Mobilizing STEM Education for a Sustainable Future

Why Theories of Change Matter

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In the January meeting we will ask Critical Advisors to propose new or adapted *theories of change* that can accomplish our shared vision for higher education. It will be useful, therefore, to review some of the theories of change that have already been used in efforts to improve quality and access in STEM education and to consider why some STEM reform efforts based on particular theories of change (whether implicit or stated) may be more or less successful than others. To this end, the principal purpose of this paper is to argue that theories of change are powerful yet often unacknowledged guides for human action for change. We first explain what a theory of change is; then we present our findings from a modest preliminary study of theories of change in a small sample of projects that the National Science Foundation solicited and subsequently funded to improve STEM education. The paper concludes by discussing the implications of unarticulated theories of change for our efforts to mobilize STEM education for a sustainable future.

What is a Theory of Change?

People are, mindfully or not, theorists of change. That is, they are theorists insofar that they engage in a mental process by which they develop ideas that allow them to explain why events ought to occur (Turner, 1982). As a way of managing the uncertainty of everyday living, people rely on personal theories, or predictive assumptions, about the best ways to achieve desired effects. Personal theories about what kinds of action will bring about desired changes and *why* some actions work best are but one of many forms of a person's tacit knowledge and thus typically remain unstated. For the purposes of this project, we are working from this definition: *A theory of change is a predictive assumption about the relationship between desired changes and the actions that may produce those changes.* Putting it another way, "If I do *x*, then I expect *y* to occur, and *for these reasons*."

Theories of change can drive programs as well as people. Programmatic theories of change are relevant to our meeting because change-oriented programs and reform efforts often tacitly reflect the theories of change of the program's designers. Because reformers tend to jump from identifying a problem to choosing ways of ameliorating it, they often do not articulate the reasons *why* those strategies will achieve the desired changes—that is, the program's theory of change. **Theories of change matter because they are usually implicit, and what remains unseen cannot be questioned.**

A crucial factor in designing successful reform efforts is making programmatic theories of change explicit. Evaluators and grant-making organizations, which are especially interested in why changes do or do not occur as hoped for, have found that one powerful way to improve the chances that a set of activities or program of action will succeed is to help the organizers specify the reasoning that serves as their theory of change (Connell & Kubisch, 1998; Sullivan & Stewart, 2008; Weiss, 1995). Doing this can expose predictive assumptions that do not hold up for various reasons. Among the most common pitfalls are not basing implied or stated theories of change in reality or evidence; failing to consider plausible alternate explanations; relying on limited perspectives; and basing them exclusively on strong affective commitments.

To demonstrate the value of explicating programmatic theories of change, evaluation researcher Carol Weiss (1995) uses as an example a job-training program for disadvantaged youth. To help these youths avoid negative social experiences (e.g., criminal activity, illicit drug use), the program sought to teach them "job readiness skills," such as dressing appropriately, being punctual, and getting along with supervisors and co-workers. The logic on which this program was based consisted of a chain of assumptions, of which these are a few:

- Training for attractive occupations is (or can be) provided in accessible locations.
- Information about the program's availability will reach the target audience.
- When young people hear of the program's availability, they will sign up for it and attend regularly.
- Trainers will offer quality training and will help youth learn marketable skills.
- Youth will internalize the values and absorb the knowledge.
- Having attained the knowledge and skills, the youth will seek jobs.
- Jobs with adequate pay will be available to the participants.
- Employers will hire the participants to fill the jobs.
- The youth will perform well, and employers will be supportive.
- Youth will become regular workers and wage earners.
- Youth will not engage in socially undesirable behaviors such as drug use, crime, and so forth.

As Weiss (1995) points out, making this reasoning explicit shows which assumptions may be problematic. For example, people with experience with running this kind of program will point out that instruction is often subpar and that finding dependable trainers is difficult. Moreover, depending on the setting and economic circumstances, it may be the case that few job opportunities are available even for those program participants who indeed learn positive job readiness skills.

By making explicit the assumptions that constitute a program's theory of change, it becomes possible to improve the "bet" made by program designers and funders that taking particular courses of action will achieve the outcomes they desire. Therefore, one way to increase the chances that a change initiative—such as reforming undergraduate STEM education—will succeed is to explicate its theory of change and then critically examine its reasoning about causes and effects.

