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A Final Case Study of SCALE Activities at UW-Madison: The Influence of Institutional Context on a K–20 STEM Education Change Initiative

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A Final Case Study of SCALE Activities at UW-Madison: The Influence of Institutional Context on a K–20 STEM Education Change Initiative

Matthew T. Hora and Susan B. Millar

Executive Summary

The enduring lesson from SCALE activities at UW-Madison is that efforts to change the culture of teaching and learning in STEM departments should focus on illuminating and then shifting the pervasive cultural schemas that faculty hold for teaching and learning. One strategy for doing so is to create officially sanctioned venues where individuals from different disciplinary backgrounds are led by a skilled facilitator or "culture broker" to focus on commonly shared pedagogy-related challenges. Leaders would benefit from being aware of and sensitive to the deeply entrenched nature of cultural schemas and their embeddedness in the local institution.

Institutions of higher education (IHEs) play an important role in math and science education by offering undergraduate instruction, operating teacher training programs, and providing in-service training for K–12 teachers. The National Science Foundation (NSF)–funded System-wide Change for All Learners and Education (SCALE) project sought to effect change in its partner IHEs by creating a transformative culture through cross-cultural working teams that operated at the intersections among K–12 districts, colleges of education, and colleges of mathematics, science, and engineering (SCALE, 2005). The SCALE goals for IHEs are as follows:

1. To improve science, technology, engineering, and mathematics (STEM) *undergraduate* education;

2. To improve collaboration between STEM and education faculty on *preservice* programs;

3. To improve collaboration between IHE faculty and K–12 districts on *in-service* training; and

4. To improve institutional *policies and practices* that support these activities.

As part of the SCALE IHE case studies line of work, this paper provides findings on the effects of the SCALE project at the University of Wisconsin–Madison (UW-Madison) between May 2003 and August 2007. Case studies of SCALE's partner IHEs—the California State University, Dominguez Hills, and the California State University, Northridge—have been produced. A cross-case analysis of the three IHE case studies will develop a diagnostic approach to evaluating STEM education interventions in complex organizations, with a particular focus on organizational context.

Methodology

A particular challenge in studying change processes in complex educational environments is that researchers have tended to focus on discrete elements, such as curriculum or assessment practices. For example, Anderson and Helms (2001) argued that reformers need to “come to grips with the totality of this complex situation” in order to fully understand these complex dynamic systems and the basis for accepting, rejecting, or adapting reform initiatives (p. 4). In response to this challenge, our methodological approach is to analyze the SCALE project through the lens of organizational culture. We define *culture* as patterns of behavioral norms, beliefs, and values that are differentially internalized and expressed by individuals *and* larger collectives, each operating within the structural and social constraints of different administrative units. In this formulation of culture, neither the institutional context nor individuals are secondary considerations; each is treated as an integral component of the context of an IHE. Our emphasis on culture enables us to situate an intervention within its local context and thus to systematically observe the “black box” of reform implementation. It also enables us to provide SCALE leaders and NSF with three different types of actionable knowledge:

- Knowledge of the key components of the institutional context pertaining to the SCALE project, their influence on the project’s implementation, and key leverage points for future reform;

- Evaluation findings about SCALE activities and their outcomes, including effects on the institutional context; and

- Knowledge of how the institutional context and a specific SCALE activity influenced one another.

This qualitative case study used a repeated cross-sectional design, with in-depth interview data collected at Time 1 (T1; February–June 2006) and Time 2 (T2; June–August 2007). Other data collected for this research included official university and SCALE documents and observations of SCALE meetings. Nonrandom sampling procedures were used to identify interview respondents—22 at T1 and 25 at T2, for a total of 47 interviews with 42 unique individuals. Interviews were coded using a scheme we call the *institutional context framework* (ICF), which is based on preliminary analyses of the SCALE IHEs (Hora & Millar, 2007) and includes the following code families: external environment, internal structure, resources (fiscal and social), collective values and beliefs, individual sense-making, and practices. Next, queries of the transcript database were conducted to identify high frequencies of code applications for specific codes and code combinations. These reports were then analyzed inductively, and findings were constantly compared to other sources of data. Additional analytic procedures included (a) a causal network analysis that organized data by time and sequence and posited mechanisms of change and (b) an exploratory analysis of cultural schemas held by different groups of SCALE participants.

