of communities of practice (CoPs) perceive CoP design (membership, structure, communication, activities, and organization to support new knowledge development and action) shapes the ability to achieve goals (around undergraduate STEM pedagogical change and diffusion)?

We utilized both qualitative and quantitative data to answer this question as we examined how these communities are designed to facilitate engagement and contribute to outcomes. Our findings related to the ways that communities of transformation (CoTs) are designed to engage faculty and accomplish their outcomes, and we found this to be distinctive from the literature on communities of practice and social networks. Therefore, the findings below represent distinct and new ways to think about designing STEM reform communities to be successful. These findings are also supplemented by section 7, on the formation and lifecycle of CoTs, which reviews how these communities developed the engaging philosophies and communities described here. These two sections together are meant to help readers understand how CoTs can be structure to best meet their goals.

Communities of Transformation as Unique and Important Professional Development Opportunities

Before describing how these communities are designed for engagement and the achievement of outcomes, it is useful to compare the opportunities presented by CoTs to other professional development opportunities available to faculty, such as conferences or workshops organized by disciplinary societies or on-campus professional development resources. This comparison can show some of the potential advantages of CoTs.

In disciplinary societies, research is often the main focus of professional development. Typically, these societies bring together large numbers of faculty and have few venues for more intimate interactions that lead to deep learning. In contrast, the reform communities of transformation in this study focus on educational outcomes, particularly as they arise from developing faculty as teachers and contributing to individuals' efficacy for leadership and change. These communities engage in faculty development more intentionally, drawing on research on teaching and learning that is ignored by many traditional forms of professional development. Also, as a result of the interpersonal component of these CoTs, these communities provide ongoing support for faculty members over the course of their careers—we noted that many of the communities we studied would provide letters of support for faculty in their tenure and promotion processes.

Among on-campus professional development opportunities, Centers for Teaching and Learning often offer training around the latest development or issue in pedagogy (e.g., problem-based learning), but this training may not be aligned with faculty members' interests. Most such teaching development is practical in orientation. In contrast, the CoTs in this study provided teaching-oriented professional development that was decidedly philosophical in orientation; participants gained a deep connection to this new approach to teaching, something impossible through a simple skill-development session. Because the CoTs were founded on a specific philosophy toward STEM reform and teaching, they provide faculty with sustained, focused development opportunities, rather than ones where the focus constantly changes.

These communities also differ in the level of engagement and trust developed through involvement in them. As we

mentioned earlier, the benefits cited in conjunction with our interview and observation data suggest that these communities are incredibly fulfilling, both personally and professionally. Individuals indicate this sense of fulfillment in their descriptions of the trusting relationships that are formed through their involvement. A defining feature of these communities is the ongoing opportunity to develop relationships in intimate settings, through intentional engagement with both leadership and community members. This shines through in the trust that participants describe as operative within these communities. In CoTs, engagement is modulated across the various sizes of gatherings, offering faculty opportunities to participate in both large group and more intimate settings.

In Table 6.1, we outline these key differences we identified among professional development opportunities through campus-based efforts, disciplinary/professional societies, and the communities of transformation we studied. These differences, which were not only communicated to us by community members but also observed by us through participant observations at community meetings and events, suggest some of the ways in which these communities benefit individual faculty participants and their home departments and institutions.

Designing for Engagement

These four CoTs offered a wide variety of ways to engage individuals, including workshops, newsletters, social media, presentations at disciplinary conferences, websites, resources, and publications. Two design facets were most influential in contributing to participants' sense of engagement with the community: 1) the philosophy, which was most often epitomized through a signature event; and 2) relationships, which were formed through peer-to-peer learning, brainstorming with others engaged in similar STEM reform efforts, and opportunities for mentoring.

We captured our findings about how to design for engagement and outcomes in the model in Figure 6.1. The central and most important aspect for these communities was the philosophy, with all the other elements emerging out of this core. Resources, key events, and others are all important as they embody this philosophy. Thus, CoTs for STEM reform embody their philosophy of pedagogy in their activities, resources, communications, and all other activities. The next circle is personal interactions that progress from peer-to peer learning to more focused brainstorming to formal mentoring. We begin by describing the themes that emerged from the first phase of qualitative data collection, followed by general findings from the survey portion of the study.

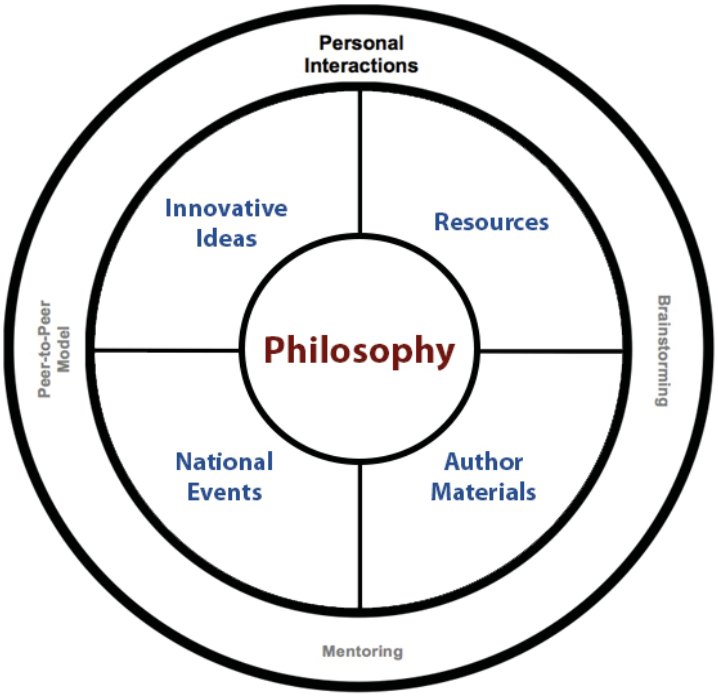


Figure 6.1
Model of Core Design Characteristics for Engagement in STEM Communities of Practice

Table 6.1
Comparison of Typical Professional Development through Campus-Based Opportunities, Disciplinary/Professional Societies, and Communities of Transformation

	Campus-Based Opportunity	Disciplinary/Professional Society	Community of Transformation
Nature of Involvement	Topic of focus tends to rotate (although some campuses have professional learning communities on a topic); involvement is occasional and not on-going; weak relationships formed	Annual involvement through meetings; typically weak relationships formed through participation	Involvement through a mix of annual events that bring people together for an extended period of time, with combination of large and intimate spaces within those meetings and a mix of ongoing communications and involvement throughout the year; potential for building stronger relationships
Focus	Focused on teaching more generally	Focused almost exclusively on research within a discipline	Focused on teaching and skill-building, utilizing a cohesive philosophical approach across experiences; community forms around this philosophy
Size	Typically an intimate size, which can be intimidating to people who want an introduction or are not sure about the involvement	Overall meetings typically large and impersonal; those focused on teaching have few places to gather	Mix of large venues that allow networking with national leaders, as well as small spaces to interact; allows a space for newcomers as well as more advanced participants to engage
Engagement	Dyadic; sometimes a more passive learning style	Typically a passive approach to discussing teaching, such as a workshop or p re-conference event	Highly interactive; collaborative and active learning approaches
Trust among Participants	Trust is difficult to develop through one-off workshops and trainings	Trust is typically lacking, with few opportunities to development meaningful connections	Trust frequently developed through intimate settings, targeted interactions, and connections that are able to grow over time

Philosophy as Design

When we asked faculty what they thought was the best or the most meaningful aspect of the CoT in which they participated, they described the philosophy of the community, which they thought was best symbolized or actualized through the signature events of each community. However, they also noted that philosophy was embedded in most of the community activities and communication. Our data about the formation of these communities demonstrate how much leaders invested in carefully constructing a compelling philosophy, typically articulated through a seminal document, posted on their websites, and reiterated throughout their materials. Each community then spent significant time embedding the philosophy in the activities and work of the CoT. This speaks to the intentionality invested by leaders within these CoTs to craft a philosophy that would be pervasive to participant experiences. The leaders of these CoTs also talked about ways they personally believed in and worked to spread the philosophy. We present the ways in which each community enacts its philosophy below as the best evidence of this theme.

THE POGIL PROJECT

For the POGIL Project, as participants described workshops and the annual national meeting, they noted how the meetings utilize the principles of the specific the POGIL Project pedagogy (active learning through guided inquiry and process features, like teamwork), which means that meetings include very active sessions, are learner centered, and use process principles, such as assessment and group work. In addition to using the specific group-work process, each session at the POGIL Project's meetings ends with the specific the POGIL Project approach to assessment, dubbed SII (Strengths, Improvement, Insights). As a result, the philosophy that undergirds the STEM reform promoted by the POGIL Project also is reflected in the way that members of the community interact with one another at events and through communications. Additionally, the physical spaces in which all of the meetings and events take place also reflect this philosophy. The POGIL Project organizes its events so that sessions are always in rooms with movable tables and chairs, boards and other working spaces, and technologies that enable more active learning.

SENCER

SENCER's philosophy, documented in the *SENCER Ideals* (see Appendix 4A), focuses on capacious questions, context over content, interdisciplinarity, and the connection of science to civic issues and relevant problems. Making meaning, pursuing intellectual curiosity, and fostering a democratic sense of openness are additional strong values held as a part of the philosophy of SENCER. We witnessed each of these characteristics active in the SENCER annual conference. Each of the speakers alluded to questions of meaning and important problems that need to be resolved through science, and leaders implored people often to reflect about the higher purposes of education. One participant described how the philosophy resonated and permeated activities, events, and communication: "They bring a fundamental epistemology that's very different than a lot of groups of people that I know to all their work. They really have this much more phenomenological approach to teaching, which is kind of an awareness of the methods they're using in teaching and just a willingness to think about values, and mission, and care, and love, and the things that actually make us more and more human. They can talk about things like truth, beauty, and goodness without it being seen as something polar to the very materialistic approaches of Western science." Reflection on meaning and questioning was built into each of the sessions. The annual event took place at a picturesque university on the west coast, where there are a variety of gardens, atria, and benches—all areas for reflection. The events reflected the interdisciplinary philosophy by not only inviting faculty across disciplines, but also by using sessions consistently to discuss the need to work across disciplinary boundaries. Also, educators from non-traditional groups often considered outsiders in academe, whether informal educators (e.g., museum staff) or part-time instructors, are actively included in SENCER discussions, and participants from these groups noted "feeling empowered."

PROJECT KALEIDOSCOPE

For PKAL, the *What Works* documents capture their philosophy of active learning, experiential learning, and acknowledgment of diverse learners' needs. The Summer Leadership Institute (SLI) epitomizes the focus of their philosophy on the importance of developing leaders to enhance STEM reform. Leadership using these principles is the mantra of PKAL. The principles related to *What Works* are seamlessly connected to the activities of the SLI. Over the years PKAL has conducted a series of signature events, assemblies, and workshops for their various sub-groups,

with each of these events intentionally encapsulating the key principles of "what works" in STEM reform. Further, participants spoke about how the underlying philosophy of PKAL includes value of mentoring, relationships, and developing people and their careers. As a result, events always include groups of mentors to provide feedback, time to build relationships, directed time to meet with mentors, and a focused discussion of careers and ways to develop individuals. While most of the CoTs have some elements of relationship building and mentoring that we will describe in the next section, this was a particularly significant aspect of the philosophy and practices of PKAL.

BIOQUEST

BioQUEST's signature summer workshop embodies its philosophy related to teaching as the process of problem-posing, problem-solving, and peer persuasion, known as the *Three P's*. The workshop is an opportunity for faculty to be problem-solvers, creating new materials to help teach biology. Participants also engage in the role of problem-posing to understand the types of issues addressed through their problem-solving activities. In this setting, they engage in groups to do their work, which involves peer persuasion. Thus, the underlying *Three P's* are utilized to shape the workshop structure and process. Participants described this approach as being on the cutting edge, future-oriented (i.e., oriented toward what will be needed in the future training of scientists), challenging, and creative. BioQUEST does not develop prepackaged materials for this work, but expects participants themselves to create new teaching materials. The persuasion aspect of this philosophy can also be seen in the almost conflictual dialogue that takes place as people debate ideas to move towards more solid pedagogical materials. For example, workshop participants were asked to present their emerging ideas to other faculty attending a co-located conference occurring at the same time. This forced them to persuade and respond to criticism from relative outsiders who were not as aware of the pedagogical approaches or philosophies. Like the POGIL Project, the work spaces for BioQUEST meetings are set up to be highly interactive, with a computer for each individual, movable tables and chairs, and small rooms for breakout sessions or group work. BioQUEST participants often leave the workshop without a finished product, but they have learned a process that will involve future problem-posing, problem-solving, and persuasion, which fits into this philosophy of STEM reform.

Personal Interactions: Peer-to-Peer Learning, Brainstorming with Others, and Mentoring

In addition to the pervasive philosophy itself, members mentioned interactions with others in the community as the most engaging component of participation in these CoTs. Personal connections/interactions were reported in the data over 200 times and were by far the longest report from our hyper-research codes. The main categories of interaction that were mentioned in interviews or observed were: 1. peer-to-peer learning; 2. opportunities to follow up and brainstorm about practice with peers and collaborators; and, 3. mentoring. All of these interactions progress toward more directed or involved interactions and provide energy for faculty to continue to reform in the face of departments and institutions that may not be supportive. One participant summed up the sentiment expressed by many as follows: "One of the best aspects was simply meeting people that were really impressive people that had lots to share. The sort of willingness to share. I would say my personal relationships or personal experiences with individuals in the network has been the best thing for me."

PEER-TO-PEER MODEL

Participants noted their own engagement with the overall model of learning from peers, and they highlighted the importance of this model for these communities. The peer-to-peer model was evidenced within all four CoTs through all of the events we attended and observed. Many people shared that the other opportunities for professional development, available through centers for teaching and learning or attendance at disciplinary conferences, often lack connection with peers teaching similar courses within similar disciplines. They felt that the information that they garnered through the CoT was more directly applicable because it came from peers attempting to do the exact same work in similar contexts. The CoTs also emphasize the importance of peer-to-peer learning in person and in relatively small settings, while large disciplinary conferences and workshops were mentioned as ineffective settings for

developing real relationships. The processes of developing trust and of participants getting to know one another are critical if advocacy and mentorship are to play a role in STEM reform. Thus, people emphasized the importance of in-person opportunities to build relationships that eventually turned into more detailed brainstorming and mentoring experiences (described below).

The signature event of each CoT provides ample opportunity for meeting people. The settings for these events are often isolated, helping to ensure that participants spend time together. Lengthy introductions are included at the beginning of these events, and faculty typically work in pairs and teams to maximize interaction. There are typically planned social hours, meals, and field trips to ensure time to bond.[8] Most events include late evening social time with wine, games, or both. Many also institute specific programs or policies to ensure that people develop relationships, such as a buddy system between a newcomer and an alumnus/a. At the end of each signature event, people are invited to continue contact, and they are told about other opportunities, such as future events, authoring resources, joining the listserv, and newsletters. The notion of using the community as a resource is activated in the signature events of the CoTs.

BRAINSTORMING WITH OTHERS

Faculty also spoke about connecting with people to brainstorm and obtain advice. One participant described leaving the first event attended through a CoT and understanding this important ongoing and developing relationship: "You were engaging with someone and making a connection [at the event], and chances are, if you actually did go back and implement that plan, you could contact those people for help." Another participant described the role of communities over time: "A sounding board, advisors, mentors. Always a place to go with questions. Okay, it was a safe place to go when sometimes it wasn't safe to be in my department with certain opinions." Many participants came to their first event thinking this would be a one-time interaction, but left with a strong notion that they had a group of people that they could now contact for support in their teaching. These more informal connections often developed into more formal mentoring relationships over time.

MENTORING

Over time, individual phone calls and e-mails among participants turned into more formal mentoring relationships. This formal mentoring was integrated into various practices: for PKAL, into its leadership institute and regional networks, and for SENCER, into its fellows program and annual dinner. This opportunity for more formal mentoring relationships was mentioned as one of the most valuable aspects intentionally fostered through the communities. One participant talked about the roles of mentors: "Really having recruited and picked good people as mentors, and having them be available as resources or sounding boards was helpful, faculty always mention that. The mentoring was vital to my success." Designing for engagement means attracting the right types of individuals, as well as creating a sense of accountability to give back to the community. Some of the communities even name these individuals; for example, in PKAL they were called the village elders. These 30–50 mentors understood that they were part of this sub community that had a mentoring responsibility, and they actively enacted this role for extended periods of time, some up to 30 years. One of the village elders described how gratifying it is to be a mentor: "I'm now mentoring probably eight or nine young people, and I keep in contact with them when they've got things going on, they brainstorm with me. And I find that reciprocal mentoring as just wonderful." Later in the conversation she mentioned how the community itself helped mentors to see that they can also learn and be enriched through these interactions. Communities can help to foster these mentoring relationships in ways that make them mutually rewarding. These mentoring relationships turn into very tangible advice about departmental politics, grants, tenure and promotion, publications, and the like. Mentors often wrote letters for grant projects and tenure and promotion files.

8 For example, SENCER facilitated trips to science and art museums, and PKAL offered hiking in mountains, exploring the town, or driving to a nearby national park.