<u>Analyzing Theories of Change in a Sample of STEM Education Reform Programs and Projects</u>
To illustrate the way in which STEM reform efforts are guided by theories of change that are often implicit, we followed Weiss's example and extracted the theories of change embedded in 9 projects funded by the National Science Foundation. We focused on three NSF programs that sought to improve STEM education: the Math-Science Partnerships (MSP), Course, Curriculum, and Laboratory Improvement (CCLI), and the Chemistry Curriculum Initiatives. From each of these programs, we selected three projects that varied by discipline, target of change, geographical region, and so forth. Using program solicitations and project summaries that are publicly available through the NSF's web site, we inferred the theory of change within each program and in funded projects that we sampled from each program. We describe each program and project sufficiently to clarify the theories of change that inform particular strategies of action.

I. The Math and Science Partnership Program

<u>Program Description.</u> Since 2002, the Math and Science Partnership Program has sought to improve learning outcomes in mathematics and science by all students, at all preK-12 levels. Claiming that there is a "close relationship between student achievement and teacher knowledge and teaching

skills" (p. 1), the authors of the 2002 MSP program solicitation argued that providing excellent education in math, science, and technology depends significantly on the quality of the preK-12 instructional workforce—namely, well-prepared and well-supported schoolteachers. Because high quality teacher preparation and professional development are necessary but not sufficient for improving student performance in math and science, systemic change of math and science education must address "other essential components of the educational system [that] include the availability of a challenging curriculum and instructional materials, the judicious use of technology to support instruction, and assessment systems . . . that inform classroom instruction" (p. 2). Believing that "student learning also depends on successful interactions among leadership, resources/partnerships, policy/infrastructure, strategic decisions/interventions, [program] sustainability, and outcomes/evaluation" (p. 2), the MSP sought to foster partnerships between school districts and institutions of higher education as well as other stakeholders (e.g., community organizations, private foundations, professional societies, education research organizations, and so forth). The insistence that higher education must play a critical role in preK-12 education reform distinguishes the MSP program from other NSF-supported systemic education reform efforts.

Drawing on these assumptions about how elements of the educational system are related, the 2002 program solicitation claimed that the MSP program would achieve its long-term outcomes by supporting exemplary partnerships that address these four goals:

> (1) To enhance significantly the capacity of schools to provide a challenging curriculum for every student, and to encourage more students to participate in and succeed in advanced mathematics and science courses; (2) To increase and sustain the number, quality, and diversity of preK-12 teachers of mathematics and science, especially in underserved areas, through further development of a professional education continuum . . . ; (3) To contribute to the national capacity to engage in large-scale reform through participation in a network of researchers and practitioners that will study and evaluate educational reform and experimental approaches to the improvement of teacher preparation and professional development; and (4) To engage the learning community in the knowledge base being developed in current and future NSF Centers for Learning and Teaching and Science of Learning Centers (pp. 2-3).

<u>MSP Program Theory of Change:</u>
As we mentioned before, a program's theory of change is more than identifying ends and means; it includes predictive assumptions about *why* taking a certain course of action will attain a desired outcome. In the case of the MSP program, our best inference about the primary theory of change in the 2002 solicitation appears to be this:

> If preK-12 educational systems and institutions of higher education can find ways to develop and sustain fruitful partnerships that address the program's four major goals (i.e., increasing participation, transforming professional development, etc.), then participating schools will increase their capacity for meeting high standards for learning and for significantly reducing achievement gaps in the mathematics and science performance of diverse student populations. These approaches, effectively implemented, will foster "systemic" improvements in math and science education across the PK-12 and postsecondary systems.

Although this theory of change makes clear the programmatic means (school-university partnerships) for pursuing its desired ends (wide-scale improvement of student achievement), it offers no explanation for *why* this approach will attain these desired improvements. That is, what sort of reasoning might explain why this approach would have more success than other approaches? What evidence can be lined up that would make these predictive assumptions credible and defensible? In the 2002 MSP solicitation, which not only attracted dozens of proposals but also was a basis for determining which proposals were funded, the rationale for using partnerships to improve student achievement is not obvious. Admittedly, NSF program solicitations traditionally do not expound at length on the research bases for designing a program in a particular way. Still, considering that the National Science Foundation had allocated $160 million to the MSP program, it is somewhat surprising that the solicitation does not offer more to explain why this kind of program would achieve its desired outcomes.

In our examination of the MSP program's theory of change, we also looked for theories of change in three Comprehensive projects that were funded through the first funding cycle of the MSP Program. What follows are summaries of each project and the theories of change we inferred from them.