Findings

Institutional Context

An IHE is grounded in its geographic location and history, its particular structural and social systems, and its unique milieu in the world of higher education. Founded in 1848, UW-Madison is the flagship campus of the University of Wisconsin System and a designated land-grant university with an explicit mission to serve the state of Wisconsin. UW-Madison is an internationally recognized research university with an annual budget of $1.8 billion. In the fall of 2006, it enrolled some 28,000 undergraduate students and 9,000 graduate students (of whom approximately one fourth were teaching assistants [TAs]) and employed some 2,000 faculty, 1,500 instructional academic staff, and 4,700 other academic staff. Its teacher education program is relatively small: In 2006–2007, it certified 125 students to teach in elementary education, 15 students in secondary math, and 22 in secondary science.

We turned to our interview transcripts to identify more detailed factors within this institutional context that were salient to the SCALE intervention, playing either a supporting or an inhibiting role. Contextual factors that *supported* achievement of SCALE goals, organized according to the ICF, include:

- *External environment:* NSF funding requirements lead faculty to consider "broader impacts," and demand for graduate students in STEM education is growing.
- *Internal structure:* Several campus leaders actively support reform, interdepartmental forums (particularly in math) exist, and a governance system based on faculty autonomy minimizes structural constraints on faculty.
- *Resources:* A cohort of permanent academic staff focus on STEM education, networks of STEM educators were fostered by historic and active reform efforts, and large numbers of graduate students work as TAs.
- *Collective values and beliefs:* A guiding mission of the university is the Wisconsin Idea;[1] IHE actors widely recognize the need for K–12 teacher professional development in the STEM disciplines; and problem-solving approaches differ in the STEM and education disciplines, and each approach has merit.
- *Individual sense-making:* Faculty status and reputation afford individuals the freedom and safety to participate in reforms, and faculty get involved in reform efforts for various personal reasons (especially family and intellectual curiosity).
- *Practices:* Some STEM faculty are already engaged in preservice or outreach activities, and some already use inquiry-based pedagogy.

Contextual factors that *inhibited* achievement of SCALE goals include:

- *External environment:* UW-Madison's place in the hierarchy of higher education prioritizes research, and K–12 district hiring policies and policy changes pose challenges.
- *Internal structure:* Departmental tenure and promotion policies discourage teaching innovation, departments can be isolated "silos" that discourage collaboration, large undergraduate STEM courses encourage didactic instruction, lack of policies for instructional practice and TA training leads to autonomous classroom practices, and STEM course requirements for preservice candidates are considered inadequate.

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[1] The Wisconsin Idea holds that "the boundaries of campus are the boundaries of the state."

- *Resources:* Funding pressures and limitations put a strain on resources, and the growing need for remedial courses for incoming students siphons off funds that could be used for other purposes.

- *Collective values and beliefs:* Assumptions regarding research excellence and scientific legitimacy influence faculty priorities and instructional decisions, the distinction between "hard" and "soft" sciences fuels long-standing tension between departments in the School of Education and some STEM departments, and doctoral training socializes students to value research over teaching.

- *Individual sense-making:* Funding pressures and workload minimize the time faculty can spend on reforms.

- *Practices:* A didactic approach to instruction dominates.

As the evaluation findings indicate, these factors influenced how SCALE was implemented. On the one hand, the demanding faculty workload and the prioritization of research accomplishments at UW-Madison made it challenging to recruit STEM faculty for the project. On the other hand, the STEM education community is extensive, and previous grants had fostered an active and supportive community of faculty and academic staff, many of whom became involved in SCALE. Furthermore, the SCALE principal investigator (PI), a STEM faculty member and administrator with extensive contacts and institutional knowledge, deeply influenced how SCALE was designed, implemented, and perceived at UW-Madison. Also, guided by the SCALE theory of change, he and others took into account the great size of the university and its many decentralized and autonomous units and focused on planting small seeds of change at strategic points in the system, built on existing efforts, and worked with committed individuals at all points in the continuum of teacher training and professional development. That is, SCALE introduced into this institutional context a multifaceted intervention intended to impact the teacher training and professional development process at multiple points.