The survey findings reinforce the importance of philosophy and relationships in contributing to participants' effectiveness in STEM reform work (See Table 6.2). These results are especially telling considering that the survey was administered to a much more representative sample of community members than were represented in the leadership interviews, suggesting the importance of philosophy and culture in these communities. We anticipated that the faculty participating in the survey would be less involved with the CoTs than those we interviewed, and that these elements of philosophy and personal interactions may be less important to them. However, when participants were asked to rate the importance of various design characteristics in contributing to their work, participants on average ranked items pertaining to philosophy and relationships as more important than other design principles, such as communication vehicles, mechanisms for feedback, sub-groups, grant activities, and events. *Innovative and new ideas* and *community philosophy* are the first and second most important design characteristics for participants. The innovative and new ideas disseminated by the CoTs in this study stem directly out of their philosophies, like guided inquiry, active learning, or case-based approaches. Participants indicated that the characteristics were also influential in contributing to institutional reform efforts.

The other top-rated design characteristics by-and-large reference the importance of personal interactions in helping participants' effectiveness in STEM reform. These characteristics include *opportunities to connect with other faculty and STEM leaders, having a safe space, inclusive practices, and the opportunities to be mentored*. It is clear that having the opportunity to connect with others in an environment that is safe and inclusive, like the environments we observed at the community events, carries through to this representative sample. The consistency across the interviews, observations, and survey data clearly indicate that philosophy and personal relationships and interactions are central components for aspiring communities to attend to when pursuing STEM reform.

In addition to the these analyses, we also utilized ordinary least squares regression models to examine the extent to which design characteristics of these communities, along with different types of engagement in these communities, were associated with our five outcome factors (learning & improving practice, skill development for leadership & change, networking, departmental change, and institutional change). Tables 6.3 and 6.4 display the coefficients for these variables in the models.[9]

LEARNING AND IMPROVING PRACTICE

We begin first with the model for learning and improving practice. Several engagement variables are significantly, positively associated with participants perceiving that they learned and improved practice, after controlling for the other variables. These are (in order of effect size): indicating greater continuity of involvement, attending more national events, indicating a longer tenure of involvement with the community, and authoring materials for the community. Thus, individuals who have been involved in the communities longer and more continuously can be expected to exhibit greater benefits in terms of learning and improving practice, while also attending more events and authoring more materials. Participants placing greater importance on several design variables is also positively associated with the participants perceiving benefits related to learning and improving practice. Specifically, participants who have been exposed to and value community philosophy, community leaders, community culture, innovative and new ideas, and community resources report greater benefits related to learning.

9 The beta coefficients indicate the strength of the expected relationship for each variable to the dependent variables. Each coefficient represents the portion of a standard deviation increase in the dependent variable for a standard deviation increase in each variable. For example, a participant who scores one standard deviation above the mean for extent of involvement is expected to score .11 standard deviations higher on the dependent variable "Learning & Improving Practice." These tables show only the coefficients pertaining to the design and engagement characteristics. We controlled for a variety of other factors in the models, including institutional characteristics (e.g., control, size, Carnegie classification), professional characteristics (e.g., position classification, discipline, motivation for involvement), and personal demographics (e.g., gender, race/ethnicity).

Table 6.2: Importance of Design Principles for Individual and Institutional Effectiveness in STEM Education Reform [a]

	Individual	Institutional
	Mean (SD)	Mean (SD)
Innovative and New Ideas	2.91 (0.78)	2.58 (0.86)
Community Philosophy	2.87 (0.86)	2.51 (0.91)
Opportunity to Connect with Other Faculty	2.79 (0.89)	2.43 (0.93)
Opportunity to Network with STEM Leaders	2.69 (0.94)	2.49 (0.95)
Community Culture	2.66 (0.89)	2.36 (0.88)
Safe Space	2.64 (0.96)	2.39 (0.95)
Inclusive Practices	2.54 (0.94)	2.27 (0.93)
Opportunity to be Mentored	2.49 (1.02)	2.31 (0.94)
Community-Specific Resource	2.45 (0.94)	2.21 (0.91)
Community Leaders	2.45 (1.00)	2.21 (0.96)
Different Opportunities for Involvement	2.44 (0.92)	2.25 (0.90)
Seminal Documents	2.42 (0.94)	2.32 (0.93)
Opportunities for Early-Career	2.38 (1.05)	2.40 (0.96)
Opportunities for Mid-Career	2.37 (0.97)	2.32 (0.94)
Heterogeneity of People Involved	2.37 (0.97)	2.26 (0.97)
Presence at Disciplinary Meetings	2.27 (0.86)	2.06 (0.82)
Opportunities for Late-Career	2.26 (0.99)	2.19 (0.95)
Communication Strategies	2.26 (0.86)	2.12 (0.86)
Sub-Groups/Grant-Related Initiative	2.25 (1.02)	2.30 (0.99)
Local/regional Events	2.24 (0.94)	2.11 (0.89)
Annual Events	2.13 (0.95)	1.98 (0.84)
Mechanisms for Feedback	2.06 (0.88)	1.99 (0.87)
Community Staff	2.00 (0.99)	1.87 (0.92)

NOTE: [a]Scale: 4-point scale: 1 = Not at all important; 2 = Somewhat important; 3 = Very important; 4 = Essential

SKILLS FOR LEADERSHIP AND CHANGE

Beginning with engagement variables, we find that attending national events, indicating more continuity of involvement, and having more peers from one's home institution involved in the community are significantly, positively associated with this dependent variable. As for design characteristics, participants noting the importance of community leaders and community philosophy result in the two largest positive effects for this perceived benefit, followed by valuing innovative and new ideas.

NETWORKING

Again, several engagement variables are significantly associated with networking after controlling for other variables in the model. Specifically, having more continuous involvement, attending national and regional/local events, and authoring materials for the community are positively associated with networking, while having more years of involvement in the community is negatively associated with networking.[10] Turning to design variables, greater emphasis placed on community leaders and community culture is positively associated with networking, as well as valuing opportunities to connect both with other faculty and with STEM leaders.

Thus, the nature of faculty engagement in reform efforts matters, but effectiveness of engagement is also tied to important design characteristics. Our models suggest that several engagement and design variables are important across our outcomes. We measured a variety of possible engagement activities, including attendance at a variety of events, engagement in different community activities, membership in different groups within the community, and the nature and extent of involvement generally in the community, yet we found that continuous involvement and attendance at annual events were the most important engagement variables in our study. In addition to engagement, we found that culture and community leaders also play a role in contributing to these outcomes.

Reinforcing the Importance of Philosophy and Interactions

It makes sense that annual events, continuous involvement, and community culture, philosophy, and leaders were significant in our models, given our understanding of how these communities of transformation strategically try to impact STEM reform (Table 6.3). Our interviews with key leaders and our observations of these annual, signature events revealed the importance of these events in reinforcing the underlying culture and philosophy of these communities. We saw that community leaders and event organizers act intentionally to infuse the community philosophy into the content and organization of sessions, and we observed how the culture of each community is present at these events in the ways that members interact with one another and with the key leaders. In other words, community is genuinely fostered in these environments, and it is influenced by the philosophy communicated by leaders in both event content and organization. We also observed individuals who had attended many events engage in deeper engagement and relationship building at these events, behaviors that can be attributed to their continuous involvement and ability to remain connected to the community.

Deeper Engagement Matters for STEM Reform

The findings related to continuity of involvement, engaging multiple members from a campus in the community, and length of involvement suggest the importance of deeper engagement in contributing to the outcomes in our study (See Table 6.3). These variables speak to an active engagement, which signifies faculty engaging more deeply, for extended periods of time, and with their peers. These communities can foster such active engagement in order to influence faculty members and allow them to see benefits from their involvement in these communities. As we described earlier in this section, the ways in which these communities differ from traditional professional development opportunities can contribute to this deeper engagement.

10 This seems at first paradoxical, as one might assume that the longer exposure people have to a community the more connections they can make and the greater their networks can grow. We think this finding suggests that the benefit of community involvement in growing one's professional or personal network likely comes through in early years of involvement, as individuals who are looking for support in STEM reform are likely reaching out to others and growing their support network for engaging in such work. Longer involvement is positively associated with other outcomes, suggesting that as individuals are involved longer in the community, their goals for support likely shift from needing others to gathering knowledge and skills for personal growth and institutional change.

Table 6.3
Engagement and Design Coefficients from OLS Regression Models for Three Individual Outcomes Related to STEM Education Reform

	Learning & Improving Practice		Skills for Leadership & Change		Networking	
	β	*SE*	*β*	*SE*	*β*	*SE*
Engagement and Design Variables						
Characterized Extent of Involvement	**.11*****	.03	**.08****	.03	**.17*****	.03
Attend: National Event	**.09****	.03	**.08****	.03	**.08****	.03
Design: Community Leaders	**.10*****	.03	**.19*****	.03	**.15*****	.03
Design: Innovative & New Ideas	**.09*****	.03	**.06***	.01	.01	.03
Design: Community Philosophy	**.15*****	.03	**.12****	.04	.06	.03
Design: Community Culture	**.09****	.03	.07	.04	**.13*****	.04
Activity: Author Material	**.05***	.02	.02	.03	.05*	.02
Years Involved with Community	**.08****	.03	.04	.03	**-.09****	.03
Design: Community Resources	**.08****	.02	.03	.03	-.01	.02
Number of Peers Involved with Community	.00	.02	**.05***	.02	.04	.02
Attend: Regional/Local Event	.01	.02	.03	.02	**.11*****	.02
Design: Connection with Other Faculty	.01	.03	.00	.04	**.11****	.03
Design: Connection with STEM Leaders	.04	.03	.03	.03	**.09****	.03
Activity: Present at Community Event	.00	.03	.01	.03	.03	.03
Activity: Present Material at Prof. Meeting	.03	.02	.02	.03	.03	.03
Activity: Publish about Community Work	-.02	.02	.00	.02	.01	.02
Group: Leadership/Board Member	-.07	.08	.07	.09	.04	.08
Group: Project/Grant-Based	.04	.05	.04	.06	.07	.06
Design: Different Involvement Opportunities	.04	.03	.02	.03	.00	.03
Design: Safe, Supportive Space	.04	.03	.02	.03	.01	.03
Design: Inclusive Practices	.00	.03	.02	.04	-.01	.03
Design: Opportunity for Mentoring	.04	.03	.04	.03	.03	.03
R^2	**.596**		**.528**		**.587**	

*NOTE: * p < .05; ** p < .01; *** p < .001; Variables were standardized prior to entering them in these models, which results in the coefficients representing effect sizes.*

Community Engagement and Design Matters more than Institutional, Professional, and Personal Characteristics

While we were able to observe significant effects in their relationships to our outcomes, the same was not true by-and-large for the other factors that influence faculty behavior in our models. While we noticed an occasional significant coefficient scattered throughout our models, in general a participant's institutional type, discipline, and rank/appointment status were not significantly associated with the outcomes we measured, when accounting for our other engagement, design, and motivation variables.[11] We think this points to the potential for CoTs resembling those in our study to contribute to overcoming some of the typical barriers to reform mentioned in the literature, including institutional reward structures or policies that value research productivity over improving teaching, disciplinary cultures that place more emphasis on research, and lack of institutional leadership toward a culture that values teaching (Austin, 2011; Henderson et al., 2011). While it is true that institutions have complex policies and structures that are difficult to change and address—such as those related to tenure, promotion, and rank—and disciplines exert control over how faculty may engage in STEM reform, we observed no meaningful differences across these indicators in our models. For the most part, regardless of where faculty work, their position, or their discipline, they reported greater benefits related to teaching, leadership, and networking through engaging with the important aspects of these communities, and they expressed motivation to attain these benefits. While we can only speculate on the future impact of these communities, their efforts could very well contribute to the bottom-up change that scholars in the field identify as possible through faculty engagement (e.g., Sunal et al., 2001). We turn now to the organizational outcomes.

Organizational Outcomes Related to STEM Reform

After controlling for institutional, professional, and personal characteristics, we identified several participant involvement and CoT design variables that are significantly associated with departmental change (See Table 6.4). Three aspects of involvement and activities are positively and significantly associated with participants reporting departmental change due to their involvement in the CoTs: length of involvement, peer involvement, and presenting materials related to community involvement at professional/disciplinary meetings and conferences. In addition to these involvement variables, the salience of three community design variables is also positively and significantly associated with departmental changes—community culture, community leaders, and innovative and new ideas of the community. We observed that community involvement and design shared many of the same relationships with institutional change as it did with departmental change. Length of involvement, greater peer involvement, and presenting materials related to community involvement at professional/disciplinary meetings and conferences are all positively associated with institutional change, after controlling for institutional and faculty characteristics. However, not all involvement experiences have positive effects; for example, involvement in a project or grant-based group is negatively associated with participants reporting institutional change. Of our design variables, participants perceiving community culture and community leaders as important for their work is positively associated with institutional change.

Deeper Engagement Matters for STEM Reform

Prolonged involvement and presenting about the community to outside audiences were both associated positively with our outcomes. These two variables suggest that a deeper engagement in these CoTs can have benefits for individuals hoping to influence broader institutional goals for STEM reform, in addition to the individual benefits highlighted above (See Table 6.4). In order to present about a community's pedagogical or other reform strategy

11 In this report, we only highlight relevant findings related to the communities. For more detailed analyses including institutional type, discipline, and rank/appointment status, please see Gehrke & Kezar, 2015.

Table 6.4
Engagement and Design Coefficients from OLS Regression Models for Departmental and Institutional Change Related to STEM Reform

	Departmental Change		Institutional Change	
	β	*SE*	*β*	*SE*
Engagement and Design Variables				
Years Involved with Community	**.15*****	.04	**.13*****	.04
Number of Peers Involved with Community	**.12*****	.03	**.19*****	.03
Activity: Present Material at Prof. Meeting	**.11****	.03	**.10****	.03
Design: Community Leaders	**.09***	.04	**.12****	.04
Design: Community Culture	**.13****	.05	**.13****	.05
Design: Innovative & New Ideas	**.09***	.04	.04	.04
Group: Project/Grant-Based	-.07	.07	**-.17***	.07
Characterized Extent of Involvement	.05	.03	-.05	.04
Attend: National Event	.06	.03	.02	.03
Attend: Regional/Local Event	.05	.03	.06	.03
Activity: Present at Community Event	-.01	.04	.07	.04
Activity: Author Material	.04	.03	.01	.03
Activity: Publish about Community Work	-.04	.03	.01	.03
Group: Leadership/Board Member	-.01	.11	-.15	.10
Design: Different Involvement Opportunities	-.01	.04	.03	.04
Design: Community Resources	.03	.03	.02	.03
Design: Safe, Supportive Space	.03	.04	.06	.04
Design: Inclusive Practices	.01	.04	.01	.04
Design: Connection with Other Faculty	-.04	.05	-.03	.05
Design: Opportunity for Mentoring	-.01	.04	.04	.04
Design: Connection with STEM Leaders	.07	.04	-.02	.05
Design: Community Philosophy	.04	.05	.07	.05
TOTAL R^2	**.425**		**.488**	

*NOTE: * p < .05; ** p < .01; *** p < .001; Variables were standardized prior to entering them in these models, which results in the coefficients representing effect sizes.*

to outside audiences, a faculty member must engage long enough and deeply enough to feel comfortable with the material and be able to communicate the strategy's nuances to audiences less familiar with the work. These types of presentation also communicate an individual's expertise, which can translate to increased legitimacy and leadership on the individual's home campus. This in turn can help these individuals to foster more change through their efforts. Additionally, the fact that prolonged involvement is positively associated with the reported institutional change outcomes reinforces that STEM reform is complex and takes time (Austin, 2011; Henderson et al., 2011). Designers and participants of these and other future CoTs cannot labor under the false impression that brief engagement in these communities will lead to larger changes; our findings indicate that those who are involved for longer periods of time report greater change. This suggests that such efforts must persist long enough to engage faculty over longer periods of time to see these changes take hold.

Collective Effort for STEM Reform

Our other key engagement finding points to the idea that change is a collective effort, as faculty who reported having more peers involved in the same community with them reported greater change on both the departmental and institutional levels (See Table 6.4). The communities in our study can serve as venues for multiple members of an institution to engage together in activities related to STEM reform, and the efficacy of such arrangements was reinforced by qualitative data. We observed this as a successful strategy in particular when CoTs encouraged members to engage in their activities as campus teams. Team members met in the spaces created by the CoTs, and they participated in conversations about bringing strategy back to their home campuses and about how they might work together when they returned. The qualitative research revealed, however, that such collective action does not only occur due to intentional focus by CoTs on gathering together institutional teams. Interviews with active community members revealed that there was a positive effect associated with simply having peers at their home institutions who had experienced the same workshops or developed through the same community. These commonalities acted to give participants a sense of shared language and trust on their campuses, even when they had not participated concurrently together with the other individuals. As a result, we conclude that organizational learning within an institution is enhanced by having multiple members of that institution participate in the same community. Such contributions to institutional reform are often cited as benefits of involvement in communities of practice (Allee, 2000), and the CoT model seems to offer this insight into how it can be augmented.

Community Design for Departmental and Institutional Change

We also identified several design characteristics of communities of transformation that are positively associated with departmental and institutional change (See Table 6.4). Specifically, the presence of key leaders and community culture are positively related to both institutional and departmental change. Based on our observations and interviews, we are not surprised to see the data bear out this association. First, leaders in the community play important roles of influence for community members. The four communities in our study were all founded by visionary individuals who continuously recruit a cadre of leaders to be active in community operations and generally visible at community events. These community leaders exemplify effective leadership styles, which serve as models for community members for how to lead change efforts when they return to their campuses. This allows for diffusion of these practices from non-organizationally situated communities, such as the CoTs studied, outward to multiple institutions. These leaders also set the tone for community gatherings and events in which faculty learned from one another in peer-to-peer settings, fostering cultures of active engagement, trust, and support among community members.