1. The El Paso Math and Science Partnership (award: approximately $29.5 million) includes three urban school districts that encompass El Paso, nine rural school districts, the University of Texas at El Paso (UTEP), El Paso Community College, the Region 19 Education Service Center, and El Paso area civic, business and community organizations and leaders. Like other MSPs, the El Paso MSP aims to improve student achievement in mathematics and science among all students, at all preK-12 levels, and to reduce the achievement gap among groups of students. The five main goals of this particular partnership include (1) engaging university and community-college leadership and mathematics, science, engineering and education faculty in working toward significantly improved K-12 math/science student achievement; (2) ensuring the number, quality and diversity of K-12 teachers of mathematics and science across partner schools, particularly those with the greatest needs; (3) building the capacity of area districts and schools to provide the highest quality curriculum, instruction and assessment, and to ensure the highest level achievement in mathematics and science for every student; (4) ensuring a K-16 alignment of mathematics and science curriculum, instruction and assessment; and (5) prioritizing research on educational reform and preK-16 partnerships.

2. The Milwaukee Mathematics Partnership: Sharing in Leadership for Student Success (award: approximately $20 million) comprises the University of Wisconsin-Milwaukee, the Milwaukee Public Schools, and the Milwaukee Area Technical College. The Milwaukee Mathematics Partnership seeks to substantially improve mathematics achievement for the 100,000 K-12 Milwaukee Public Schools students through achieving the four following goals: (1) to use a Comprehensive Mathematics framework to lead a collective vision of deep learning and high-quality teaching across the Partnership; (2) to institute a distributed mathematics leadership model based in professional learning communities; (3) to develop a Teaching Learning Continuum that builds and sustains the capacity of teachers to use a deep personal understanding of math to improve student achievement; and (4) to develop a Student Learning Continuum to ensure all pK-16 students have access to, are prepared and supported for, and will succeed in challenging mathematics.

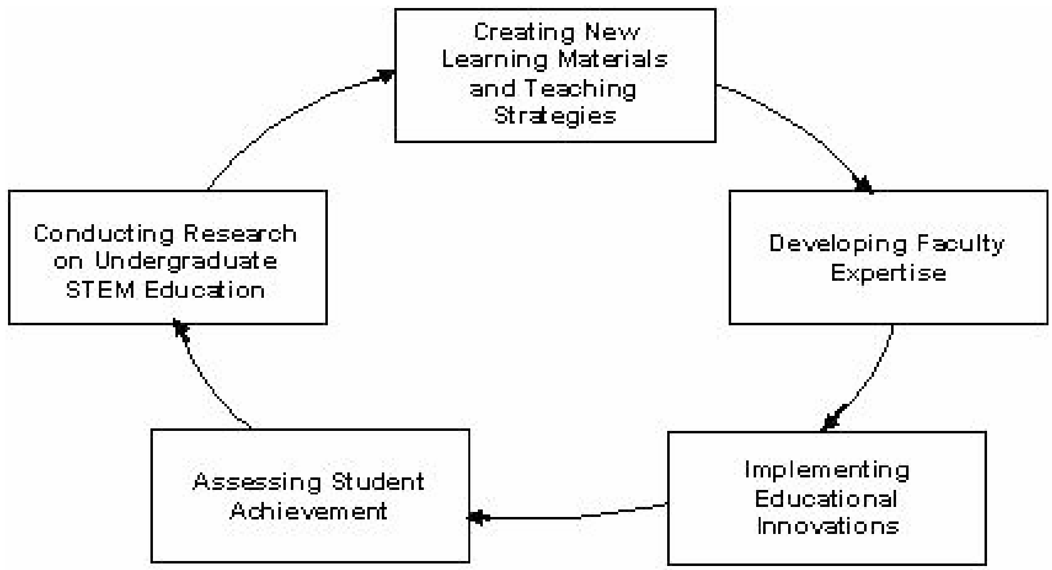
3. The Appalachian Math Science Partnership (award: approximately $25 million), which includes 38 Kentucky school districts, 9 Tennessee school districts, 5 Virginia school districts, the Kentucky Science and Technology Corporation, and 10 institutions of higher education led by the University of Kentucky, seeks to strengthen and reform education in math and science in pre-K through grade 12 classrooms in participating districts mainly by building an integrated elementary, secondary and higher education system in this underserved region. The partnership will unite the efforts of teachers, administrators, guidance counselors and parents in local schools with administrators and faculty at area colleges and universities. Collaborations among these stakeholders from numerous regional education systems—both K-12 and postsecondary—will meet felt needs for (1) preservice teacher and administrator education, (2) professional development of preK-12 personnel; (3) student learning opportunities, including parent/community enrichment; and (4) research that advances understanding of rural education reform; addressing these needs will lead to greater student achievement in math, science, and technology.