Evaluation of SCALE

We describe each SCALE activity and its outcomes, identifying project effects on different components of the organizational context. The project comprised nine primary activities, involving 25 STEM faculty, 8 education faculty, 15 graduate students, and 14 academic staff as project designers and implementers, and 867 K–12 math and science teachers as participants in professional development activities. In line with the SCALE theory of action, we organize these activities by three major goal areas: (a) *preservice* programs in math and science, (b) *in-service* professional development, and (c) *technical assistance* to the K–12 sector. At the end of this section, we also present a summary of SCALE outcomes organized in terms of the ICF.

In addressing *preservice* programs in math and science, SCALE focused on two interdepartmental committees that were charged with revising course requirements for teacher candidates. The *Elementary and Middle School Math Preservice Committee* focused on a series of courses offered by the Department of Mathematics—known as the *Math 13X sequence*—that are required for all preservice elementary and middle school candidates. Beginning in December

2005, a rotating cast of approximately 12 faculty members and graduate students from the Math Department, 7 faculty members from the Department of Curriculum and Instruction (C&I), and 5 math leaders from the Madison Metropolitan School District (MMSD) met to discuss revising the existing courses and creating new ones. Outcomes for this activity include new curricula for four Math 13X courses, three new courses that may constitute an optional minor in mathematics, a Math 13X course that was team-taught by a math faculty member and an education faculty member in spring 2007, an increased level of dialogue between the Math and C&I Departments and MMSD staff, and reported shifts in instructional practices for three math instructors. The *Middle School Science Committee* was formed in early 2006 to assess the science requirements for students in the elementary education program at UW-Madison. With 10 STEM faculty, 3 education faculty, and 2 K–12 faculty as members, the committee had met three times as of May 2007 to discuss revising course requirements. Outcomes for this activity include the creation of a new interdepartmental committee (where before there had been no forum for dialogue), further development of the STEM education community at UW-Madison, and improved capacity to develop new grant proposals, as evidenced by the rapid development by several members of this committee of a proposal to the ExxonMobil UTeach program.

In addressing *in-service* professional development for K–12 teachers, SCALE focused on three projects in which UW STEM faculty and academic staff designed and facilitated workshops in collaboration with local K–12 districts. The *science immersion units* are a learning opportunity in which students engage in scientific inquiry over an extended period (4 weeks). Teams of four SCALE staff, seven MMSD staff, and three UW academic staff collaboratively developed grade-specific science immersion units for kindergarten and the third, fourth, sixth, seventh, and ninth grades. These units were designed to address the MMSD science standards and were introduced to MMSD science teachers through intensive 5-day training sessions. Outcomes for this activity include 297 MMSD teachers who participated for an average of 11.5 hours per person, an Immersion Toolbox curriculum guide for K–12 teachers, further development of MMSD and UW-Madison networks based on STEM education, and reported changes in the practices of K–12 professional development designers at UW-Madison.

The *Math Masters Project* was funded by U.S. Department of Education Mathematics and Science Partnership (MSP) grants. Its primary goal was to support ongoing implementation of the Connected Math curriculum in MMSD and nearby districts. Teams of five UW-Madison mathematics professors, one engineering professor, and two MMSD math educators collaborated to design and facilitate 15 one-credit (20-hour) courses for K–12 math teachers. These courses were based on five of the “big ideas” in middle school mathematics (number operations, geometry, measurement, algebra, and statistics and probability). A secondary goal for this activity was the informal professional development of STEM faculty. Outcomes for this activity include 438 K–12 teachers who participated for an average of 18.5 hours, pre- and post-test results showing statistically significant gains for participants in all five content courses, an unprecedented level of access for MMSD personnel to some faculty (particularly in the Math Department), and the creation of a new program for elementary teachers—Extending Math Knowledge (EMK)—that SCALE leaders initiated when funding for Math Masters expired.

The *Science Masters Project* focused on improving K–12 teachers’ knowledge of science and student learning through intensive professional development workshops. It was developed in collaboration with 10 regional school districts and UW-Madison. Slated to operate from

November 2006 through August 2009, as of September 2007 the project had involved one MMSD representative and seven STEM faculty as workshop facilitators. Outcomes for this activity as of August 2007 include nine workshops for 85 middle school teacher participants and further development of the STEM education community at UW-Madison.