Cultures of Personal Support

These communities also exhibit cultures that value and place personal support at a premium; the presence of such cultures are associated with change outcomes on participating faculty members' campuses. The culture that is fostered in CoTs through community events, resources, and communication materials is a supportive one in which faculty are provided valuable feedback and mentorship to help them seek changes on their home campuses. Faculty further experience this culture of personal support through the sharing of strategies and best practices, as they learn in a peer-to-peer environment (Kezar & Gehrke, 2015a). These findings related to culture should be understood in conjunction with the importance of key leaders, as those individuals not only set the direction and tone of the community, but serve as mentors and provide personal support for community members. As a result, leaders can provide guidance and even consult on departmental and institutional changes being sought by community members, thereby creating a sense of personal support that is both localized in mentorship relationships and also pervasive across many experiences and activities available through the CoT. The combined value reported to arise from these key leaders and community culture suggests that these factors should be key considerations for CoTs to influence broader change in STEM reform. Specifically, these types of communities will gain by being intentional about the ways that their leaders represent and model cultures of support across a range of engagements and activities.

Summary

In general, we identified several key strategies for STEM reformers to use in order to engage faculty to contribute to broader organizational change outcomes at their home institutions. Reformers interested in starting or designing CoTs to contribute to STEM reform should a) provide adequate support to keep faculty involved for longer periods of time; b) seek involvement from multiple individuals within single institutions in their communities; c) engage community members in activities and development to help them gain mastery over the material in order to communicate their work beyond the community; and d) identify key leaders who can both support faculty and foster a culture of engagement. By using these strategies, we found that these efforts can effectively engage faculty in the kinds of bottom-up change efforts advocated for in the literature and shown to correlate with broader institutional and departmental outcomes for STEM reform. In section 7, we shift attention to the broader shape of these communities over time; in particular, we describe their lifecycles in order to highlight how effective communities form and continue to evolve.

VII. Formation and Lifecycle of Communities of Transformation

Our research found that the formation and lifecycle of these communities of transformation (CoTs) closely mirrors the literature on communities of practice (CoPs; reviewed in section 2). In this section, we describe the defining features of each lifecycle phase of a CoT: from *potential* to *coalescing*, followed by *maturing* and *stewardship*, and finally *transformation*. The *maturing* and *stewardship* phases entailed such important and distinctive characteristics from the traditional CoP literature that we go into greater depth on them in sections 9 and 10, respectively.

The trajectories of these four CoTs were all similar in that they tended to start with developing the philosophy and then materials to support that philosophy. They next moved to dissemination, and, lastly, they thought about community development. Compared to traditional CoPs, the CoTs we studied spent much more time on domain and practice development before focusing on community. Yet, the leaders of each CoT acknowledged that thinking about the community development earlier would have been helpful.

Potential Phase

It is important to note that there can be some overlap in the first two phases—potential and coalescing—as communities are beginning to form. We present different events in these two phases, acknowledging that some of these events may occur in an earlier or later phase depending on how the community is forming. What is clear is that the events in the potential and coalescing phases do fall before the maturing phase.

The four CoTs shared several characteristics in terms of aspects that defined their potential phase, including years of gestation, initial grants, key leaders coming together, efforts to develop and refine the philosophy, and the task of identifying a home.

YEARS OF GESTATION

Each CoT spent several years refining its pedagogical approach and ideas for STEM reform, eventually resulting in the detailed philosophies each community currently espouses for improving STEM education. During the early years, courses and activities were piloted and tested. Faculty gathered to refine ideas about the STEM reform to be pursued. In retrospect, what seems critical for sustained CoTs is that many years be devoted to refining ideas; this is pivotal to long-term success. For example, SENCER started in 1989 with an interdisciplinary science course on AIDS at Rutgers University, but the course and its accompanying pedagogies were refined for over a decade before the leaders obtained funding and launched SENCER as a community. These early leaders gathered scientists at Rutgers who were concerned about whether conventional science education was adequate to the task of preparing students to solve real world problems. Similarly, the POGIL Project worked over the course of eight years to refine pedagogical ideas that connected guided, process-oriented approaches to inquiry. PKAL gathered for six to eight years to define their approach toward "what works" in undergraduate education. BioQUEST gathered computer scientists, philosophers, and scientists to develop ideas of the way computers could revolutionize teaching and make it more student-centered and engaging.

Grants prior to becoming a formal community. One important way that the communities were able to test their potential was through grants they received to refine ideas. While the work started informally with faculty meeting at disciplinary conferences or within an institution, obtaining grants allowed them the time and resources to work together to refine ideas, legitimating their work to a larger community. Additionally, grants allowed for collecting data

about the efficacy of the ideas as they were put into practice. While all early-stage CoTs obtained grants, some ideas required even more support, due to the nature of the innovations they entailed. For example, BioQUEST computer simulations required more infrastructure support to develop initial models, and the community founders accordingly sought corporate and foundation funding for this.

KEY LEADERS COMING TOGETHER

Each CoT was developed by an individual leader or a few individual leaders who had a passion for the ideas. These individuals provided the energy, passion, and resources to articulate the potential of these ideas and help move the communities toward the coalescing phase. It was essential to the success of the potential phase that there was a person who took up the mantle to support these ideas and pursue grants, working to gather people, to identify a home for the efforts, and to create conversations. While leadership continues to be important throughout the lifecycle, it is likely that none of these communities would have been able to persist beyond the potential phase without a key leader (or set of leaders) who drove the work of the fledgling community. Every person we interviewed underscored the importance of Jeanne Narum (PKAL), Rick Moog (the POGIL Project), David Burns (SENCER), and John Jungck (BioQUEST). Without these individuals, it is clear that the potential of the early ideas for reform would not have been propelled forward into the formation of these four communities of transformation.

Additionally, prior to launching as a community, the organizers of these communities needed to draw in some key thought leaders in the sciences to provide legitimacy and foster involvement of others. In the earlier years, the communities hosted events that drew on the presence of such key leaders to ensure attendance by others. Several communities formed informal advisory boards as a strategy to bring in key leaders. For example, PKAL brought together academic leaders in liberal arts colleges to document evidence of "what works" in undergraduate STEM education. The POGIL Project gathered chemistry innovators in the mid-Atlantic area on a regular basis to discuss challenges in teaching chemistry. BioQUEST gathered computer scientists, STEM faculty, and philosophers to discuss the potential of technology to alter teaching in science. SENCER worked with deans through its connection with the Association of American Colleges and Universities (AAC&U), which helped to attract faculty to events.

A HOME

Each community of transformation was not part of an institution, but each found a home that provided a place for them to begin work and to locate their initial grants. While these homes did not necessarily provide resources or support, they did allow them a setting in which to work to centralize the efforts. The POGIL Project found a home with Franklin and Marshall College; SENCER began at Rutgers University before locating its first grant through AAC&U; BioQUEST began at Beloit College; and PKAL was located at the Independent Colleges Office. These institutional homes provided centralized hubs for information in terms of communication, website, and location for grants. They provided an important beginning place for the CoTs, but over time most relocated to more supportive environments as their goals became better refined.

In summary, each of these CoTs share a common history of years spent in the early stages, refining their STEM reform ideas, obtaining grants, finding key driving leaders, bringing in a set of influential faculty, and finding an initial home. These were essential years of gestation that carried each group through the stage of developing their potential, until they were prepared to launch more formally as full-fledged communities. This pre-work ensured that the first workshops and events held by each CoT were well attended by faculty, allowing the community to begin to coalesce.

Coalescing

As the communities of transformation entered the coalescing phase, they pursued several streams of essential work. Communities in this phase work to decisively name the STEM education problem, to connect themselves to the broader STEM reform movement, to develop key philosophical documents to distill the philosophies they had formulated, to foster the formation of their culture, to create key signature events, and to develop meaningful, useful materials.

NAMING THE STEM EDUCATION PROBLEM

In preparation for effectively coalescing faculty, these CoTs were successful in identifying and naming a significant problem in STEM education (e.g., lack of relevance or contextualization, passive teaching, lack of student-centered approaches) and then offering a new approach to teaching that squarely addressed the named problem. For example, PKAL responded to the urgent need expressed in national reports to address the lack of STEM graduates and the high dropout rates in STEM. PKAL tied this problem to tendency of STEM faculty to use passive approaches to teaching, rather than the best evidence-based approaches. Similarly, SENCER articulated how STEM education was not preparing students for their responsibilities as citizens, including the responsibility to engage civic problems once the students graduated with their STEM degrees. The project therefore aimed, from its earliest stages, at making STEM education focus on key civic problems, like sustainability. By naming a problem and a needed reform, each of these CoTs created a movement and began to draw members toward key areas of interest that could be mobilized to address the task of reform.

CONNECTION TO BROADER STEM REFORM MOVEMENT

In addition to naming the work, these CoTs also connected their work to a broader STEM reform community Members of each CoT talked about interacting with faculty in other groups engaged in this work—members of BioQUEST were also part of PKAL, for example. The communities also organized gatherings with others who shared an interest in improving STEM education, both at disciplinary societies, and at the meetings of national organizations and other interested groups, such as the National Academies of Sciences, the Howard Hughes Medical Institute, and the National Science Foundation. PKAL worked with various STEM reform leaders to develop the ideas for Faculty for the 21st Century, which aimed to scale reform more broadly. These ideas and many others were drawn from the advice of national leaders in STEM reform.

KEY BEGINNING DOCUMENTS

Most of the CoTs solidified their philosophy into a key document in the coalescing phase as a way to formalize ideas that had been discussed during the potential phase. It was important to formalize the philosophy in this way in order to attract and recruit faculty to join the communities. Thus, the creation of key philosophical documents built upon the CoTs' successes in naming the problems they faced. It worked synergistically with the communities' new connections to the broader STEM reform movement, allowing them to begin to gather dedicated memberships and become engaged communities. The key philosophical documents of each CoT are named below and briefly described. They are described in greater depth in Section 6.

BioQUEST created the *Three P's: Problem-posing, problem-solving, and persuasion* (Peterson & Jungck, 1988). This approach involved more active engagement of students in the education process, through strategies such as having students teach one another and using curiosity and interest inspired by problem-posing to drive learning.

The creation of key philosophical documents built upon the CoT's successes in naming the problems they faced. It worked synergistically with the communities' new connections to the broader STEM reform movement, allowing them to begin to gather dedicated memberships and become engaged communities.

Project Kaleidoscope created a philosophy document called *What Works: Building Natural Science Communities* (PKAL, 1991). The document focused on active learning that is made relevant by being connected to real-world examples in context. This is achieved using techniques such as service learning, undergraduate research, and other engaged pedagogies, while taking into account students' diverse backgrounds, thus making science a more collaborative and peer-based enterprise.

SENCER created the *SENCER Ideals* (see Appendix 4A). The *SENCER Ideals* focus on capacious questions, context over content, interdisciplinary, and the connection of science to civic issues and relevant problems. These areas of pedagogical concern constituted a significant departure from science education at the time they were written. While the POGIL Project does not have a seminal or key document, their philosophy is summed up in the approach to pedagogy that is their namesake: process-oriented, guided-inquiry learning.

Each of these guiding philosophies for teaching had strong resonance with faculty, who reported to us the efficacy of writing down these philosophies so that they could be used to solidify ideas for STEM reform. In this way, these written documents helped to bring new people into the CoTs by energizing and activating them about the possibilities for change.

The culture often reflected the philosophy that each community had developed, which became part of the core values of the group.

CULTURE FORMATION

During this phase each group also developed a distinctive culture for which it became known. The culture often reflected the philosophy that each community had developed, which had become part of the core values of the group. These cultures also developed around core characteristics related to the leaders who had developed the CoTs, as well as the key and influential faculty who had joined over time. We describe the cultures of each of these communities of transformation below.

PROJECT KALEIDOSCOPE. In interviews, participants identified the culture of PKAL as offering a safe space for experimentation and being supportive of faculty members' needs, whether those needs be in pedagogical experimentation or career development. Respondents reiterated the roles of mentorship, relationships, and partnerships as underlying core characteristics of this community. As one faculty member noted: "People stay involved because of commitment to each other." Faculty also spoke about the compelling and cutting-edge ideas at PKAL, the synthesis of many big ideas in science, the engaging sense of urgency for change, and the openness of the community toward new ideas and ways of thinking. Faculty commented on feeling empowered and challenged simultaneously by the culture of PKAL. They spoke about the energetic and friendly environment, and always about the passion around teaching. A focus and emphasis on leadership development was mentioned by most faculty, as well as a sense of accountability that comes with being a leader. Many described how PKAL embraced faculty across different disciplines, which was a strength of the community, since it created opportunities for cross-disciplinary conversations. Many people spoke about the PKAL way of conducting an event, which is one third introduction, one third active, small-group work, and one third reflection and accountability (i.e., what will you do once you leave?). PKAL events also include rituals that help members to demonstrate and reflect upon the community's on-going commitment to one another. The PKAL practice of developing notebooks for events was also noted as an important resource for expressing cultural values, with inspirational quotes, places for reflection, and research and ideas to inform practice.

THE POGIL PROJECT. The POGIL Project's culture was guided by the peer-to-peer model, with faculty learning from one another through workshops and other opportunities. Because of the emphasis on active learning and group work epitomized in their philosophy, the culture of the POGIL Project is built around small-group work and highly active interactions. Faculty spoke about the emphasis on feedback and assessment at the POGIL Project as very much a strong part of the culture, a practice that they really appreciated in order to support them as a research- or information-informed community. Participants noted a sense of intensity as part of the culture, which results from constant evaluation, questioning, and a driving curiosity. For some, this focus on evaluation and critique might lead to less of a sense of openness and inclusiveness. However, the POGIL Project also espouses a commitment to creativity, as exemplified by the practice of writing activities. Accordingly, many people describe their interest in being a part of the process of creating pedagogical materials. Many faculty also noted how the POGIL Project's community was informed by a culture of science, in which it is okay to fail and to experiment, and learning takes place through trial and error. Rick Moog, the POGIL Project's leader, is noted for the slogan: "We work hard and have fun." Working hard is expressed through the intensity and sense of values that are parts of the culture, but the creativity, trial and error, and occasional light heartedness in social settings demonstrate the fun aspects of the community. According to our research, that ethic very much characterizes the culture of the POGIL Project.

SENCER. Participants described SENCER's culture as highly inclusive of all educators, whether they be students, faculty, staff, or informal educators. Community members described a minimal sense of hierarchy, exemplified by the fact that students were given equal voice to faculty. Those involved spoke about "all ideas being valuable and an open-

ness—this is non-elitist." There was also much discussion of feeling empowered, and of how this is connected to the lack of hierarchy and support. SENCER fosters a culture that is interdisciplinary, thereby supporting a view among its members that all sciences are important, and that there is no hierarchy related to one's discipline. While we found this sense of inclusion among members, we also heard expressed a feeling of challenge, driven by a deep intellectual curiosity connected to the SENCER ideal of capacious questions. Faculty reiterated that they stay involved because of intellectual engagement that permeates the culture. The culture was described in terms of emotions, and many people spoke about SENCER helping them to regain their passion for teaching. SENCER's culture connected them to the original reasons they started studying science. Faculty described how there was also a sense of meaning related to teaching and research, and that the goal of the community was to help people reconnect with a deeper sense of meaning about their work. They told us that teaching is not seen as a skill or strategy in the SENCER community, but as an art form and something that requires personal reflection. Creativity and departure from pre-packaged sets of ideas were seen as key elements within this community. This culture is expressed literally through the community's insider language that are a part of each annual conference.

BIOQUEST. Like SENCER, BioQUEST was characterized by participants as a culture of "challenge." The community is designed to encourage faculty to move out of their safety zones. As a leader in the group noted: "This is not for people who like comfort; we are constantly rethinking teaching and exploring new areas of biology." There is a sense at BioQUEST of being on the cutting edge of biology, anticipating its future. The word "innovative" was used constantly to refer to the culture. Participants also noted BioQUEST as having a culture of creativity; the community does not provide pre-packaged ideas for teaching, but pushes people to develop their own approaches. In this way, teaching becomes a research activity, a scholarly inquiry. This dovetails with a belief that the faculty is just as much a learner as the student. The BioQUEST summer conference puts faculty in the role of student, and it uses active learning to have them explore an issue from that student perspective. Participants in the community used the metaphor of a mobile teaching and learning center to describe their work. As in PKAL, many faculty in the BioQUEST community talked about their future-oriented culture as being constantly on the edge, developing new ideas that will work in the future. An important part of this orientation is the idea of openness—making all materials free and available. BioQUEST also has a very flat and nonhierarchical culture. They use the language of "coworkers," no one is assumed to have more expertise than another, and there are no explicit leaders. Dissenting voices are encouraged, which participants note as "always welcome and [we] feel this is part of a healthy culture." Most other CoTs were not characterized by this same sense of debate and active openness to disagreement. Over the years, BioQUEST participants could recount many different areas in which the leadership group itself had significant disagreements over direction. But they felt that the openness to debate helped them shape their direction productively and maintain a healthy community. They noted how, early on, the community was dominated more by men (an artifact of more men doing work in technology), but they described that this changed over time. With the shift to more women in the community, the culture also adopted more of a focus on diversity and social justice.