Project Theories of Change: All three of the MSP projects described above have the same general theory of change: *If critically important stakeholders in pK-12 and postsecondary systems collaborate to design and implement better ways to prepare and support pre-service and current teachers in math and/or science, then students in participating schools and districts will achieve better scores in math and science.* Because the projects we sampled have similarities in goals and strategies that strongly reflect the MSP's embedded theory of change, we believe they are largely *implementing* the program's vision of how improvements in math and science education are to be achieved. The project summaries are nearly interchangeable, and the theories of change of the three projects and the MSP program are tightly aligned. However, as these are never overtly stated, they have to be inferred from description of goals and tactics. Rationales for why these strategies might achieve these goals are not offered.

II. The Course, Curriculum, and Laboratory Improvement Program

Program Description: As expressed in its 2007 program solicitation, the primary goal of the Course, Curriculum, and Laboratory Improvement (CCLI) program is to "stimulate, evaluate, and disseminate innovative and effective developments in undergraduate STEM education" (p. 4). To achieve this overarching goal, the CCLI program funds projects that it believes will introduce new content incorporating cutting-edge developments in STEM fields; produce knowledge about learning; and improve educational practice. The relationship between knowledge production and improvement of practice in undergraduate STEM education is represented by a cyclic model with five components: (1) creating learning materials and teaching strategies; (2) developing faculty expertise; (3) implementing educational innovations; (4) assessing student achievement; and (5) conducting research on undergraduate STEM education (see figure 1).

Figure 1. The CCLI Program Cyclic Model



According to the CCLI solicitation,

> In this model, research findings about learning and teaching strategies that show promise give rise to faculty development programs and methods that incorporate these materials. The most promising of these developments are first tested in limited environments and then implemented and adapted in diverse curricula and educational institutions. These innovations are carefully evaluated by assessing their impact on teaching and learning. In turn, these implementations and assessments generate new insights and research questions, initiating a new cycle of innovations. (p. 5)

The CCLI program solicits proposals for three types of projects that represent three phases of development. Phase 1 projects typically address one program component and involve a limited number of students and faculty at one academic institution; their maximum project budget is $150,00 for 1 to 3 years. Phase 2 projects build on smaller-scale successful innovations or implementations to refine and test these on diverse users in several settings; the maximum budget is $500,000 for 2 to 4 years. Phase 3 projects combine established results and mature products from several components of the cyclic model, and, drawing upon a diversity of academic institutions and student populations, strive to achieve a demonstrable national impact; maximum budget for Phase 3 proposals is $2,000,000 over 3 to 5 years. Finally, regardless of project scope and budget, all proposed projects were asked to incorporate what the solicitation described as "important program features": a focus on students; use of and contribution to knowledge about STEM education; STEM education community-building; expected measurable outcomes; and project evaluation.

<u>CCLI Theory of Change:</u> Unlike the newer MSP Partnership program, which we claim does not have a well articulated theory of change, the more-established CCLI program is based on a theoretical cyclical model that assumes a number of things. First, it appears to assume that efforts to improve undergraduate STEM education should start small with "grass roots" efforts at change. This is demonstrated by two features of the program solicitation: the option of proposing small-scale projects willing to experiment on a product or activity that falls within one of the five components of the cycle; and the requirement that larger projects must be scaled from successful trials in smaller

projects. Thus, implicit in the CCLI theory of change are assumptions about the scalability of innovations—and other research suggests these assumptions about scalability may be unwarranted. As Seymour (2007) points out, despite an investment of significant resources—namely, large amounts of money by the NSF and other funders to seed innovation, the establishment of numerous networks of reform-oriented faculty, and the accumulation of scientific and practical knowledge about how students learn--the spread of research-grounded teaching practices in US undergraduate education still remains limited. In asserting that STEM education reform has stalled, DeHaan (2005) points to the finding of a 2001 survey of research-intensive universities: Only small numbers of students at approximately 20% of these institutions have opportunities to take introductory courses that feature active learning or real-world problem solving. Thus, it may be riskier than the NSF believes to assume that large-scale reform in STEM education will come from encouraging the scaling up of successful small projects.