SCALE provided extensive *technical assistance* and support to MMSD, activity that was largely unanticipated at the time of the original proposal. The *MMSD Math Task Force* was initiated in January 2007 by the MMSD Board of Education, with the goal of convening national experts in math education and charging them with providing recommendations for future decisions about mathematics curriculum. The SCALE PI took a leadership role in the task force, recruited members from UW-Madison and other IHEs, and organized two meetings. Task force participants from UW include five School of Education faculty, two math faculty, four administrators, one graduate student, and one academic staff member. Two faculty from other IHEs (University of Nebraska–Lincoln and California State University, Northridge) also participate. As this activity is still in its beginning stages, it is too early to identify any outcomes. Another technical assistance activity was the *SCALE/WestEd Leadership Academy*, initiated by SCALE leaders who are UW-Madison academic staff. These UW leaders invited leaders from WestEd (a professional development company) to help them produce and hold training sessions based on a SCALE-developed professional development model. A team of 12 MMSD staff, along with staff from two other urban schools districts, participated in 2-day academy sessions in November 2006 and March, October, and December 2007. SCALE personnel from UW-Madison provided technical assistance to MMSD as the district began to shift from an in-person to an online professional development model. For example, SCALE staff helped ensure that this process was aligned with the SCALE and MSP goals. Finally, it is worth noting that the SCALE project enabled and supported the education research programs of several academic staff at the Wisconsin Center for Education Research through the activities of the SCALE Research and Evaluation Team.

Without measurable objectives with which to evaluate the SCALE project's activities and progress toward accomplishing its goals, it is difficult to make a definitive statement about the relative success or failure of the project. That said, the effects of the SCALE project—in relation to the size and complexity of UW-Madison—must at this point be considered modest. It is also fair to say, however, that the SCALE project resulted in a wide array of outcomes pertaining to the organizational context of UW-Madison that address the four goals of the project. These outcomes can be summarized in terms of the ICF as follows:

- *External environment.* SCALE provided high-quality professional development to 867 K–12 teachers to improve their pedagogical content knowledge in the STEM disciplines.

- *Internal structure.* SCALE created one interdepartmental venue focused on preservice science courses, reinvigorated an existing committee focused on preservice math courses, redesigned existing math courses, and created new math courses required for preservice candidates.

- *Resources.* MMSD personnel now have a high level of access to some STEM departments at UW-Madison, SCALE further enriched and developed a cohort of STEM educators, SCALE led to changes in how some academic staff designed K–12 professional development materials, and SCALE funding (for faculty release time, teacher stipends, and materials) enabled professional development that otherwise would not have been offered.

- *Collective values and beliefs.* SCALE linked the collective value of scientific legitimacy and reputation to STEM education reform, SCALE improved some IHE participants' level of knowledge about the K–12 sector, and education and STEM participants each developed a better understanding of the other's beliefs about the relative importance of content and pedagogy.

- *Individual sense-making.* Individual faculty, through participation in SCALE activities, became newly committed to improving STEM education and as a result changed how they prioritize their workload and make sense of recruitment, tenure, and promotion factors.

- *Practices.* SCALE made the relationship between UW-Madison and MMSD more collaborative and mutually enriching, facilitated new interdepartmental collaborations between individual faculty, and fostered activities that resulted in minor changes in the instructional practices of STEM faculty and graduate students.

Cultural Aspects of Mental Models

To better understand the mechanisms of the implementation process and the impact of the institutional context on SCALE activities, we closely analyzed the Math Preservice Committee. We employed a distributed theory of culture developed by cognitive anthropologists that is based on schema theory in cognitive science. Schemas are unconscious mental structures that encode information into generic units that are themselves encoded into the neural networks of the brain through repetition (Brewer, 1987; D'Andrade, 1995). Researchers have theorized that *mental models* are composed of combinations of different schemas—explanatory structures used to filter environmental stimuli (D'Andrade, 1989; Strauss & Quinn, 1998). Some schemas can be considered cultural since they are internalized from instantiated cultural forms that are "part of the stock of shared cognitive resources of a community" (Shore, 1996, p. 47). However, individuals differentially internalize these shared beliefs, values, and norms, and thus, cultural communities are always "internally differentiated and cultural models are characterized by different degrees of sharing" (Shore, 1998, p. 1). An individual's mental model is activated in response to environmental stimuli, which in educational settings consist largely of the unique context of the organization. As a result, mental models must be viewed as simultaneously situated within and influenced by the organizational context (organized in terms of the ICF in this study) and shaped by the individual's unique personal experiences and social position in that context.