DEVELOP A SIGNATURE EVENT

Each group developed a key event that brought people together as a community around the philosophy. This became a regular event that defined the CoT in each case. For some communities, these initial signature events gave way to new signature events, while others maintained the same key events over their entire histories. For example, the POGIL Project developed its three-day workshops, in which faculty are introduced to the POGIL Project approach. These workshops bring together 20–30 faculty to learn from experienced the POGIL Project practitioners. Campuses typically hosted the workshops. The POGIL Project also started an annual meeting to bring together leaders in the movement in St. Louis; thus, it had continuity through maintaining the same setting each year. BioQUEST started a summer workshop—a small gathering of 25 faculty to explore the *Three P's* philosophy. This hands-on workshop has now been offered for over 25 years. PKAL started its assemblies that brought together faculty who wanted to support curriculum development around the *What Works* ideas, bringing together close to a hundred people for each assembly. Later, the leaders developed the Summer Leadership Institute as part of the Faculty for the 21st Century program (F21). This summer institute has remained constant for the last 20 years, even after the F21 program ended. SENCER offers an annual meeting that brings together several hundred people interested in the *SENCER Ideals*. This annual event has become SENCER's signature event, and it attracts substantial repeat attendance.

DEVELOP MEANINGFUL MATERIALS

In addition to the core philosophy document, each organization developed a series of resources and materials that were supportive of the educational reform efforts that they promote. For example, SENCER developed course modules for what a SENCER-ized class looks like, so that individuals had samples for creating their own syllabi. They also created a journal to enable people to publish information about their revised curricula and pedagogical approaches. They developed assessment materials to help individuals in evaluating their new SENCER courses. BioQUEST created a library of course materials (e.g., computer simulations) that was searchable and kept up-to-date for about 20 years. They have now transitioned to a website with curricular resources, particularly case studies, ways to use Excel for assignments, and other simulation-related materials that require less of a technology infrastructure to use. They made this transition to help less resource-rich institutions to integrate the *Three P's* philosophy. PKAL was known for creating reports after their assemblies to capture key ideas related to STEM reform. For example, they had an assembly on revising introductory science courses, and the ensuing report became a resource for ongoing change. The POGIL Project developed curricular activities and branded them as having been reviewed and approved by the POGIL Project professionals. In addition, they created textbooks that included the POGIL Project activities. Each of their workshops is accompanied by carefully developed handouts focused on helping individuals create the POGIL Project materials for themselves.

Thus, each community developed a set of important resources that became invaluable to their members at multiple tiers of engagement: introducing the STEM reform, practicing the reform, and advancing the work on both the individual and institutional levels. For example, the POGIL Project workshop materials were introductory resources for educators, while the textbooks and branded activities were intended to help more mid-level professionals further their practice. Finally, for POGIL, the creation of new materials was often a task for more advanced practitioners.

Maturing

Expansion was a major activity during the maturing phase for each of these communities of transformation, and we have dedicated Section 8 to discussing their expansion strategies. However, in this section we describe several other important activities that happened during the maturing phase, including creating a rhythm of the events for different stages on involvement, obtaining new grants, building community, leadership development, and the emergence of a distributed leadership. The maturing phase is characterized by considering ways to manage the growth of the enlarging community while also continuing and expanding that growth.

CREATE A RHYTHM OF THE EVENTS FOR DIFFERENT STAGES OF INVOLVEMENT

Each of the CoTs recognized that, to develop the community, they would need to have a rhythm of events that helped people move from introductory relationships with the practice to more advanced work, in which faculty could play an increasing leadership and mentorship role. The POGIL Project first created an introductory workshop, and then they later recognized the need for a more advanced workshop for individuals who wanted to follow up and learn more about creating activities. Those who showed interest in greater leadership involvement were encouraged to begin facilitating workshops, which often led them to be invited to participate in the annual national meeting, where a small leadership group gathered. SENCER had a similar rhythm of events, beginning with individuals becoming introduced to the community through attending their annual conference. In later years, individuals would be invited to be speakers at the summer conference. As faculty became more involved, they were often invited to the Washington Symposium or became leadership fellows. PKAL started off by inviting people to assemblies or to the Leadership Institute as an introduction. Next, engaged participants were invited to be speakers at these events, and then, later, they were more formally designated as mentors. These advanced mentors were connected to newer people who showed interest in becoming more involved in the community. PKAL also has mechanisms for identifying people who want to become more involved and increase their participation. The POGIL Project had workshop leaders designate individuals who showed particular interest, and those participants would receive follow-up contact from The

POGIL Project leaders at the home office.

NEW GRANTS

In order to develop new materials—a need that continues from the coalescing into the maturing phase—and later to expand to new audiences, each CoT developed and obtained new grants. For example, when BioQUEST wanted to reach community colleges, they created and gained funding for the C3 Cyberlearning Project. Similarly, CASE IT! was a grant to create case study activities for molecular biology and to expand reach into less resource-rich institutions. BEDROCK was a grant-funded initiative to create resources related to bioinformatics to get more mathematics into biology courses. These are examples of how their grants and the resultant materials helped them to expand into new sectors, like the community college, or into different courses, such as molecular biology. SENCER was interested in working with informal educators from museums and libraries, so it developed a grant to bring these individuals to their events and to connect them more directly to science faculty within the community. PKAL obtained a grant from the National Science Foundation to expand its regional networks so they could support more faculty in institutions across the country. PKAL also obtained funding to establish a subgroup, Faculty for Undergraduate Neuroscience, that would bring together faculty in this area to learn about more engaged pedagogy. Thus, new grants helped PKAL expand and extend its What Works principles by reaching into a new discipline. In this way, PKAL successfully moved to new types of institutions and across different fields of science, using grants to gather key educators in these new arenas and to develop customized materials to help keep its pedagogical approach appropriate to this new context. Similarly, the POGIL Project began work with high school teachers and discovered that they wanted access to more pre-packaged materials, rather than to create them independently. A grant helped the POGIL Project to create more pre-packaged activities for these teachers, thus extending the impact of the pedagogical innovation. These examples show how, while grants are critical to growth, they are also pivotal to maintaining the communities and their core functions. We will see how grants continue to serve a role in the stewardship phase, discussed in section 10.

BUILDING COMMUNITY

Each community of transformation had several strategies for ensuring or developing community over time. BioQUEST used the strategy of inviting one third new individuals, one third returning individuals, and one third more senior individuals to serve as leaders at each summer institute. Their goal was to have an intergenerational approach, in which faculty who are the new individuals attending the event would be able to interact with more senior people who are returning to the event. SENCER similarly strove for an intergenerational approach by inviting newcomers as well as returning individuals to their summer conference. They encouraged delegations from institutions to include individuals at different career stages when attending the annual conference and applying for their mini-grant program.

Another strategy for building community is to have two-way communication. Too often, intentional communities can be hampered by one-way communication, where individuals in the community receive communications, but they have few mechanisms for communicating with the leadership. Over time, each community we studied developed mechanisms for obtaining feedback, ranging from surveys, time at the end of events for open dialogue, and follow-up after attendance at events. For example, PKAL has a tradition of ending each event with people sharing how the experience has had an impact on them and allowing them to provide feedback to improve the experience for future participants. The POGIL Project has a feedback form that they provide at every event called the Strengths, Improvement, and Insights (SII) tool. The SII garners feedback to improve all of their events and to better understand the changing needs of the people in their community.

Another major strategy for building community in each of these CoTs was to invite individual participation in various activities. SENCER, for example, invites individuals to present at the summer conference, to submit mini-grants, to apply to be leadership fellows, to submit to the SENCER journal, and to create course modules for the library. BioQUEST reaches out to individuals to publish articles based on their work at the Summer Workshop, to participate in submission of new grants to develop materials, to work on creating new teaching tools, and to present at various conferences about new teaching materials. They do not wait passively for individuals to submit materials

or provide ideas for possible grants; rather, they actively reach out to individuals on an ongoing basis to invite their involvement in these activities, thus building engagement with the overall community.

LEADERSHIP DEVELOPMENT

Over time, as the communities developed, there was recognition that new faculty wanted to be mentored and supported in conducting this work. Simultaneously, the CoTs recognized that they needed faculty to lead events, to create materials, and to develop new grants. As a result of this dual awareness, these communities came to recognize the importance of developing leaders. Leadership development is linked to the rhythm of events for different levels of participation, as we discussed above. All the more advanced modes of participation—such as presenting at workshops or conferences, working on grants, serving as mentors, being asked to publish, gaining opportunities to be visiting scholars, serving on advisory boards and committees, and receiving recognitions such as fellowships—are venues for developing leaders and sustaining them within the communities. Many of the faculty we spoke with said that they would have been less likely to continue participation if there had not been ways for them to give back to the community. Leaders in these CoTs recognized the need to create opportunities for participants to play leadership roles to maintain the engagement of individuals who had contributed to advancing ideas and practices. Additionally, these advanced faculty members expressed interest in giving back to their communities. The CoTs responded by providing a variety of opportunities for this next level of engagement.

Most leadership development we encountered in these communities was informal, offered through opportunities to engage in presentations, mentoring, and grant activities. However some of the CoTs also have created much more formal leadership development activities. For example, PKAL's Summer Leadership Institute was aimed at fostering the skills of individuals who could go on to create institutional and departmental changes. The skills participants acquired in workshops such as these were also critical for their growth as leaders within the CoTs.

DISTRIBUTED LEADERSHIP

The CoTs in the study recognized that distributing leadership was essential for the growth and health of the community. To distribute leadership meant that a large cadre of faculty participated in leadership development activities, enabling them to become key contributors in planning events, creating publications and materials, serving as mentors, and playing the many important roles necessary for these communities to grow and thrive. While each community began with a small group of dedicated leaders, as the communities grew during the maturing phase they recognized that there would be no way to serve their members well without delegating responsibility. This was the impetus for these leadership development activities described above.

For example, PKAL developed a group known as the village elders that provided mentoring to various faculty, served on advisory boards, and presented at meetings and events. This group of individuals grew over time to perform all of these beneficial activities and roles within the community. In turn, SENCER fostered leadership by setting up regional innovation centers and by training and developing leaders for each of the centers. They also established regional networks and provided leadership training to support individuals working to grow these networks. POGIL used its annual national meeting to bring together a large group of rising leaders, and the community worked to ensure that leadership was distributed among this group. With this broad base of leadership, POGIL continue to develop materials, create new grants, reach out to new groups, and strategize about the future of the community.

Stewardship

Stewardship is about making the community sustainable over time. This was such a larger area of our findings that we devote section 10 entirely to the concepts and recommendations that emerged. The focus on sustainability developed organically for these communities, as their growing impact made clear the need to secure the continuity of their work. For these four mature CoTs, sustainability was central to the task of meeting goals and increasing impact, as we discuss in that section.

Transformation

As noted in the literature review on communities of practice (see section 2), transformation is the stage when a community faces a crisis that forces it to reexamine its purpose and whether it should continue. Two of the communities in our study, PKAL and BioQUEST, underwent transformations, and they have continued to grow dynamically after that process. We will describe their stories.

PKAL's longtime leader retired, and the community needed to find a new home for its work; it eventually became a part of AAC&U. The advisory board for the community underwent a process to examine whether the organization still served a purpose and should continue. In response to the retirement of the longtime leader, who had provided so much support, and the known difficulties ahead of finding new leadership and a permanent home for PKAL, the advisory board went on a long soul-searching process to examine the degree to which PKAL still had an important and distinct role to play in STEM reform. While they recognized that many different groups were now focused on pedagogical innovation, they identified that there were no other communities focused on leadership development in STEM. They also observed that PKAL's strong focus on diversity was not embraced or championed by other groups. Through an examination of their work, the advisory board identified that there was an important need to continue the work of PKAL, and they ended up embracing their transitioning to a new leader and a new home.

BioQUEST underwent two successful transitions of leadership, but its primary transition was precipitated by financial uncertainty. The tight budget times and difficulty obtaining grants in recent years forced the community to examine its purpose and to determine whether it should become a nonprofit, and whether it had enough support to continue. Over the history of this community, there have been several transitions of content and priorities, including the shift from focusing on computer simulations to using other forms of technologies to create engaging pedagogies and curricula. When BioQUEST began, there were almost no other efforts focused on this type of pedagogical approach. Through the reflection necessitated by the financial climate, BioQUEST assessed the landscape and found that their approach remained unique and viable; as a result, they have created a nonprofit organization to continue supporting the community.

Summary

This section described how these communities of transformation generally follow similar trajectories, as they recognize their *potential* for approaching a STEM reform problem, *coalesce* around the issue and begin to form community, *mature* into full-fledged communities with expanding impact, and *steward* the community onward. In response to the inevitable demands of change over time, communities are eventually forced to reflect and *transform* accordingly.

Some of our findings related to the maturing and stewardship phases provide useful information for future communities. We describe these findings in more detail in sections 9 and 10. First, we turn in section 8 to common challenges these communities encountered over the course of their evolution.

VIII. Common Challenges in Evolution

Over the course of their lifecycles, not only did these communities of transformation (CoTs) follow certain common strategies and activities, but they also experienced some common challenges. These challenges could not be charted to fit neatly into particular stages of the lifecycle. For example, funding was a problem for some in the *potential* phase, but it also influenced communities when they were *maturing*, and again played a role in the transformation stage. Similarly, the challenge posed by a shift in content focus can occur as a result of the expansion of membership that takes place in the *maturing* phase, but it might also occur later, during *stewardship* as well. We identified from our research 10 key challenges experienced by these communities that are strongly related to the sustainability model we will describe in section 10. These challenges are: funding, shifting focus, leadership becoming too identified with an individual leader, the tension between focusing on the community and focusing on projects, staleness, seeking legitimacy, counteracting the dominant culture of science education, maintaining personal and community integrity, the tension between focusing on general faculty development and focusing on a specific technique, and increasing demands on faculty. Where we observed that the communities developed solutions to these challenges, we highlight those strategies in italics to guide future communities.

Funding

In general, funding obstacles required strategic trade-offs and created challenges related to having enough staff, being able to create needed materials, and being able to support community members in meaningful ways, such as by hosting quality events to help them to accomplish their goals. All four CoTs encountered funding challenges at various times in their lifecycles. In response, some networks altered or expanded their domains of knowledge to pursue funding opportunities. For instance, one SENCER participant stated that the community was only able to survive because of its ability to branch out to different areas of instruction—general education areas, graduate courses, new chemistry courses, etc. SENCER branched out in this way "because all of these different areas provide new initiatives for funding."

Funding challenges often affected the community indirectly, through impact on network events and meetings that needed to be cancelled, downsized, or held in inconvenient locations. Some community members were directly affected through the elimination of travel grants and reductions in salary, and a few project leaders continued to work without receiving salaries. According to one participant, PKAL's principal investigator never received a salary, but would actively seek out funds for the staff. One CoT leader explained that, when "you care so much about one another's lives," the struggle to keep things going when salaries have been cut is particularly difficult.

Funding struggles tended to impact CoTs the most by limiting their ability to hire and retain administrative staff, to recruit new members, to develop new leadership, and to train community members to develop materials. Despite their grassroots beginnings, all four CoTs engaged in recruitment efforts to disseminate their STEM reform missions to larger audiences (described in section 9). These expansion efforts were much easier to sustain in the early days, when the pool of participants was small, but when the communities began to grow, grant money became insufficient—not enough to support experience that would foster strong ties or develop and disseminate best practices. The CoTs took a variety of approaches to solving funding challenges, but the common theme that came through in interviews was that it is *important to maintain flexibility in goal setting, and openness to new ideas and funding opportunities*. Uncertain financial futures sometimes prevented the CoTs from becoming over-committed to their reform goals. Though each CoT began with a particular articulation of the need for STEM reform and a mission to contribute

to that task, they have each had to evolve and adapt over time in order to secure funding and persist. Adaptability is one feature that has contributed to the success of these CoTs, and the ability to adapt without losing touch with that original mission has been crucial to their sustained impact.

It is important to note that many of the other challenges described below stem from issues related to funding. In pursuit of funding, communities can shift purpose, become too project- rather than community-oriented, and try to expand to new groups/institutions/disciplines for which they do not have adequate support. It is important for organizations that support these communities to understand these dilemmas that arise from funding shortages. Funders and other support organizations can alleviate many of these challenges by offering strategies for navigating funding obstacles, such as bridge funding, on-going support through a sustained financial model (see sustainability section of this report for examples), or partnerships with other funding organizations to continue support for CoTs that demonstrate promise. Our study uncovered "piecemeal" strategies that CoTs utilized for navigating funding challenges, but we recommend that CoTs in partnership with funders develop more systematic solutions for how their communities can be continuously supported and maintained.

Shifting Focus

Related to the need for flexibility, some of the CoTs encountered obstacles when attempting to shift the focus of their work. Shifting focus refers to the intentional adaptations that these communities undertake in response to changes in the larger environment surrounding STEM reform. These environmental inputs included financial constraints or interests of potential funders, needs of the community, and needs of students. For example, the POGIL Project decided to commercialize their materials as a solution to unpredictable funding mechanisms. To do this, the community shifted its focus from college chemistry to high school science classes, and community leaders developed a curriculum that they could market to school districts, thereby generating sufficient revenue to sustain themselves. Problems arose for the POGIL Project because high school curricula did not conform to the principles endorsed in the original mission, and this area of work "wasn't specifically written into the original grant funding [the community]." One leader explained that "there was this desire to be faithful to not only the grant and the funding, but to the original idea" The tension arose between this sense of loyalty and the need to continue to grow. For the communities that attempted to shift focus and expand to new membership and new domains, a primary challenge arose as they tried to find the leadership and expertise necessary to steer them into these new territories, to draft materials for these subjects, and to attract diverse, new community members. This challenge highlighted the tension between pursuing viable, secure avenues for the community and being opportunistic about new possibilities. At times a CoT made the mistake of following a new area or expanding to a new group simply because the opportunity existed. The pursuit of such a new direction without consideration of the community's overarching mission led to turmoil and challenge.