Second, the cyclic model assumes that its five components are in sequence. As the solicitation explains, creating innovative learning materials and teaching strategies should be "guided by research on teaching and learning, by evaluations of previous efforts, and by advances within the disciplines" (p. 6). In turn, new materials will lead first to develop faculty expertise and then implement the innovation in actual educational settings, the success of which at improving student learning must be assessed. Although the model stipulates that any of the five components can be a starting point in the cycle, it links the components with one-way arrows, specifying in the solicitation text what must precede and follow each. This feature of the model reflects unstated assumptions about how innovations are scaled up, one assumption being that achieving large-scale improvements in undergraduate STEM education must involve all five components. Moreover, it attempts to link an organic, "bottom-up" approach to change that drives the smaller projects with one that is sequential and (absent any proof of concept) unproven as to whether the cycle truly functions as expected. We also do not learn whether and how discoveries made in one funded project are disseminated to potential users and their adoption realized. There seems to be no extra-project, intra-program mechanisms to make the model work.

In short, although the cyclic model brings greater conceptual clarity to *how* this particular NSF program will achieve its primary outcomes, the solicitation does not necessarily articulate *why* these means are equal to or better than other approaches to attaining the same aim. Although the CCLI program model does a better job than the MSP program of specifying a particular approach to change, it really does not explain in convincing terms why the cyclical approach is more likely to succeed than another approach.

In examining the theories of change in projects funded by the CCLI program, we focused on three Phase I projects. What follows are summaries of each project and the theories of change we inferred from them.

1. Authentic, Career-based, Discovery Learning Projects in Introductory Statistics (award: $176,000) aims to improve achievement and to change attitudes for students who take a first statistics course in either high school or college by developing and testing a model for learning in statistics that suggests that career-specific discovery learning will enhance outcomes for students. Supplementary materials include a faculty guidebook to help design discovery-learning projects and a workbook of introductory level problems from specific majors. The initiative fosters collaboration between mathematics and other departments, especially those in the social and behavioral sciences, business, education and health sciences.

2. Developing Engineering Lifelong Learners through Freshman Seminars and Faculty Development Workshops (award: $150,000) is developing a seminar course for first-year engineering students that will instill in them a commitment to lifelong learning and associated skills such as self-directedness, metacognition, and critical reflection. The courses are organized around a portfolio project through which students develop a vision of engineering as a profession and make a conceptual connection between mathematics and science and this vision. Faculty development workshops will assist faculty in delivering the seminar course.

3. Building a Basic Biology Concept Inventory (award: $285,000) is developing a basic Biology Concept Inventory (BCI) that will enable the field to reliably quantify student learning at the introductory college level. The objective is to provide the field with reliable data on student learning as biology departments around the country attempt to improve student achievement. The existence of a Biology Concept Inventory is argued to have the potential to impact the teaching of biology to thousands of undergraduates throughout the country, much as the Force Concept Inventory and the Astronomy Diagnostic Test have impacted the teaching of Physics and Astronomy.

<u>Project Theories of Change:</u> Perhaps in keeping with the more organic type of change encouraged in Phase I-type projects, the theories of change we have inferred from these three projects are all quite different. The first project, for example, is betting that situating statistics in career-related topics and problems is an approach that will improve the achievement and attitudes of students in their first statistics course. The second project believes that a seminar for first-year engineering students is a good way to cultivate a disposition in engineers toward lifelong learning. The third project is the most research-based, assuming that if it can create and test a biology concept inventory, then it will be adopted by instructors who want to identify and rectify pervasive misconceptions in biology courses. Their diversity notwithstanding, these projects incorporate key features of the CCLI program's theory of change (e.g., a focus on students, contributing to STEM education knowledge base, etc.). This short discussion precludes a close examination of the particular theories of change in these three projects (e.g., Is a single seminar enough to make lifelong learners? If you build a biology concept inventory, will the faculty use it?). However, we still can say that none of the three projects appears to put forth the kind of theory of change that explains not only *why* its particular approach to solving its key problem will work but also how the good outcomes it achieved will be taken up and used more widely, how changes will be sustained, and how the products of several successful trials can be combined and institutionalized in departments, across disciplines, or spread throughout the education system.

III: Systemic Changes in Undergraduate Chemistry Curriculum
<u>Program Description:</u> Between 1995 and 2002, the Systemic Changes in the Undergraduate Chemistry Curriculum program sought to bring about major improvements in the undergraduate chemistry curriculum and teaching methods by building on the most promising results of previous NSF-funded work. This program is distinctive in that it chose large, multi-institutional projects that built on smaller grants made over the previous decade through other NSF programs. In the following account, information contained in formal program and project descriptions is augmented by information provided by project evaluators.