We believe that this approach—by accounting for how individuals variously interpret, internalize, and instantiate organizational values, attitudes, and knowledge—enables us to develop a more adequate understanding of organizational culture than an approach that presents knowledge as uniformly shared and distributed across a complex organization. Working within the interpretive tradition of Strauss and Quinn (1998) that uses natural discourse to identify cultural aspects of mental models, we identified the cultural schemas (Table 1) exhibited by at least three individuals within a group of math educators (N = 6) and a group of mathematicians (N = 8) who participated in the Math Preservice Committee. It is important to note that our sample drew heavily on faculty and graduate students who were conversant with education-related topics and more than likely represented a subgroup within their respective departments. Further, cultural schemas are not cognitive structures that all group members exhibit; instead, they represent discrete values, beliefs, or norms that individuals may or may not exhibit and employ in a given situation. To illustrate this point, one respondent noted that there is “[N]o unified voice in the Math Department” about education issues.

Table 1
Cultural Schemas Exhibited by Mathematicians and Math Educators

	Math instruction	**STEM education reform**
Mathematicians	• Teaching math is a straightforward and relatively easy task. • Content considerations are more important than pedagogical concerns. • Teaching preservice teachers is different from teaching other students.	• Mathematicians have a role to play in K–12 math curriculum and teacher training. • Mathematicians are the content experts, and School of Education faculty are the learning experts. • Math education as a discipline has some problems with rigor. • Solving problems in mathematics is very different from solving problems in education.
Math educators	• Math is a human endeavor and not an objective set of rules. • Math instruction should be driven by content and learning theory.	• School of Education faculty are the learning experts, and mathematicians are the content experts. • Mathematicians need to become reflective practitioners. • Solving problems in mathematics is very different from solving problems in education.

It is useful to consider the origins of these schemas and the way they operate within the unique context of UW-Madison. Faculty respondents identified two ways that these schemas were socially transmitted. First, doctoral training at their alma maters constituted a socialization process into the practices, knowledge, traditions, and cultural models of their disciplines. Second, this assemblage of disciplinary techniques, habits, and cultural forms was reformulated within the unique milieu of academic departments at UW-Madison. The defining feature of the UW-Madison environment is the demanding workload and the attendant pressures on faculty, especially those without tenure. Seen through this lens, individual mental models shaped how the SCALE project was interpreted and ultimately acted upon (or not). Interestingly, an important factor that led some STEM faculty to become involved in the committee was a strong interest in K–12 education fostered by their children’s attendance at local public schools.

These cultural schemas were then “imported” into the Math Preservice Committee from each individual’s respective disciplinary home and became integral features of the committee’s ensuing process. At the outset, most committee participants noted a high degree of willingness to collaborate and deal with the problem at hand, and the commonly held schemas provided a foundation of agreement upon which the committee was able to build. However, it did not take long for committee members to find disagreements about math education, and it was primarily through these conflicts that elements of the cultural models were made visible. Some of these points of disagreement are important to understand as they remained a persistent challenge for the duration of the SCALE grant. Barriers to effective collaboration included each group's lack of expertise in the other's discipline, differences in the language used by each group, and the entrenched views that each group held about the other. We speculate that the cultural schemas implicitly conveyed by the SCALE intervention were more similar to those of the math educators than they were to those of the mathematicians, as math educators generally had few disagreements with the intent and design of the committee, while some mathematicians had some significant disagreements. This has important implications for how participants perceived the intent of the reform, and if and how the reform will be allowed to permeate the existing practices and cultural schemas of the Math and C&I Departments.