Funders and other support organizations can alleviate many of these challenges by offering strategies for navigating funding obstacles, such as bridge funding, on-going through a sustained financial model, or partnerships with other funding organizations to continue support for CoTs that demonstrate promise.

Communities that encountered these challenges overcame them by reflecting on their purpose, and by deciding how best they could serve their community with limited options. The decisions were often difficult, requiring the CoTs to decide between the immediate needs of community members and the needs of the community or mission itself. It will become apparent in the review of the sustainability model in section 10 that these challenges could only be navigated successfully through obtaining on-going feedback and assessing work. These were ways for community leaders to reflect on their practice and to ensure that they shifted when needed, but also maintained the essential focus. *Another strategy for a successful shift in focus was to communicate clearly with the community about the rationale behind a possible change in direction.* For example, BioQUEST let faculty know that its shift from curricular development to faculty development was in response to a need to disseminate ideas more broadly.

Community Leadership Too Much Identified with an Individual Leader

Each of these communities was started by a charismatic individual, who became strongly identified with the community as its driving force. Over time, though, each community realized that it needed to distribute leadership, a step that became critical to sustaining the community in the maturing and stewardship phases. However, each community experienced a challenge associated with shifting authority, decisions, and identification to a broader set of individuals. The role of voice or spokesperson for the community was often narrowly embedded in a single leader or two. Various faculty members commented: "When you think about PKAL, you think of Jeanne Narum"; or "SENCER would not be SENCER without David Burns"; or "John Jungck was a really influential leader and father of BioQUEST"; or "Rick Moog—he lives POGIL; he is what people identify with."

The leadership challenge was to maintain the strong, charismatic leadership that inspired people to join and engaged current members, but also to distribute the leadership so that in a time of leadership transition, or health leave, or another situation in which the main leaders could not meet the needs of the community, there were others who could effectively do the work. For the POGIL Project, the annual steering committee became a venue for training leaders and distributing leadership to a broader group. When we observed this meeting, we noticed how core the POGIL Project leadership was spread over seven or eight faculty members, with each one equipped to make key decisions and also to speak as the voice of the POGIL Project. These individuals led strategic planning efforts, gave regular presentations, and headed major grant projects. Another example of distribution of leadership was BioQUEST's effort to create a leadership team as John Jungck stepped down, rather than to just replace him with a single individual as leader. Similar to the POGIL Project, a subset of individuals began planning events, giving presentations, and defining strategic directions for BioQUEST. Thus, *the key strategy for overcoming the challenge of distributing leadership is to create a structure that locates leadership within a team, steering committee, or planning group, thereby expanding leadership and creating infrastructure for further leadership development.* It is worth noting that advisory boards did not appear to offer enough of a structure to achieve this purpose, as they still often relied on an individual leader who remained the seat of decision-making.

Project-Focused versus Community-Focused Decisions

The urge to pursue particular opportunities—often because of funding—can result in a community becoming project- rather than community-focused. Often a grant-funded project focuses on a particular idea—interdisciplinary teaching, involving informal educators, integrating more math into teaching a science discipline, a geographically-oriented service project, etc. The reason for the narrow project focus is that funders desire new areas to be explored and are reluctant to continue funding a good idea to be disseminated and continued. However, even when such funding streams were directed at tangential projects, they usually allowed the community some infrastructure money to help it to continue its core work. While these types of projects generally became incorporated into the broader community ideas for improved practice sooner or later, the faculty described them as projects that they either "did not see as central to the community" or "were waiting to see the purpose." This led the leaders of the CoTs to spend a significant amount of their time and energy on the task of shepherding such project through the community, as opposed to working on fostering the overall community. Accordingly, there was a concern expressed often among faculty that the community received less attention when various projects mounted. Faculty were typically interested in the philosophical underpinnings of the community and its space for improving practice, not in its particular projects or initiatives. Yet, the communities needed to secure funding in order to support the infrastructure to hold their annual events; grant-funded projects provided the way to make these community events happen. One CoT leader described this challenge: "You can't get funding for helping faculty improve their practice in general. So we have to write these very specific project proposals. We know that this has us focus then on these projects, but there is no other way to stay afloat. We tried writing more general grants, but they never get funded." Compare this perspective to the way a faculty member describes the feeling as leaders pursue their grant projects: "I worry about the community; they don't

see themselves in some of these new projects. I see less and less people continuing their involvement. This will become more of an organization that people cycle through rather than an on-going community." *The communities in this study addressed this challenge by ensuring that some project funding went to more general support for the community. They also worked to translate grant ideas into more general lessons or ideas that would have resonance with the larger community.*

Staleness

All of the communities dealt, to some extent, with the sense of staleness that arose after the first wave of enthusiasm in the work faded. Across its ideas, leadership, and written materials, as a community widens its boundaries it risks diluting its intensity, as "changing markets, organizational structures, and technology can render the community's domain irrelevant" (Wenger et al., 2002, p. 109). For instance, one SENCER participant complained of attending the same lecture at multiple events: "I feel like they have evolved, but in some ways maybe not as much as I'd like to see, because it seems like we're still relying on the same [ideas]…what was great in 1990 [is] not the best thing since sliced bread in 1998." One BioQUEST participant stated that "new people are not as powerful a force as you might think because the collective group that is committed to volunteerism has to also be committed to being self-critical" and to reflecting on "what's not working or what's working well, what's changed as an external dynamic that you need to adjust to." Staleness can prevent communities from evolving. Interview participants suggested that successful communities must remind themselves that they "don't know everything," and these communities should "never get to the point where we think that [they] know exactly how things should be and how people should do things."

Solutions to staleness depended on the particular cause of the problem. *For some communities, stale leadership was a barrier to growth, so new leaders and new voices were essential to community survival.* One leader stated, "the biggest challenge is to make sure that new leadership comes in," but it is important that leadership does not stray too far from the original vision of the community, because this could turn away long-standing community members. For some, the primary concern was in fact keeping their mission and philosophy intact. As a result, *these communities dealt with staleness by using technology and new ideas to develop new tools, thus changing their approach while retaining their philosophy and identity as a community.* Note, however, that solutions to staleness can also lead to other challenges in the future, such as balancing grants in new project directions with the ongoing needs of the existing community, as discussed above.

Legitimacy

Legitimacy is best described as recognition by dominant institutional structures. The dominant structures that define legitimacy for these CoTs are the norms and values that govern the mainstream academic community. Due to a multitude of factors, all four CoTs to some degree lack legitimacy in this sense. One of the primary reasons for this is their focus on teaching and pedagogy in the higher education community. As most CoT members at the time of this research were faculty members employed at post-secondary institutions, participants often felt pressures from their colleagues and administrations to focus on different aspects of faculty life, such as research and grant funding. Faculty members who concern themselves primarily with teaching tend to exist on the periphery of dominant structures in academia. For instance, one SENCER member described the community as comprised of "fringe faculty." SENCER members were "the ones who were not avoiding the complex issues, like climate change, or acid deposition, or habitat fragmentation, or equity issues. You know, so we started out as a fringe faculty, but we believed in what we were doing." One POGIL Project leader stated that "beginning chemistry instructors have told me that, if they were to try to do any of this POGIL stuff, they would not be given tenure." The legitimacy challenge was closely intertwined with recruitment and engagement, as a lack of community legitimacy tended to deter potential members who sought acceptance through dominant institutional structures, like research and publishing.

The communities tried to address this deficiency of legitimacy for their members by creating awards, providing fellowships, awarding seed funding and grants, and offering other ways to recognize members of their community. They also gained legitimacy by working with national organizations such as the National Academy of Sciences, and by recruiting influential faculty leaders. The communities additionally bolstered legitimacy for their approach to STEM reform by engaging in research to gather evidence of the efficacy of their work.

The Dominant Culture of Science Education

Members of each CoT identified a shared cultural challenge common across efforts to reform STEM pedagogy. Participants reported that the science community values content knowledge as the most important principle of education, so efforts to improve teaching were resisted if they threatened ideas about what material would be covered in class. This cultural aspect of the art of science pedagogy was noted as an issue that each community had to navigate in order for their community to engage faculty, to obtain buy-in, and to help faculty engaged in innovations to be successful on their home campuses. *The communities addressed this challenge by questioning this assumption (and providing a rationale for why it was not valid) and equipping faculty with counter-narratives to help them argue in support of their approaches to teaching.*

Maintaining Community Integrity

A common theme across the data was the struggle the communities faced between staying true to their original missions and evolving or adapting to changes in their environments in order to survive and sustain themselves. The challenge of maintaining integrity refers to the tension that arises when the orientation of the larger STEM community is not aligned with the needs of the particular CoT and its members.

For some of the CoTs, these challenges manifested as matters of loyalty—some had difficulty sustaining the same kind of personal commitment from their members that they had inspired in the early stages. For instance, PKAL's grassroots beginnings attracted a community of deeply devoted followers, but after PKAL's merger with AAC&U, there were concerns among the community members that the people and traditions at the heart of PKAL would be absorbed by the larger organization. One participant stated, "Because it's such an old [community], and there are such deep loyalties, to move so quickly with changes and new initiatives would have been a mistake, I think, without really having a deep appreciation for those traditions and what they mean to the people who hold them so dear." A similar struggle emerged for the CoTs that had developed regional groups as a strategy to counteract the challenges of geographic distance. For example, SENCER's regional centers were successful in some regions and not others, mainly because participants struggled to feel connected to the larger purpose within their separate centers. Community leaders described the difficulty of developing a cohesive identity that could translate from the national to regional groups; effective leadership of the regional centers largely depended on this identity. One SENCER participant reported, "The faces of the regional projects are not necessarily people who connect and foster community in quite the same way. And so I never felt a connection to the southern center, I never felt compelled to participate in stuff down there."

The most effective solution to the challenge of maintaining integrity is flexibility – the ability to adapt to uncertain environments. This often required self-reflection on the community's mission and philosophy, and conscious decision-making about which aspects of the community, if any, can be compromised in the interest of survival.

Other challenges of integrity tended to accompany the management of knowledge and materials in the face of growth of the CoTs. As all of the communities expanded from their grassroots origins, they had to evolve in order to remain relevant to the communities that they served; with continued growth, this became a more difficult task. According to Wenger, McDermott, and Snyder (2002), "established communities regularly experience a tension between developing their own tools, methods, and approaches and being open to new ideas and members" (p. 104). New members were essential to ensure growth, and growth was necessary for survival. However, new members brought new ideas, and in order to benefit from these ideas, the community needed to display a certain degree of flexibility in both its structure and its knowledge domains.

The most effective solution to the challenge of maintaining integrity appeared to be flexibility—the ability to adapt to uncertain environments. This often required self-reflection on the community's mission and philosophy, and conscious decision-making about which aspects of the community, if any, can be compromised in the interest of survival. For example, in order to maintain its unique identity and approach, the POGIL Project began to brand its materials. The community leaders determined what distinguished the POGIL Project activities from the non-POGIL Project activities, and they began to certify materials based on standardized requirements. Another example is PKAL, which was able to grow while maintaining existing ties by respecting long-standing traditions, and by asking that members acknowledge their new role "to explore new things for PKAL, new directions, expanded directions, but to do that while also honoring what PKAL has historically meant to those who have been involved."

Focus on General Faculty Improvement versus a Specific Pedagogical Approach

Each of the communities, with the exception of the POGIL Project, focuses broadly on using evidence-based teaching practices and on improving teaching, but not on single, specific techniques. Even the POGIL Project, which had a more particular approach, reported movement away from a "pure" POGIL Project approach toward the broader inclusion of evidence-based, active-learning strategies. The other three communities advocate for a broader philosophical re-orientation in STEM education: to think about teaching as a scholarly activity, to consider and reflect on teaching, and to review and inform one's practice after considering a variety of approaches that may fit different styles, disciplines, or purposes. One faculty member commented on this challenge: "When I first was introduced to PKAL, I was confused: What were they advocating for? I was looking for a specific idea, and they offered many different ideas. And, over time, new ideas kept being introduced. Not until I fully understood what was being asked of me—to consider and reflect on my teaching, not just to adopt a practice—did I appreciate or understand. I know that it is hard for other faculty to understand as well."

In order to address this challenge, the CoTs *developed partnerships with members of the teaching and learning improvement community who provided a language and framework for their work.* For example, the POGIL Project invited many faculty who conduct research on teaching, identified as discipline-based education researchers (DBER), to join and inform the community. These faculty attended the POGIL Project's leadership events, including their national steering committee meetings, and helped the community by communicating this broader approach to improving teaching practice. PKAL also involved DBER faculty and invited them as speakers at events. Similarly, BioQUEST partnered with individuals from the faculty-development community to help introduce a shared language and a network of people who could provide advice from the scholarship of teaching. Beyond these individual community efforts, the STEM community as a whole is becoming increasingly familiar with the scholarship of teaching, informed by recent reports from the National Academy of Sciences (2012) on the history of DBER, as well as by key findings shared by other high-profile organizations. This sector-wide shift provides a stronger foundation for the work of these first CoTs focused on general teaching improvement. Leaders in the CoTs were careful to note, however, that *communities need to bring in "mainline science" faculty to remain legitimate, not just gather together a subset of faculty viewed by the disciplines as 'science educators.'*

Increasing and Changing Demands on Faculty

A growing challenge for these CoTs relates to the changes in faculty workforce. First, each community noted that faculty are increasingly employed in contingent positions (70% of faculty nationally) and that this trend is prevalent across all institutional types and most disciplines, particularly math, chemistry, and biology (for more details about these trends see www.thechangingfaculty.org). Contingent or non-tenure-track faculty are typically given no funds to support professional development, which makes their involvement in these communities problematic. Leaders within the CoTs noted their concerns about the future of STEM reform: "How will we continue this work when the majority of faculty do not have positions that allow them to participate as professionals and improve their practice?" Unless there are shifts in institutional policies and pressures from outside, faculty will not be able to benefit from these communities.

Second, tenure-track faculty are pulled in many directions, are increasingly overloaded with institutional service and leadership, and are required to obtain more grants than they were in the past, making involvement in these communities challenging. As a leader in one of the CoTs commented: "It is harder and harder to get the attention of the up-and-coming generation; they have less time and I fear for the future of communities like ours, given the current trends in faculty hiring and the demands on young tenure-track faculty."

Third, in certain sectors, such as community colleges, faculty are stretched and overcommitted to the point that it is hard for them to find the time to improve their teaching. Heavy teaching loads and year-round teaching can make professional development a luxury that is out of reach. BioQUEST has been working with community colleges for nearly a decade, and it understands the struggle of faculty in this sector to become and remain involved. In general, however, while this is an important and evolving challenge, the CoTs have not intentionally addressed the changing needs and demands placed on the faculty today.

Summary

The communities of transformation in our study encountered many of the same challenges as they evolved and grew as communities. Understanding and acknowledging the challenges these communities face, and the strategies they use to respond, can help future communities as they encounter similar challenges. While many of these challenges can stem from funding issues, they each pose unique problems to be solved by growing communities; we have tried to highlight some of the most effective strategies above. In the following section, we describe the ways in which the CoTs in our study expanded their scope in the maturing stage by focusing on new areas, such as disciplines and educational sectors, for pursuing STEM reform.

IX. Expansion Strategies: More on the Maturing Phase

As noted in the last section, we identified a host of avenues that the communities of transformation (CoTs) used to expand during the maturing phase. Given that communities of practice (CoPs) often tend to be more localized and rarely have the stated goal of expanding widely, the literature on CoPs does not have much information about expansion strategies. Our study is the first to document these types of expansion strategies for communities of this nature. This section builds on section 5, which described outcomes of the CoTs and the broader impacts that they have had over time. The expansion strategies outlined in this section provide more detail about how CoTs can have an impact across many spheres—disciplinary, national, and even international.

The communities in our study adopted six foci to spread reforms and promote growth; we have used these foci to organize the results sections below. The six foci are *disciplinary, institutional, sector-wide (e.g., liberal arts, research university, etc.), constituent-based, national, and international,* and we present them in this order, expanding outward from the most local to the widest scope. This can be visualized like the layers of an onion (see Figure 9.1). All of these foci must inform efforts to deepen and spread STEM reform, and we hope that this section assists future STEM reform leaders to grapple with them. In Table 9.1, we present a summary of the findings for each focus; within each focus we include information related to growth, strategies, leverage points (arising from strengths, capabilities, or history), and related challenges. In this section, we describe and document the various approaches to STEM reform in each of these areas. The CoTs' stories of the maturing phase demonstrate how communities decide on strategic approaches that build on their emergent strengths. These types of community efforts have not been captured in any other study. These collective approaches to learning can also be considered as an expansion of the traditional literature on CoPs, offering a new set of growth strategies not found in earlier studies.

Leaders of each CoT connected their interest in expanding their communities with their aspirations to meet the needs of STEM reform, but they reported that they were not aware of the multiple levels or foci from the outset. They described how knowing about these foci would have been helpful to their expansion, sustainability, and success, which is why we have decided to highlight them in this section. While this section outlines the strategies, leverage points, and challenges connected to each focus area, we direct the reader to our paper on the maturing phase (Kezar & Gehrke, 2015b) for more detailed analyses.