<u>Program Theory of Change:</u>
Our inferences about the program's theory of change stem from the nature of the projects chosen for funding. The essential strategy of the Systemic Changes in Chemistry Curriculum program was to "pick winners"; it selected five projects that had already begun to address the key problem of how to encourage the spread of research-grounded methods of teaching and learning, and curricula that

addressed real world issues. These were cross-institution collaborations that had already been effective on a smaller scale under these programs. They became, essentially, larger-scale experiments in how to disseminate promising practices.

This program was the first major initiative to promote real-world relevance in science curricula, and all of the funded projects developed and promoted teaching materials that reflected this focus. Thus, one (of several) theories implicit in this program was that *students will become interested and engaged in chemistry, and will understand it more deeply, if they can see the significance of what they are learning for their own lives and for the world around them.*

Embedded in project selection was also the theory of *dissemination by peer-led professional development*. All selected projects used peer-to-peer workshops in which faculty (and student teaching assistants) taught each other how to use research-grounded teaching methods, and drew in increasing numbers of chemistry faculty who were interested in (or already experimenting with) these methods. Thus, these projects were a testing ground for the theory *that widening uptake of best practices can be leveraged by hands-on encounters with new teaching methods in a risk-free, supportive, and highly convivial network of peers*. Contacts made in workshops continued in meetings in which class and lab materials were developed, and commitment to "reformed" teaching methods was reinforced. The (implicit) theory of change in this method was *effective dissemination by infectious engagement.*

The program was also, in effect, funding grass-roots activity in which individual and small groups of faculty were engaged with faculty from other chemistry departments. The learning communities built up in four of the five projects were cross-institution rather than within-institution networks. Engagements by whole departments were rare, and participating (notably pre-tenured) faculty were somewhat sheltered from the disapproval of departmental colleagues by support from senior members of the project network.

Regional workshops that carried the growing body of faculty teaching expertise, methods, and materials to a widening circle were funded for several years after the five-year project funding had ended. A sister program gave awards to department-based groups that undertook to "adapt and adopt" the methods and materials of the core project groups. Although (as reported by project evaluators) both the project participants and the program officers implicitly understood the methods they were developing—often as they went along—and the rationale that supported them, these were not explicitly stated.

It is clear that the program was "systemic" in intent because it encouraged applicants to spread new methods and materials to colleagues in science teaching preparation, community college science faculty, high school science teachers, and college teaching assistants. Although project proposals expressed an intention to address these ambitious goals, the grass-roots organizations that ran the projects were limited by organizational constraints and thus varied in the extent to which they could meet them.

Below we describe three of the five programs funded under this program. The first two projects, ChemLinks Coalition and Modular Approach to Chemistry Curriculum Reform, were persuaded by program officers to work as one cooperating project—"ChemConnections"—because of the similarity of the two projects' goals and methods.

1. ChemLinks Coalition: Making Chemical Connections (award: $2.8 million) was a five-year collaboration with the ModularChem Consortium to change the way students learn chemistry, to increase scientific literacy for all students taking chemistry, and to promote a process of educational reform. Participating faculty developed, tested, and disseminated modular course materials that use active and collaborative approaches to learning. These materials, targeted to the first two years of the chemistry curriculum, drew upon real-world questions important to students and to society that could be answered only by learning and using the necessary chemistry. Questions often addressed environmental issues from the perspective of personal choices, such as “Would you like fries with that?” “How do I know what’s in my drinking water?” and “Paper or plastic?” The project focused largely (though not exclusively) on introductory chemistry courses that included non-science majors and those taking chemistry as a supporting course, as well as chemistry majors. It sought to interest and engage students who are fearful of taking chemistry and find it difficult. The project was undertaken by a coalition of leading liberal arts colleges and research universities that already had experience working together on chemistry curricular reform, and leveraged Project Kaleidoscope’s extensive network to involve a larger and more diverse group of institutions in making systemic and sustainable changes in undergraduate chemistry education.

2. Sweeping Change in Manageable Units: A Modular Approach for Chemistry Curriculum Reform (award: $3 million) sought to develop new curricula, materials and methods to encourage the appreciation and learning of science, especially chemistry, by every undergraduate student. In collaboration with the ChemLinks Coalition, this project developed, tested and refined modules at the two- and four-year colleges and research universities comprising the two consortia. Modules lasting between one to four weeks were designed that presented fundamental chemistry to students in the context of a real-world problem or application and emphasized the links between chemistry and other disciplines. Like ChemLinks, ModularChem emphasized teaching methods that reflected current research in the learning sciences and encouraged active learning. The project constructed a framework for the continuous improvement of curricula, and shared workshops and sessions at national and regional meetings with ChemLinks and members of the other chemistry project to disseminate their work.

3. Workshop Chemistry Curriculum (award: $1.6 million), a consortium of ten senior and community colleges at the City University of New York, and the Universities of Pittsburgh, Pennsylvania, and Rochester, developed and disseminated a new model of teaching, *Workshop Chemistry*, which provided a collaborative learning experience that increased student involvement and involved students as mentors. A prototype workshop model developed at City College in a general chemistry course for science and engineering majors was expanded and refined for a broad range of courses including preparatory chemistry, chemistry for allied health sciences, organic chemistry, instrumental, and analytical chemistry. Students who served as workshop leaders were given a natural introduction to teaching that was formalized through a Teacher Preparation component of the project. Student Workshop Manuals that include the problem solving, model building, and simulation activities of the workshops were produced for each course and disseminated. New project partners were invited to view workshops, to participate in faculty development activities, and to implement pilot workshop courses at their own institutions.

<u>Project Theories of Change:</u> Looking across these three programs, we note the themes of making chemistry accessible to a wider student range through real-world relevant science, and the dominant strategy of dissemination via expansion of cross-institutional faculty networks as learning communities. The embedded theories of change that we have described were largely developed in

practice by the project participants themselves with reference to a broad outline offered by the program.

The two closely related projects of the ChemConnections collaboration produced modular teaching materials that reflected the theory that *students will become interested and engaged in chemistry when they see its relevance.* Thus, *real-world content makes chemistry more accessible.* As the modules incorporated active, interactive, and discovery-based pedagogies to convey the re-conceptualized content (and in some cases, learning assessment methods), they reflected the theory that *students learn more deeply when what they learn and the ways in which they learn it are coherently related.* This project was also committed to multi-media teaching methods (which were incorporated into many of the modules) which again implies a theory that *teaching with technology promotes effective learning.*

Although this project's leaders originally envisioned a conventional dissemination strategy based on presentations at disciplinary meetings, they quickly joined in the process of using regional peer-led workshops, work-focused (i.e., module development) meetings, and learning community building methods of their ChemLinks partner. These occasions became the meeting place for collaborators from community colleges, HBCUs, and high schools. Thus, by experiment rather than prior design, the twin projects embraced the theory that *reform initiatives can be effectively disseminated and articulated across different educational levels by regular meetings of network members in which real work (such as curriculum and teaching methods development) is done in an egalitarian, collegial atmosphere.* In their reports, the projects' evaluators noted the high level of involvement of community college chemistry faculty in network events.

The third Chem Curriculum Initiative, Workshop Chemistry, enacted a theory of change that, though similar to the two other projects, differed with respect to the role that students could take in learning chemistry. Workshop Chemistry's team-learning model of instruction meant that students who did well were given an opportunity to become peer leaders who coached their classmates and worked closely with course instructors. Thus, central to this project's theory of change is the assumption that *students learn chemistry better when they (a) take a structured role in helping their peers learn the subject matter and (b) can apprentice with faculty to learn how to foster greater student learning.*

<u>Summary of Findings</u>

In the case of the Math-Science Partnership program, its theory of change consisted of predictive assumptions about the effects that partnering preK-12 programs with institutions of higher education would have on student achievement in math and science. As we noted, these assumptions were not directly articulated in the program solicitation and treated as a given. The theories of change of the programs receiving awards hewed very closely to the MSP programmatic theory of change. Thus, this implicit theory of change about the impact of partnerships was accepted by and reflected in the programs. Perhaps the enormous stakes attached to getting a multimillion dollar NSF award contributed to uncritical adoption of the program's predictive assumptions about preK12-postsecondary partnerships. The alignment between projects and the program solicitation suggest an implementation approach to changing STEM education—that is, the projects collectively bought into the program's predictive assumptions and are carrying out its change strategy.

Compared with the MSP program solicitation, the programmatic theory of change in the Course, Curriculum and Laboratory Improvement solicitation was more evident, explicitly drawing upon a formal model which assumes that scaling up STEM reform is achieved through a cycle of curriculum development, faculty development, implementation, assessment, and research. However, the solicitation did not articulate by what mechanisms successful projects would leverage uptake of their methods and materials, that is, how this model could actually work in scaling up the results of successful experiments. It also includes no explanation of why this is a good model fit for achieving its purpose. As with the MSP program solicitation did, the wager the NSF placed on this approach is treated as an obvious bet. Despite its formal design, this is essentially a hands-off program that is closest to competitive research. The three CCLI Phase I projects we examined employed different theories of change; this diversity seems characteristic of Phase I awards. In contrast to an implementation program like the MSP partnership, the CCLI program is more of an experimentation program.