Disciplinary Focus

Two of the communities—the POGIL Project and BioQUEST—used disciplinary or professional societies in their approaches to achieving STEM reform. The assumption underlying this strategy is that disciplinary societies strongly shape the teaching norms within their respective fields, and that by working through them it is possible to effectively alter the approaches to teaching within different fields. There were four main strategies these CoTs used within the disciplinary focus: *developing textbooks, developing other materials, conducting meetings at disciplinary societies, and obtaining grants that were focused on reaching new disciplines.*

The POGIL Project created a partnership with a publisher in order to develop a series of textbooks that use the POGIL Project activities for different disciplines. By developing textbooks, they aimed to spread the POGIL Project by making the resources and materials readily available, noting the importance of working with publishers that provide marketing for textbooks. In addition to textbooks and publishing agreements, materials and resources related to an innovative teaching technique were also placed on websites (particularly in searchable databases) so that faculty

from different disciplines could identify activities and resources to include in their classrooms. For example, BioQUEST has created an extensive collection of materials that are searchable on their website, including case studies, Microsoft Excel activities, and computer simulations, all targeted to specific disciplines and usable to meet the needs of various biology or chemistry courses.

In order to ensure that faculty in various disciplines use these rich resources, both of these communities put together presentations regularly at disciplinary conferences and guide people to their textbooks and free online activities and materials. Over the years, they have also had booths at disciplinary conferences that describe their materials. However, in order to continue to create materials to address the needs of various disciplines, grant funding both of these communities have relied on grant funding, and they have also sought out grants to develop activities and textbooks as they move into new disciplines. One POGIL Project leader described an experience with a subgrant that was pivotal to expanding into a new disciplinary area: "One area [in which] we weren't doing much work was mathematics, and now we have a grant to develop the POGIL Project materials for Calculus, which is a huge area on every campus." Individuals involved with these grants worked not only to spread the POGIL Project ideas through the new materials, but they also often became leaders within their disciplinary communities as a result of involvement in these grants. This helped them to spread the word amongst their colleagues. Thus, the grants served a role in terms of creating new leadership within new disciplines.

Leadership in these two communities described the challenge of expanding into new disciplinary societies and working to maintain a presence across various disciplines. Each community had initial success within a single discipline, but then struggled due to overextension of time, leadership, and resources, as they attempted to expand or even to maintain their presence within that discipline over time. Various leaders talked about the importance of moving in new directions only where there is clear leadership and energy: "We recognize that if there is not a critical mass of interested faculty, then going in a new direction, even when there is a desire, just won't pay off. You also have to have materials that resonate with that discipline and that is hard before you develop leadership there. So we are more cautious now and really weigh not just is there a need, but are there leaders and people willing to put in lots of time and energy into a new area."

Institutional Focus

Two of the communities decided to focus on creating STEM reform through institutions by encouraging the spread of practices across science departments within particular campuses. The assumption behind working with institutions is that they establish the reward structures and policies to which faculty must respond; therefore, without working with institutions, reform is unlikely. The vehicles or strategies for an institutional approach included *having teams of faculty and administrators attend events, forming institution-based grant projects, utilizing consultancies, supporting general or broad curriculum-based projects, and emphasizing leadership development.*

Both SENCER and PKAL have a practice of inviting teams of faculty and administrators to attend their annual conferences, events, and symposia. One leader described the way these campus teams were pivotal to their reform approach: "One of the things that PKAL pushed is traveling together as a team to events, and I think that that helps the local people stay together and develop relationships. You don't hesitate to contact those people when you need advice later when back on campus." Leaders described how changes were unlikely to occur if only individual faculty members attended events and were isolated change agents upon their return to their institutions. Administrators were included in these teams, to support changes in policies and practices on campus. The events were structured so that teams returning to campus could take action to institutionalize the changes.

Another approach to STEM reform at the institutional level was to obtain grant funding for projects that were aimed at change across particular institutions. PKAL obtained grants over several decades that were aimed at institutionalizing changes through interdisciplinary teaching, active learning, or using more culturally relevant teach-

ing approaches; these grants funded groups of institutions (often 12 to 30) in projects aimed to serve as models for institutionalizing reform. These projects were designed to help spur change at other institutions.
Consultancies are a third strategy for creating institutional change and spreading reform. PKAL obtained a grant from the Keck foundation to conduct close to 100 institutional consultancies with the goal of moving institutions further along in their reform efforts by providing expert advice from experienced practitioners. SENCER established what it called "house calls," in which SENCER leaders would come out to campuses to help faculty and administrators think about ways to "SENCER-ize" their curriculum.

A fourth strategy for institutional reform is visible in SENCER's overall institutional approach. SENCER focuses on an institution-wide adoption of a pedagogy and approach to science education; it does not aim at changing single courses, departments, or even individual faculty, but in altering the overall curriculum of science and general education courses. This automatically involves many faculty across the institution, and it is focused on creating broader discussion about teaching and learning across departments.

Both PKAL and SENCER recognize that institutional changes required leadership, particularly leadership built among faculty who often lack strategies for implementing change and the skills of persuasion, vision setting, and relationship building. As a result, both communities created leadership development activities and programs to help cultivate change agents that could institutionalize the changes they were promoting.

One challenge related to the institutional focus and approach is the task of helping teams to maintain momentum when they return to their campuses. This was not always a focus for the communities studied, and it could perhaps have increased their impact on the institutional level. An additional challenge related to grant funding is that funders generally do not provide enough long-term financial support to foster institutional change; this change takes more time than provided by most grant terms. A third, more general challenge observed is that strategies, such as consultancies, were sometimes abandoned when the communities lacked the expertise to maximize them as leverage points for institutional change.

Sector-wide Focus

Several of these communities began their work with small liberal arts colleges; this is likely the result of the fact that much of the STEM reform movement originated with experimentation within this sector. Several of the communities in our study used this history, and the relationships that it left behind, as a base to spread across the sector. CoTs can encourage uptake across a significant number of institutions within a sector by leveraging national associations that work with these sectors and becoming visible in their collective dialogues, communication avenues such as newsletters and publications, and events such as annual conferences. The assumptions underlying a sector-based strategy are that different institutional types require attention to different needs and that various drivers influence sectors in different ways. Among the CoTs in our study, PKAL emerged from a consortium of small liberal arts colleges; SENCER gained traction through affiliation with the Association of American Colleges and Universities; and BioQUEST and the POGIL Project both started at innovative liberal arts colleges. In general, the focus on sector was far less central to strategy, as compared to the disciplinary and institutional foci, which were the primary drivers of decision-making. Within this sector-based approach, albeit limited, there were three relatively *common strategies* deployed: *partnering with associations, consortia, or groups that represent the sector, obtaining grants to work with the sector, and hosting gatherings for individuals from that sector.*

The first strategy, partnering with associations, consortia, or groups representing the sector, is fairly self-explanatory. Because most sectors are represented by national and regional organizations, the communities partnered with these organizations to create joint publications, to present at their conferences or meetings, and to provide communications about the work of the reform communities and its potential impact within the sector.

The second strategy, obtaining grants to work in a new sector, proved effective for several of the communities studied. For example, BIOQUEST developed a grant, called "C3 Cyberlearning Project," that worked directly with community colleges to create materials for biology courses that include active learning approaches, embedding the BioQUEST *Three P's* of problem-posing, problem-solving, and peer persuasion.

Another approach to working with a sector is to host meetings that bring together key leaders from that particular sector. For example, PKAL gathered private liberal arts presidents and key leaders from time to time to discuss STEM reform priorities in the context of the liberal arts mission. Similarly, the POGIL Project drew on its foothold in the Mid-Atlantic region by gathering faculty from liberal arts colleges in the area to discuss STEM reform and to help spread those ideas.

There were several challenges related to the sector-based approach. Sector-based grants tended to be temporary, and it could become a strain on resources to sustain those funding relationships. One respondent noted, "We have tried for years to get more grants for working with our minority-serving colleges, but funders seem to feel: 'well, we gave you that money so you should be all set now.'" Another source of difficulty arose from being solely identified with a specific sector when trying to expand the community's reach. For example, PKAL has been misidentified as exclusively an organization for liberal arts colleges, limiting its impact across sectors. Another challenge for this sector-wide approach is the task of maintaining the interest of leaders (e.g., presidents) in the sector, as they are often drawn in many different directions and have competing priorities.

Constituent-based Focus

Two of the communities played active roles in attempting to connect important constituent groups (including students, policymakers or legislators, informal educators, and teachers) that they felt helped to enable STEM reform efforts and broaden the impact of their work. It is important to describe this area of focus, because the CoTs felt that engaging these constituent groups could contribute to reaching reform goals. SENCER, for example, works to include student groups in conferences, events, and communications. Their assumption is that reform will require outside pressures or resources to be successful, and students bring this perspective. Similar to the other focus areas, strategies to reach out to constituent groups draw upon *partnerships, hosting meetings, and obtaining grants.* Below, we describe the various ways the CoTs deployed these strategies with different groups. Each constituent group affected is italicized to help illustrate the connective aspect of this approach.

The POGIL Project leaders referenced *students* as partners in the process throughout their materials and trainings, while SENCER believed that STEM reform efforts should be student-centered and should include the student voice. One practitioner told us that, "philosophically, it is important that we included students in events because this is ultimately about making learning relevant for students." Another important reform community is *policymakers*. SENCER created the Washington Symposium and Capitol Hill Poster Session, an annual event that brings faculty, administrators, and student leaders to Washington, DC, to present on the individual reform efforts that were going on at particular campuses. At the event, poster sessions are presented to congressional staff to show how campuses are changing, particularly as they work to solve public policy issues related to sustainability, health care, poverty, etc. The goal of this strategy is to gain greater support in terms of grant funding for STEM reform efforts and to encourage more state and local support for STEM reform. SENCER also works with *informal educators* from museums, libraries, and science centers. These constituents have resources and materials that can be utilized to make learning more active, experiential, and relevant for students. As a result of this commitment, SENCER obtained a grant to partner more actively with informal educators and to host them at conferences. The POGIL Project leaders also actively work with *high school teachers*; they have obtained several grants to bring their teaching methods into different school districts and develop high-school-level the POGIL Project materials and activities.

Participants expressed several concerns with this constituent-based approach. Faculty involved with reaching out to

these new groups worried about whether these efforts added value to the existing community as well as to the new groups. Reaching out to new constituents can diffuse the leadership, energy, and resources of the community. There are also concerns about whether the CoT has the expertise and materials needed to support the new community members, and if new members will be obtaining enough value to stay a part of the community in the long term. A faculty member captured these anxieties: "Given this is a new group, not faculty, it's hard to know if we can provide a meaningful community for them. What value do we add? Will they come back? We just don't know exactly given this is not a direction we have gone before."

National Focus

All of the CoTs also worked at the national level to spread their reforms across the country and to embed it within state, regional, and federal or national groups with the power to alter the infrastructure of support for STEM reform. By operating at this wide, networked level, these communities can connect actors across disciplines, institutions, and sectors to enhance STEM reform efforts. In terms of strategies to spread their efforts nationally, STEM reform community leaders created *regional networks, developed other networks or communities, hosted broad stakeholder meetings, and participated in national reform efforts.*

A strategy used by all of the CoTs to expand nationally was to establish regional networks or communities. Typically, each community used grant funding to establish and set up a regional network or several networks and to build regional leadership. This was the initial approach used by PKAL, SENCER, and the POGIL Project. Another approach with a national focus is to host broad stakeholder meetings. PKAL attempted to create a national presence by hosting meetings in Washington, DC, with the major national higher education groups at the end of each of its grant periods.

These communities also participated or were otherwise included in national reform projects, and they used this visibility as a lever to create change. For example, BioQUEST leaders regularly were part of national biology reform discussions hosted by the National Academies and other important national groups. This participation resulted in major recommendations, such as *BIO 2010* (National Research Council, 2003). PKAL was instrumental to the creation a variety of different national networks aimed at STEM reform, each more specialized in its mission, such as the National Numeracy Network. By creating new STEM reform communities, these CoTs furthered their influence and impact nationally in the arena of STEM reform.

One of the biggest challenges to working on the national level relates to a leadership gap inherent to the iterative process. CoTs found difficulty fostering the same level of enthusiasm and leadership in the regional communities, as compared to the central community. Another challenge is that communities often devote much time and energy to engaging in the national dialogues and connecting with national efforts for STEM reform, sometimes with little attention returned to them for their work. This can create a tension for the CoT, between giving time and energy to these national efforts and nurturing the core community and its immediate impact.

International Focus

A last focus for expanding the work of the CoTs was to explore the possibilities of international outreach. To build an international focus, the communities utilize advisory boards and encourage and accept international invitations. We did not find well-articulated assumptions underlying the global efforts of these communities at present, but some participants suggested that other countries may have ideas that can enrich our own practices, and that the enthusiasm around these reforms in some other countries may actually fuel efforts back in the U.S. At the time of our research, BioQUEST had the strongest international reach and exposure, and this was a result of including international individuals on their advisory boards and making international connections to teaching and learning centers and

disciplinary leaders abroad. However, this still constituted a relatively minor emphasis in the community's work. One BioQUEST leader described how this international work developed: "John [the original leader of BioQUEST] had a lot of interest in more international issues, and we began to include international leaders on our advisory board and also started to get lots of invitations to travel and present our materials. So I think it really started as a result of his interest." But, when that original leader stepped down, there was less interest in international efforts, and the existing efforts began to dissipate over time. The POGIL Project also has accepted invitations for international visits to Australia and New Zealand, but these international connections have not yielded a systemic focus as yet.

In terms of challenges for international approaches, some participants noted that it can be problematic if this work is purely driven by a single leader. As shown in the BioQUEST example, once their leader stepped down there was limited interest to continue this work. Therefore, leaders need to have succession plans for international efforts they start—especially when the leaders are near retirement. Those trying to reach out internationally also mentioned as obstacles the time it takes to travel and the need for in-person connections to make viable CoT connections internationally. There was discussion about whether there is a way to create branches of the POGIL Project, SENCER, and other groups internationally, or if it was better for the home community to simply expand its membership outward from the U.S. For all of these groups, these international efforts were still experimental, both in terms of developing strategies and in terms of being able to demonstrate impact. This was clearly an area of growth in the future.

Summary

In this section, we described the ways in which the communities of transformation in our study expanded their work through six different foci—disciplinary, institutional, sector-wide, constituent-based, national, and international—as they sought to grow and spread their reforms. Each of these foci contained important strategies for communities to expand to reach more faculty and to scale their reforms. There is also much to learn from the challenges that arose for work in each of these areas. This work coincided with the maturing phase of the CoTs; in section 10, we turn to the stewardship phase and to a model for sustainability of communities, informed by our data.

Table 9.1: Summary of Focus Areas, Leverage Points, Strategies, and Related Challenges

Focus Area	Purpose, Strategies, & Leverage Points	Challenges
Disciplinary Focus *Used by the POGIL Project and BioQUEST*	**Purpose**: Shape overall discipline and scale throughout profession **Strategies**: 1. textbooks, curricular materials; 2. meetings at disciplinary societies; and, 3. obtaining grants focused on reaching new disciplines **Leverage point:** Access to influential disciplinary leaders either within community or through community members	Lack of expertise to develop materials and texts Strain to resources if discipline is a secondary strategy Need to maintain disciplinary alliances already gained as community presses into new disciplines Danger that a critical mass emerges within discipline too slowly, and too many resources are absorbed in effort
Institutional Focus *Used by PKAL and SENCER*	**Purpose**: Shape institutional policy and rewards to work on institutionalizing changes within institutions **Strategies**: 1. working with groups or teams from campuses; 2. institution-based grant projects; 3. utilizing consultancies; 4. leadership development; and 5. focusing on institution-wide adoption of pedagogy **Leverage points:** Partnerships with organizations connected to institutional leaders on campuses, or institutional leaders that are already part of the community	Need to support teams after they return home Without an established leadership development program, faculty may fail to translate these skills onto campus Short-term perspective of funders related to institutional change strategies Faculty leadership of community may be inexperienced with working with administrators (especially challenging for consultancies)
Sector-wide Focus *Used by PKAL, the POGIL Project, SENCER, and BioQUEST*	**Purpose**: Achieve scale by working within an entire institutional sector (e.g., liberal arts colleges), achievable by recognizing and addressing particular needs and drivers of influence for different sectors **Strategies**: 1. partnerships with associations, consortia, or groups that represent the sector; 2. obtaining grants to work with the sector; and, 3. hosting gatherings for individuals in that sector **Leverage points:** Have an entrée through connection to leaders, influential campuses, or other role models in a sector	Community can become overly identified with a particular sector and have trouble gaining recognition as relevant for other sectors Sector grants tend to be one time only, and sustaining relationships within a sector can become a strain Sector leaders change priorities regularly, and it is hard to capture their interest

Focus Area	Purpose, Strategies, & Leverage Points	Challenges
Constituent-based Focus *Used by SENCER and the POGIL Project*	**Purpose**: Scale impact by connecting to important constituent groups that enable STEM reform efforts **Strategies**: 1. partnerships with constituent groups; 2. hosting meetings; and, 3. obtaining grants to support work with constituent groups **Leverage points:** Location of community leaders in DC for access to policymakers, active leadership of students in community, and demand from a group—i.e., teachers—to incite passion in the work	Difficulty formulating a clear mission to work with these groups, often with no intangible benefits for community Difficulty measuring or communicating value added to the constituent groups targeted Challenge of maintaining connection and providing materials to support constituent group as not the primary audience or members within the community
National Focus *Used by PKAL, the POGIL Project, SENCER, and BioQUEST*	**Purpose**: Scale by spreading the reform across the country and embedding it within state, regional, and federal or national groups **Strategies**: 1. creating regional networks; 2. developing other networks or communities; 3. hosting broad stakeholder meetings, and, 4. participating in national reform efforts **Leverage points:** Concentration of community members and leaders in a particular region and connection to other networks or national efforts	Difficulty of replicating energy and culture of national community within local and regional areas Lack of local leadership or weaker leadership as compared to that which exists at national level Conflict between building national partnership or broad stakeholder meetings while maintaining support for the core, local work of the community
International *Used by BioQUEST and the POGIL Project*	**Purpose**: Scale impact by reaching out to faculty and institutions in other countries **Strategies**: 1. building international presence on advisory boards; 2. accepting and encouraging national and international invitations **Leverage point**: No real evidence of consistent leverage points in our research	Leadership interest must be continuous and not too centralized in order to maintain international connections Time investment