Finally, in the case of the Systemic Changes in the Undergraduate Chemistry Curriculum program, its theory of change, like that of the MSP program, was largely unstated. However, unlike the MSP program, which was more prescriptive, the CC program had a strategy of looking to previously funded projects that had successfully used variations of peer-to-peer professional development to improve how undergraduate chemistry was organized and taught.

The Chemistry Curriculum Initiatives program is one of the NSF's first major efforts to leverage improvements across and beyond the STEM higher education system. It promotes several strong objectives, all of which are represented in the five projects it funded. It charges these projects to be system change experimenters, who are to figure out in practice how broadly agreed principles of dissemination can be made to work. Both the projects' successes and the barriers they encountered make them the active authors of an evolving theory of system change. These projects offer good proof of concept for the peer-led model of professional development and diffusion of improved pedagogies, real-world relevant curricula, and learning assessment methods that express learning objectives: many of their products and methods are still in wide use. How far this theory of change, as developed and refined by this set of projects, might have gone in disseminating these practices and building faculty capacity to sustain them is unknown because the program's theory of change did not take account of the time it would take to establish new methods. Funding ceased after five years, and workshop dissemination funding was discontinued notwithstanding strenuous efforts by the five collaborating projects to sustain it. This raises an important question about whether the NSF should proactively sustain and extend experiments in change that show good results rather than following a research model that funds largely innovative experiments like the CCLI program.

Implications

As we noted previously, Weiss (1995) argues that programs trying to bring about change are predicated on predictive assumptions about the relationship between actions and outcomes. Theories of change reflect important yet often invisible choices by program designers to select one change strategy over others. Making any kind of guess—"educated" or otherwise—about the best course to achieving a desired but uncertain end is always a wager of sort, and as such, a theory of change is a kind of bet that one's approach to change is, in light of the situation at hand, the best tack to take. It involves appraising not only the potential benefits of the program but also all the factors that affect the likelihood that the chosen course of action will be better than its alternatives. Although these choices and predictive assumptions are important considerations in program design, they are, Weiss asserts, often hidden from plain sight and thus cannot be evaluated as to their soundness. Over time, an implicit theory of change may come to be taken as the status quo, and no longer seen as a bet made by program designers in the past.

What our study of NSF programs and projects shows about Weiss's claim is that program solicitations do not typically disclose the full chain of primary assumptions and key choices that program officers make in designing a program; if they did (as Weiss demonstrates in her own example of the job training program), then project proposers, principal investigators, and other project designers could themselves critically consider which assumptions would and would not hold in their local contexts. Moreover, the solicitations we examined suggest that implicit theories of change still profoundly shape the theories of change in projects that respond to them. A danger of designing funding programs with unarticulated theories of change, then, is that the projects they attract and support may not recognize the assumptions on which they are organized; this lack of insight may affect a project's ability to achieve the program's desired ends. Without a clear idea of *why* programs work as they do and what makes programs more or less successful, then NSF programs and projects must keep rediscovering what brings about desired change. Based on our examination of a few programs and projects, we suggest that NSF has a blind spot with respect to seeing the need for making its theories of change explicit. This blind spot may be one reason why key aims of the NSF's Division of Undergraduate Education—namely, sustainability and expansion of practices proven to encourage greater student learning in math and science—have persistently eluded the NSF.

Thus, the charge of the January meeting is to develop theories of change that can effectively serve the vision of mobilizing STEM education for a sustainable future. These theories—whether new or synthetic—will need to avoid the pitfalls that that this paper has discussed, and be guided by the wisdom that Weiss and her colleagues have offered. The Critical Advisors are asked to develop a well-delineated, coherent, set of theories of change that are appropriate to the scale of the endeavor and are as comprehensive as the scope of the vision may demand. They will need to reflect a realistic appraisal of the structural and cultural factors that can enhance or limit chances of success; explain why the approaches suggested are likely to work, and how the elements in the resulting proposed design can be made to articulate effectively. In struggling with this fundamental challenge, the Critical Advisors will also be contributing to a better understanding among policy-makers, funders, and education reformers how to use theories of change to their best advantage.

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