X. Sustainability Model: Understanding the Stewardship Phase

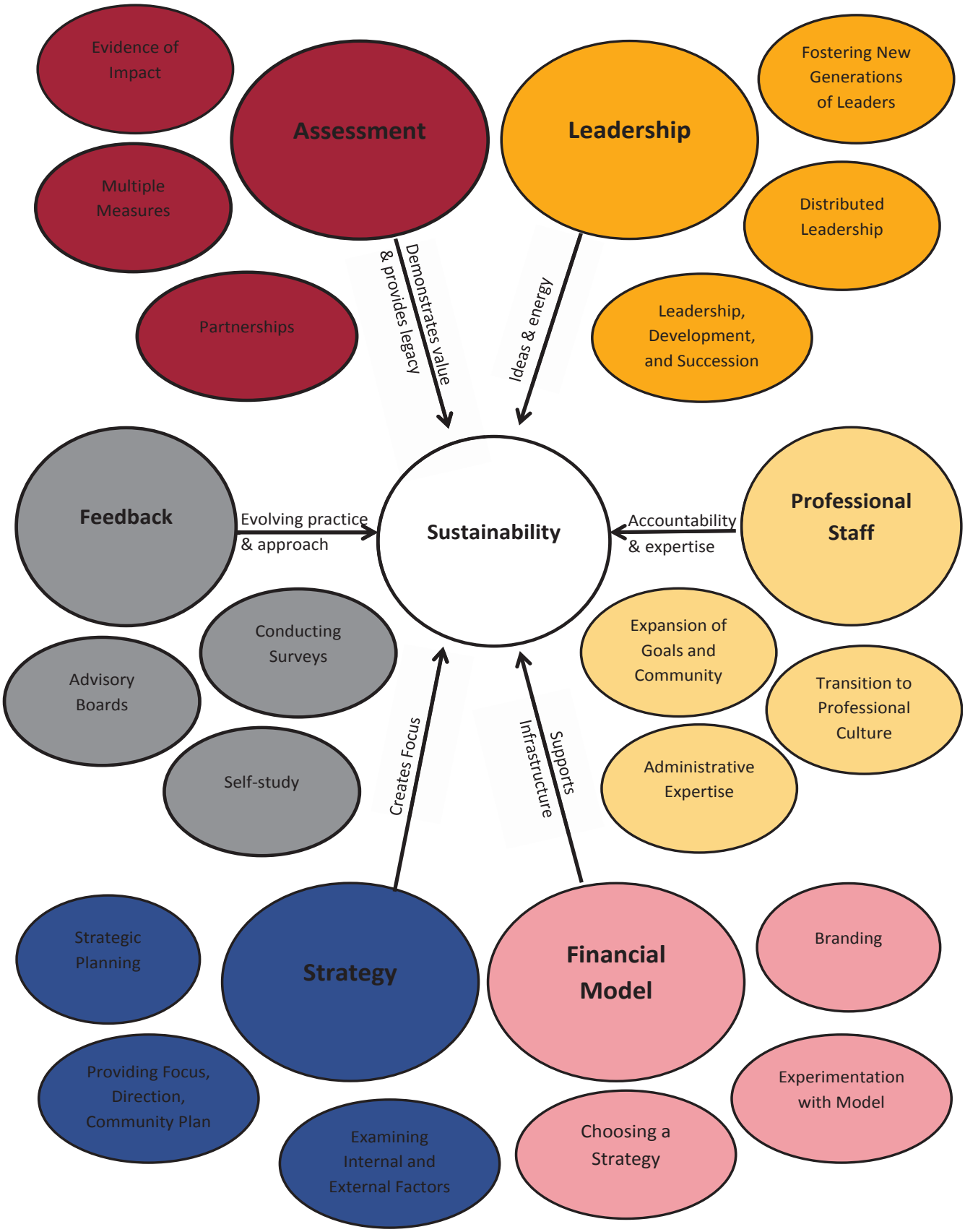
Each of the four communities of transformation (CoTs) initially started without any sense that it would become an ongoing community for faculty-led STEM reform. About five to seven years into their existence, each CoT began to realize the importance of its impact and began a trajectory towards developing a sustaining model. Viewed through the lens of the model of Wenger et al. (2002; reviewed in section 2), the communities were all in the stewardship stage at this time. Each CoT was reacting to the challenges noted in that model, and each also faced the additional concern of building infrastructure to create sustainability—this latter concern is more closely reflected in the professional learning community literature, also described in section 2. The findings of our research describe the important sustainability features that these communities formulated, and how these features enabled the CoTs to continue. Drawing on our findings, we describe here a model for sustainability for communities of transformation, with the following features: 1) *leadership* development, distribution, and succession planning; 2) a viable *financial model* (branding, distinctive identity); 3) a *professional staff*; 4) mechanisms for *feedback* and advice; 5) research and *assessment*; and 6) an articulated *strategy*. Importantly, we found that the elements of this model were represented in each CoT in our study, but often developed to varying degrees. This serves as a reminder that these CoTs are not ideal cases. Throughout the sections below, we highlight some of the challenges in each area that can make difficult the task of striving toward sustainability.

Figure 10.1 (Page 70) captures the sustainability model that emerged from our study in order to help guide future communities. Each area is identified with a particular direction needed to advance sustainability. *Feedback* helps the community to evolve; *assessment* provides legitimacy and enables funding; *professional staff* ensures work is conducted and supports accountability; *leadership* creates ideas, maintains energy, and ensures that the culture and philosophy of the community is lived out in its practices; a *financial model* ensures stability for staffing and makes it possible to stay focused on impact; and *strategy* ensures focus critical to maintaining the community identity/mission. There are often several avenues available to address each area of the sustainability model. For example, in the area of *feedback*, communities may use advisory boards, self-studies, or surveys; by offering multiple strategies, we hope to give new communities the flexibility to find solutions that fit their strengths and goals. We believe that these findings are applicable to other CoTs inside and outside higher education, specifically other non-organizationally situated communities of practice. We now review each element of the sustainability model.

Leadership Development, Distribution, and Succession Planning

A key component of sustainability is ensuring continuity of leadership through a succession plan. Our findings show how leaders in these CoTs provided the enthusiasm, passion, vision, ideas, and public face of the community. Such community leaders also helped support the philosophy and mission of their CoTs by embodying and practicing the community ideals and values. Even when a CoT had a more distributed leadership structure, participants looked to a small number of individuals to epitomize the philosophy, values, and culture of the community. While we saw how communities tried to distribute these values among a variety of individuals, sustainability seems to be dependent on having some individuals that are "central," embodying these values and characteristics. In order to support sustainability, a variety of different leadership issues need to be addressed. These include: 1) an ongoing cycle to bring in new generations of individuals that may potentially move into leadership positions; 2) the development of individuals that are part of the community to play leadership roles; 3) occasional retirement of longstanding leaders, including on advisory boards, in subgroups/communities, and in voluntary roles, in order to allow fresh ideas to emerge in all groups; 4) distribution of leadership among members; and 5) succession planning.

Figure 10.1: Sustainability Model for Non-Organizationally Situated STEM Reform Communities of Transformation



A Viable Financial Model

As non-organizationally situated communities of practice, these CoTs depended on grants for support of their work. Each CoT experienced periods during which it became difficult to obtain grants, and forcing the community to face the possibility of phasing out of existence. Also, the CoTs regularly found themselves stretching their missions to obtain funding, thus threatening the identity and shared goals of the community. Stable financing is necessary for these communities to avert these crises and continue to have an impact in their areas of reform. This is an issue that most community leaders shied away from for a few reasons: as faculty, they typically lacked expertise in business and financial planning; their communities had an ethic that supported open access, and it was frowned upon to charge for items or services; and, they often did not see the financial aspects as central to community activity. To become sustainable, each CoT considered and ultimately selected from among a variety of financial models, including: 1) becoming a membership organization; 2) selling materials or resources; 3) charging for events; 4) creating a partnership with another organization; and 5) becoming a nonprofit organization, which often included utilizing a variety of the aforementioned strategies.

A Professional Staff

The human resources of each CoT typically consisted of a few faculty members funded through a grant and an expanded set of volunteers. With some CoTs, the initial leadership was completely voluntary and unpaid, not funded from a grant or any other source. Several of the CoTs continued working for years with a shoestring staff—one or two individuals funded through grants or shared personnel with other projects. Many participants noted the challenge of working in this minimal way, and it was captured succinctly by one: "I think that we can do better in terms of our processes, procedures, and policies, and this just goes back to the whole conversation we had earlier about having internal structures within Project Kaleidoscope that kind of determine how we move forward in a systematized way. It's hard to expand when there's no structure underneath. It's hard to just rely on a grassroots approach and expand at the same time."

Yet, through success obtaining multiple grants, the expansion of the community, or increasingly ambitious goals, these communities evolved to establish a more professional form of human resources. Without the evolution to a more professional staff, communities are unable to complete the work designated in their grants successfully or to meet their larger community goals.[12] Moreover, a professionalized staff led to sustainability in each case by ensuring work completion, by establishing that appropriate expertise exists, and by maintaining accountability. In their mature form, the professional staff of these communities ensured that goals were met in order to facilitate further funding and maintained the accountability that a volunteer base often was unable to enforce. This is not to say that volunteer staffing and leadership is not essential for the success of the CoTs; rather, fully depending on volunteers makes these communities vulnerable.

Formal Feedback and Advice Mechanism

Sustaining the CoTs requires systematic feedback about their work. Communities of transformation starting organically often lacked the practice of obtaining feedback at all, or they received limited feedback; however, this changed over time. The most frequently utilized mechanism for feedback was advisory boards, but CoTs also used other forms of feedback from their members, such as surveys, formal evaluations, or self-studies. Feedback helps a community to evolve and to address challenges, thus fostering sustainability. A community leader described the importance of "be-

12 As they grow larger, communities of practice can often take on structures that resemble organizations (Wenger et al., 2002), but they are still distinctively CoPs because of the work they do.

ing self-critical and questioning our ways of operating" as one of the most significant parts of sustainability. Another community leader noted how feedback that challenged assumptions was important to success and sustainability: "And that's really the way PKAL functioned, it was to keep reflecting on testing, challenging its conception of what worked in undergraduate STEM education and then to use that vision to shape a response to whatever was pressing." Feedback can come in many forms, including: 1) advisory boards and/or steering committees; 2) surveys and other assessments that get feedback from community members; 3) two-way communication mechanisms, like social media; and 4) general reflection, self-questioning, and using a critical eye to reflect on how the community is operating and where it is going. The most successful systems for gathering feedback were those that were embedded centrally within the guiding philosophy, such as the POGIL Project's strengths–improvements–insights model, which ensured that each event and resource would garner enough feedback to allow for ongoing improvements.

Assessment/Research

Another key component of sustainability is conducting assessment or research to demonstrate the value and impact of the community over time. Demonstrating the impact of the community is significant for continued grant funding, but it also functions to demonstrate value as the community transitions to a membership organization or attempts to partner or merge with another organization. Any approach for creating a viable financial model also depends on demonstrated evidence that the community has added value in connection with its mission, goals, and/or participants. One individual shared the importance of assessment to the community's long-term sustainability: "I don't think we had any idea early on that the assessment would help with funding or creating opportunities to present and expand our membership, but it has done that, and I see how it's one of the key factors in our sustainability. I mean it makes sense that you can demonstrate that the ideas actually work." A more formal feedback mechanism, as described above, typically buttressed efforts to conduct assessment and research. These two facets of sustainability are inter-related, as CoTs can capitalize on processes for receiving feedback to develop additional and more in-depth assessment.

A Community-Derived Strategy that is Articulated, yet Evolving

Over time, each community recognized that it had a particular niche and expertise that was of interest to others. The CoTs used this understanding to center or focus their work; their work, however, was not always focused on developing this niche. At times, individual leaders decided on new directions that were outside their communities' known strengths; this led to diffusion of efforts that was symptomatic of a lack of strategic direction within the CoT. As the communities matured and moved toward sustainability, they recognized the importance of a strategic focus. An articulated strategy typically took the form of a strategic plan for the community, but it might also be a strategy document that is less formal. While planning typically was focused on developing the specialty or focus area of the CoT, leaders also had to create a plan for the community itself, addressing questions, such as: How do we continue to bring in new members? How do we continue to engage members with different levels of expertise? How do we build leadership? This is how the notion of strategy connects to leadership and staffing. A community leader noted that, "you have to plan for community as well: How do we keep the enthusiasm? How do we bring in new people? And how do we have enough critical mass? This needs to be part of the strategy as well." Creating a strategy provided an opportunity for CoTs to examine external factors that might be important for the future—for example, changes in funders' grant directions or new technologies. While the communities were always scanning their environments, a narrow group of leaders might do so selectively, based only on their particular interests. A wider strategic planning process allowed for a much broader community involvement, introducing a more representative set of external concerns to be brought into strategy development.

Articulating a strategy also helps the communities to hone their direction. Many spent time drifting along, doing the work required by the most recently funded grant rather than identifying work that was best suited for the specific community and its niche. For example, PKAL identified that its perceived strength was in leadership development, and it began to focus activities more in this area to draw on its well-known expertise. The POGIL Project identified that it needed to expand from a narrow pedagogical strategy (i.e., process-oriented guided inquiry learning) to a broader one (i.e., active learning) that better encapsulated the work of the community and would position it to reach many more faculty members. BioQUEST had long focused on simulations and complex technological interventions, but its leaders realized that they could move to simpler technologies, such as Excel spreadsheets, and still engage their philosophical approach in a way that was strategic.

Summary

As communities of transformation reach the stewardship phase in their evolution, issues and decisions of sustainability must be addressed. In this section, we described a model for sustainability encapsulating six key factors—leadership, funding, assessment, professional staff, feedback, and strategy—to inform future communities as they seek to continue their work for extended periods of time. Our findings related to sustainability, as well as those highlighted throughout this report, suggest areas for future consideration for these communities and others like them. We now turn to such considerations in section 11, where we explore ideas that could contribute to the success and longevity of these and other such communities in the future.

XI. Future Considerations for STEM Reform Communities of Transformation

The communities of transformation (CoTs) in our study have had an important impact on STEM reform, and they have increased their impact by expanding into multiple areas, such as disciplinary societies, curricular efforts, institutional change efforts, sector discussions, international efforts, and powerful constituent groups. This section is about additional areas that we identified that such communities might expand into in the future to increase their impact. The items identified below are largely drawn from our interviews with leaders across these four CoTs. They represent future directions for such communities to continue to evolve their work.

Capitalize More on Disciplinary Work

Two of the networks we studied had strong connections to a set of disciplinary societies, but many of the faculty and administrators we spoke with believed that more could be done to broaden and deepen the impact in this area. There was recognition that disciplinary societies are beginning to support teaching, not just research. With large-scale initiatives, such as the Association of American Universities' efforts to gain greater recognition for teaching, there may be greater opportunity than in the past to garner the attention of disciplinary leaders in order to support STEM reform. CoTs can work to change the dialogue and professional standards within disciplines to include evidence-based teaching practices. These CoTs are well positioned to push for change in the conversations about teaching in the disciplines. Our data suggest that one of the main avenues for faculty members to become involved with CoTs is through attending presentations at disciplinary conferences. Given that this is already a major way that CoTs are involving and engaging members, leaders within these communities might better coordinate and strategize ways to create synergy within such presentations in order to have greater impact over time. In addition, leaders within these STEM reform communities could help to establish committees or task forces focused on evidence-based teaching practices within various disciplinary societies. It is important to recognize that STEM reform is more likely to happen when multiple stakeholder groups within the overall enterprise are aligned with a similar message, such as "use more evidence-based teaching practices."

Explore Complementary Online/Virtual Ways to Foster Community

Each of these communities has experimented with various forms of technology to connect their members, particularly through social media. However, they reported that they had only mixed success with engaging faculty members. The demographic data from our survey showed that the faculties involved in these communities skew towards higher seniority. Over time, we imagine that efforts to get more junior faculty involved will result in increasing demand for technological ways to connect. As technology continues to evolve in ways that become more personal, it will become easier to ensure that the philosophical aspects of these communities—which members find so engaging—are maintained and communicated through technological means. An example to consider is the Center for the Integration of Research, Teaching and Learning (CIRTL) Network's online café course. Other technological platforms can be helpful in this area, including Adobe Connect, GoToMeeting, and Blackboard Collaborate (all virtual, video-based meeting technologies).

Focus More on Network Development

The CoTs in our study focus on community and relationship development to provide mentorship and advice for

members. They do some work to connect faculty across institutions, but they do not have intentional plans or structures for network development. When these communities tried to use regional networks for this purpose, they all struggled to get those networks off the ground. Although the regional networks were only partially successful, it is important to foster networking among members by setting up interest groups within the communities or by actively connecting faculty within similar institutions or disciplines. Although we think these communities were successful overall because of their intentional nurturing, as opposed to the more informal structure of networks, we do think that fostering informal networks within these communities could enhance and complement their work. Such networks could increase the potential for innovation to spread through the communities' membership (Rogers, 2003; Valente, 1995). More attention to the networking potential within these groups might yield additional outcomes and even greater impact and spread of ideas.

Work with Graduate Students/Align with Graduate Initiatives

None of these communities do substantial work with graduate students. While they continue to connect with faculty, it would likely benefit these communities to connect with graduate-focused efforts aimed at using evidence-based teaching, such as the Center for the Integration of Research, Teaching and Learning (CIRTL). CIRTL aims to work with graduate students to help them approach their teaching as a scholarly endeavor. The same graduate students who participate in such programs will be looking for communities to support their work once they become faculty. CIRTL has now expanded to include 26 universities, reaching the institutions that train most of the doctoral students nationally. As things currently stand, graduate students lack an introduction to the communities of transformation that can continue to support their work once they have received their degrees and begin their faculty careers. We recommend that there be greater communication between STEM reform communities and graduate student initiatives aimed at using evidence-based teaching. Graduate students may also be easier to work with on such reform effort, since they do not have deeply ingrained habits or allegiances to the status quo.

Work with Centers for Teaching and Learning on Campus

Most campuses have a center for teaching and learning (CTL) that is aimed at helping faculty to improve their practice. However, most of the STEM reform CoTs in our study do not have connections to the directors of these centers. Furthermore, they do not work with these units to recruit members or to help CoT participants to become aware of resources for support once they return to their home institutions after events. There are several advantages to working more directly with CTLs. First, they can help alleviate the isolation that many faculty feel when they go back to campus; directors of CTLs can help connect faculty with other innovators on campus. Second, by connecting many individuals who are interested in STEM reform, there are possibilities for CTLs to be a part of broader change efforts across a department or college. Some CTLs have also been successful setting up learning communities related to STEM reform. If CTL directors knew about the cadres of faculty members receiving training in these issues from CoTs, they would be more likely to set up such groups and garner institutional support for such efforts.

Work with Postdoctoral Organizations

There is a growing number of postdoctoral fellows across the country, particularly in the sciences. As more individuals move into these positions, they become another group of potential new faculty that should be mentored and trained in evidence-based teaching practices. Thus, they should become familiar with the work of the STEM reform communities. The National Postdoctoral Association would be an important group for communities to connect with in the future.

Expand Consultation Work

Three of the STEM reform communities have been involved in some form of consultation with campuses interested in more broadly institutionalizing STEM reform. While this approach was used for a short period of time, few of the STEM reform communities maintained a consulting corps to help spread and support change. None of them stopped using this approach because it lacked merit; we recommend that it be reconsidered by these STEM reform communities and adopted by future communities. This model is sustainable because individual campuses pay for the consultations, and there is money in administrative budgets to support such work. None of these STEM reform communities set up a formalized consulting corps and publicized it nationally. This could be an important resource for broader reform.

Create On-Campus Learning Communities/Communities of Transformation

Once faculty return to their campuses, they are often alone or a part of a small circle of innovators. One of the ways that the national CoTs could support local efforts is by educating individuals at their workshops and events on how to establish learning communities/CoTs back on their home campuses. Learning communities are becoming better known nationally, as there is research to support their efficacy in helping faculty to adopt new teaching practices. Learning communities can be a type of community of transformation, but they are typically aimed at meeting for a narrower, circumscribed period of time (12 to 18 months) and around a particular topic (e.g., service learning). The nationally based CoTs in our study could create workshops aimed at helping local campus leaders to develop learning communities, thus supporting faculty members as they return home to their campuses. Such workshops could draw upon the growing body of literature about learning communities and how they can best support faculty learning (see Cox, 2003; 2004).

Supporting Innovators on their Home Campuses

Another way for leaders in these CoTs to help support innovators at home is to write letters to academic leaders informing them of faculty members' involvement in evidence-based teaching practices. Communities can also create awards and fellowships to honor individuals, and they can make sure that campus leaders at participants' home institutions are aware of these recognitions. While this sometimes occurred in the CoTs we studied, it was an underutilized strategy for change. A more systemic way for these STEM reform communities to foster legitimation back on the individual home campuses will also help to seed further reform. Over time, it is important that public perceptions of the work shift; what is currently seen as innovative activity should simply become viewed as normatively strong teaching practices. Influencing the views of academic leaders on college and university campuses is an important part of this strategy.

Consider Approaches that Deeply Embed STEM Reform

It is advantageous to embed changes deeply, so that they do not fluctuate with shifts in leadership. One of the most intriguing strategies for doing this is exemplified by PKAL's work with facilities, which structurally embeds new teaching practices into the institution by reshaping the architecture of the setting in which learning takes place. Such efforts aim to change the underlying structures that prevent evidence-based teaching practices; this work is not only supportive of engaged pedagogy, but it builds reform into the institution in a way that has strong potential for persistent impact and expanded scale.

Capitalize on Other Reform Initiatives

Much of the work of STEM reform is isolated from the many other institutional learning reform efforts. Most campuses have some form of pedagogical or curricular reform efforts that are ongoing. STEM reform efforts tend to happen in isolation of these other initiatives. The reform efforts of the CoTs can be more successful when they align with the broader educational reform efforts unfolding within an institution, whether those efforts are located in general education, student support, or curricular redesign. CoTs can help faculty to identify these other reform efforts on their campuses and help them to connect in order to support their own work.

Consider Becoming a Membership Organization

Our study was able to identify several ways that the CoTs were able to sustain themselves over time (see section 10). One model that we think holds particular promise for future consideration is to become a membership organization. The Council for Undergraduate Research is an example of a community that evolved into a membership organization, now sustained by thousands of members. The size and scale of the reform CoTs in our study puts them in a position to consider this strategy to ensure long-term success and viability.

Consider a Networked Improvement Community

The Carnegie Foundation has supported reform work using a networked improvement community model in higher education. In this model, faculty and administrators work in a network of institutions aimed at similar goals. They collect and share data about improved STEM practices, create professional development activities to embed practices, and try to benefit from the power of multiple institutions working together for change. The Bayview Alliance—another STEM reform effort—uses the networked improvement community model, as well. CoTs might create similar networks among the faculty with whom they work, capitalizing on the fact that their membership spans literally hundreds of institutions, many of which have already prioritized efforts aimed at change. By leveraging their wide reach and trying to create more depth through network improvement communities, they might expand their goals of institutional change. Networked improvement communities are aimed specifically at changes at the organizational or institutional level, offering a unique possibility to expand the reach of CoTs at that level of impact.

Additional Mechanisms to Support Systemic Change

The strength of these CoTs is their ability to create buy-in and motivation for faculty to improve practices in support of STEM student success. They also help to provide individuals with a community of support in the face of departmental and even institutional opposition. We found that, as faculty move into formal roles as department chairs and deans, they also can help create change to the broader system. Particular change efforts typically do not work at all levels of the system at once; the mechanisms present in CoTs work particularly well on the ground to create individual consciousness change. However, we believe that CoTs could do more to effect systemic change at the level of incentives, promotion and tenure, and disciplinary norms. Such efforts would greatly enhance the success CoTs have already had in helping faculty members to see their potential and to become empowered to influence their institutions from the ground up. Certainly we have evidence that these CoTs have already had impact on this broader system, but we believe that they can be designed to do even more. This is the motivation behind the recommendations above, and we hope that increased work establishing on-campus learning communities, connecting with centers for teaching and learning, and training academic leaders will help to alter incentive systems and create new institutional priorities and culture.

We now turn to future considerations for research in order to expand our knowledge of CoTs and their work for STEM reform.

XII. Areas for Further Research

Our inquiry into these four communities of transformation (CoTs) reveals several areas in need of further research, particularly as we seek to understand the phenomenon of STEM education community formation and the task of scaling up reform. This section outlines several areas that would benefit further inquiry.

The Continuum from Community of Practice to Social Networks

We entered this study anticipating that some of the entities that were our subjects might reflect a network approach, and others might be more appropriately understood as communities of practice (CoPs). Through our research, however, we found that all four of the entities were best understood as communities—in particular, communities of transformation (CoTs). While the entities that we studied did not turn out to be networks, we believe that there may be reform efforts appropriate to some settings that could emerge from a more passive, networked approach. Such an approach would be defined by more informal interactions, loose structure, and a focus on fostering relationships based on common disciplines or research interests, rather than on nurturing communities like those in our study. We believe that future research should be aimed at identifying other variations of reform communities, particularly ones that act like social networks, and the challenges and opportunities of those groups. In the end, our study was able to focus on the benefits, design, and lifecycle of CoTs, and another study could do the same for networks.

Communities of Transformation

Through this study, we identified a new variant of communities of practice, which we called communities of transformation. Since we did not go into the study with the purpose of identifying and documenting the structure of a CoT, we feel that it is important that further research be conducted to better understand it as a new variant of a CoP.

As outlined in section 4, we identified three primary features of CoTs: 1. Formation and documentation of a philosophy, which is an innovative approach and radical departure from existing practice; 2. Living integration of the philosophy throughout events and activities, modeled by the leadership of the organization; and 3. A community that supports the new practice once an individual returns to a status quo community. We identified some unique aspects present in how these entities are formed (importance of formulating a philosophy), how they sustain themselves (ways that the philosophy is embedded into the design), and their outcomes (a network of change agents that helps create and sustain change in status quo spaces).

One of the important outcomes of these CoTs is that they are able to create deep changes related to STEM reform; for example, they challenge the underlying assumptions about being a scientist and approaches to conducting science. Such deep philosophical issues are often not embedded in the evidence-based teaching practices for which these communities advocate, but they emerge organically from the philosophical orientation of the work of the communities. Advocates for gender parity and improved success of minorities in STEM have identified these types of deep changes as central to the project of rethinking science and making it inclusive of broader groups of people. Much work is still needed to fully understand how these communities of transformation can contribute to the philosophical changes needed to make science more equitable. We imagine that future research can look at challenges related to

the philosophical side of these communities; for example, can it lead to philosophical divides, dogmatism, or lack of flexibility?

We also found that CoTs are not always intentional about preparing people for returning to the particular status quo cultures present on home campuses. For example, some faculty participants return to campuses that are supportive of innovative pedagogies, but the faculty are not necessarily prepared to maximize their impact in these settings. Therefore, it is important to look at the ways that these communities provide potentially different types of support for individuals that are returning to such different environments.

In addition, our study only examined CoTs that were non-organizationally located. However, this is not a necessary feature of such communities. Future research should seek to identify CoTs that may exist within organizations in order to examine their abilities to engage community members in deeper forms of engagement. Do such organization-based communities exist? Can they exist?

Social Networks within Communities of Transformation

In section 2, we reviewed the literature on social networks because the communities in our study clearly foster relationships among their members. However, our study did not focus on understanding the networks of relationships in these communities; rather, we focused more on participant engagement within the community and the ways in which community design can influence outcomes. Future research should examine the extent to which the informal networks of personal relationships formed in these communities contribute to spreading the reform strategies. Members of the POGIL Project leadership have begun this work, examining how their network of workshop facilitators has grown and their approach has spread to different parts of the United States. Social network analysis is a useful analytical tool to identify the ways in which community connections are made and grow, as well as to study the spread of adoption of these STEM reform strategies over time.

Non-organizationally Located Communities of Practice

Because the entities in our study are either not organizationally located or began outside of organizations, they face some specific challenges related to sustainability; we were able to identify many of these challenges in section 10. However, we did not go into the study considering the non-organizational character of these communities as a central influence on their design or outcomes. After seeing how the non-organizational character of the CoTs shaped sustainability, we wonder about its impact on these other areas. For example, how can the right level of mentoring be maintained within a loosely organized group? Perhaps there needs to be a balance between in-person and virtual means of connection in order to achieve outcomes in these non-organizationally located communities of practice. We did not specifically study these types of issues. Future studies should continue to explore the impact of not being organizationally located on the way these entities operate and on their ability to meet their STEM reform objectives.

Broader Impacts

Our survey was focused on individual, departmental, and institutional impacts from participation in the STEM reform communities. We initially had questions related to broader impacts, beyond the institution, but our advisory board suggested that we remove these questions to avoid cognitive overload on the individuals taking the survey and to go deeper into the impacts that were at the localized level. In addition, they advised us that individual members of the community, the target of the survey, would be less likely than leaders within the communities to identify broader

impacts. We appreciated the advisory board's advice, and we believe this was justified and important feedback. However, we also found that there are many broader impacts that these communities of transformation were able to contribute, identified in our interviews but not reflected in the surveys. We believe that continued research to identify these broader impacts will help us to understand the contribution of these communities in the long term. Currently, we have qualitative data about broader impacts, but further study is necessary to ascertain whether these findings are generalizable.

Other Approaches to Examining Outcomes

It is challenging to examine outcomes in broad-ranging CoTs such as those we studied. Because of the scale of these communities, we do not have the ability to observe changes in practice or to follow departmental changes—approaches that would be feasible in the case of a local CoP. Logistically, self-report data was one of our only viable options. One approach to measuring outcomes would be to examine institutional data from institutions at which faculty who belong to these communities work. Such research could examine if there have been noticeable improvements in objective measures, such as retention and persistence in STEM disciplines or changes to the number of STEM majors. Outcomes assessment could also be enhanced by identifying comparable institutions at which these strategies and practices are not employed, thus creating a benchmark for institutions active in these CoTs. Another approach for understanding departmental and institutional outcomes would be to survey deans or department chairs at a random selection of campuses involved. Even then, however, it would be a challenge to obtain a large sample from those campuses; surveys among academic leaders typically have low response rates. Thus, we suggest that future research focus on a subset of institutions with faculty involved in these communities. Research can then try to document changes in individual faculty, departments, and the institution broadly to try to evaluate the impact of these communities.

Comparison of Different Models of STEM Reform Efforts

Approaches to STEM reform differ in terms of their targets: some focus on disciplinary societies; others focus on institutional change (such as the Association of American Universities projects); some emphasize networked approaches (such as the Bayview Alliance networked-community approach); and others focus on individual faculty (such as the CoTs in this study). There have been few studies that examine and compare these various approaches to STEM reform, and we lack data on whether some work better for certain purposes or reasons. For example, we know from our research that the CoTs we studied are particularly important for faculty who are isolated on their campuses and do not have other reformers to work with. However, individuals who reported having a lot of support on their campuses told us they were less likely to be deeply involved with these CoTs and to have ongoing involvement. There might also be ways that various approaches and strategies for STEM reform can be aligned to support one another. Research that compares these different approaches could seek out these types of alignments and synergies.

The Tension between Stability/Sustainability and Appeal of Informal Community

We identified a model for long-term sustainability for these groups. We did wonder if, as they became more organizational and began to be more formal, the communities might lose the very features that faculty found most engaging. For example, participants identified the informal peer-to-peer work, in which ideas could be debated, as one of the most attractive aspects of these communities. Yet, as the CoTs moved in the direction of increased stability,

we could see that they lost some these types of features. Future work should examine these groups in their later, more formalized state to identify the impact on faculty engagement and outcomes associated with moving into a more sustainable, long-term model.

The Challenges of Expansion

Our research identified key avenues for expansion, leverage points to gauge which directions to expand into, and challenges of expansion (see section 9). While we unearthed some solutions to those challenges, we did not find practicable strategies to be used in every area. Future research could explore additional ways communities can overcome the challenges we identified.

The Effect of the Changing Faculty on STEM Reform

All of these communities expressed concern about the changes in the academic workforce, and particularly about the ways that these changes may impact their ability to connect with faculty. As faculty are increasingly off the tenure track, overburdened, and under-supported, how can communities initiate and sustain reform? It is important that future research explore the impact of the changing faculty on efforts to improve STEM education in general, and in particular among these CoTs.

XIII. Conclusion

As we entered this study, we were interested in understanding ways to scale efforts to improve STEM education. We leave the study with an appreciation that communities of transformation have and continue to play a central role by providing communities of support for individual faculty. Through participation in these communities, we saw lone innovators transformed into individuals who have the support, legitimacy, and camaraderie to continue their work to improve STEM within their own classrooms. We also identified how these communities support, although to a lesser extent, departmental and institutional changes as well. We charted ways that they are expanding their impact into disciplinary societies, into national groups and organizations, and even internationally. In this report, we have provided advice gleaned from our research to help communities expand their role in departmental, institutional, and even enterprise-level change.

By working on both individual and systems-level change at the same time, these communities play a unique role nationally in supporting the improvement of STEM. While their efforts currently are more effective at helping individuals, there is the capacity for these communities to grow to leverage increased change at the systemic level. Our study documented some of the systems-level changes taking place through these communities and several approaches that can be leveraged toward further impact in the future. Our research and reported findings are designed to help encourage work in this direction and to help provide a pathway for other communities that want to play a role in systems change.

By working on both individual and systems-level change at the same time, these communities play a unique role nationally in supporting the improvement of STEM.

However, it is important to note that, in some environments, a more systemic approach to change is not currently possible. On some campuses and in some environments, starting at a more local level, with a small number of faculty, may be the most viable approach. We also have evidence that the spread of good practices relies on support and connectivity offered to isolated innovators within status quo departments and institutions. The strategies of communities of transformation, namely empowering individual faculty members through enthusiasm and philosophical engagement, works from the ground up to complement other efforts to change reward structures or disciplinary values. As we consider institutional change in general, and STEM reform in particular, too often do we polarize our approaches between those aimed at individuals and those focusing on the system. Both of these approaches are required for change, and these communities of transformation offer a bridge between them. This is an important role that needs support in order to develop to its full capacity for impact in the future.

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ABOUT THE PULLIAS CENTER

With a generous bequest from the Pullias Family estate, the Earl and Pauline Pullias Center for Higher Education at the USC Rossier School of Education was established in 2012 (the center was previously known as the Center for Higher Education Policy Analysis). The gift allows one of the world's leading research centers on higher education to continue its tradition of focusing on research, policy, and practice to improve the field.

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