As outcomes of this SCALE activity, we identified (a) self-reported changes to specific schemas, (b) changes to the curriculum and pedagogy of the Math 13X sequence, and (c) a newly invigorated structural venue for cross-departmental interaction at UW-Madison. We identified only minor shifts in specific schemas for each subgroup. This finding is consistent with research on the difficulty of effecting changes to fundamental conceptual knowledge (Strike & Posner, 1985) and the resiliency of culture (Martin, 2002). Three mathematicians exhibited small shifts in the schema *content drives pedagogy* and came to appreciate that teaching mathematics is not a simple or "obvious" practice. In other cases, schemas were not changed per se, but respondents' understanding shifted. For example, four participants exhibited a greater appreciation for the other group's approach to math instruction, which suggests a more nuanced and grounded understanding of the schema *solving problems in math is different from solving problems in education*. Among the participants who reported shifts in this schema were graduate students, who exhibited a certain emotional and intellectual distance from the more contentious schema discussed above, which may be related to the fact that they were in a relatively early stage of socialization.

We speculate that the importance of changes to these schemas is potentially large, as they enabled the increase in respect among the participants that the committee needed in order to proceed with its mission (e.g., redesigned math courses and renewed interdepartmental collaboration). This said, we caution against assuming that shifts of this type will automatically translate into changes in behavior, particularly classroom practice. As for the new structural venue for interdepartmental interaction that SCALE enabled, we note that at T1, a goal of the Math 13X Committee was to involve School of Education faculty in the decision-making process regarding the Math 13X sequence. However, at that time there were few, if any, opportunities for the values, beliefs, and perspectives of School of Education faculty to affect decision making about these courses. By T2, SCALE had changed this committee into a forum in which the cultural schemas of all constituent groups came into contact—and sometimes conflict—with one another. By providing this forum, SCALE had altered a key structural element of the UW context that enables the formation and reproduction of cultural schemas. This analysis suggests that shaping the culture of an organization may include efforts to change or alter the structural, social, and symbolic milieu in which individuals operate, but the actual cognitive processes that constitute individuals' "habits of mind" are much more difficult to change. It is especially important to realize that cultural schemas and individual mental models operate according to a logic that is most likely inaccessible to leaders and change agents (unless they are insiders to that cultural group), and thus leaders may need to employ a flexible and multifaceted toolkit of "frames" through which to analyze their organizations (Bolman & Deal, 2003).

Conclusions and Analyst Recommendations

To understand the impact of SCALE on UW-Madison, one must bear in mind the relationship between the key contextual factors and institutional change processes identified in this study. Research universities like UW-Madison are large, complex institutions consisting of many different, loosely coupled colleges and departments that largely operate according to their own logic, rules, and norms. The disparate yet interconnected contextual factors identified in this study operate in a dynamic fashion such that a change in one may yield unpredictable and even imperceptible movement in others. While SCALE did not foment a sea change at UW, by focusing its efforts on relatively small and discrete points within the UW context—redesigning STEM courses for preservice teachers and engaging faculty and academic staff to support K–12 teacher professional development—it nonetheless effected some very real changes at multiple points at T2. (See the Findings section, above.)

We propose that SCALE's enacted theory of change demonstrates that change must be pursued simultaneously on structural, sociocultural, and individual levels in order to produce improvement that is sustained over time,. Based on research on organizational change, we postulate that an approach that addresses a plurality of factors is an effective—possibly a necessary—strategy at institutions such as UW-Madison, because such an approach is commensurate with the complexity and multidimensionality of the institutional context. We therefore consider the enacted SCALE theory of change to be promising, as long as its implementation is guided by a sophisticated understanding of the multifaceted nature of the barriers and supports within an IHE. This latter condition was met in the SCALE project because the SCALE PI had extensive institutional knowledge and memory to draw on in designing the reform effort and thus had an astute understanding of the organizational context. However, relying on an individual local leader may result in a project that is focused only on the leader's ambit of experience and thus does not engage a wider range of programs and personnel. The enduring lesson from SCALE activities at UW-Madison is that efforts to change the culture of teaching and learning in STEM departments should focus on illuminating and then shifting the pervasive cultural schemas that faculty hold for teaching and learning. One strategy for doing so is to create officially sanctioned venues where individuals from different disciplinary backgrounds are led by a skilled facilitator or culture broker to focus on commonly shared pedagogy-related challenges. Leaders would benefit from being aware of and sensitive to the deeply entrenched nature of cultural schemas and their embeddedness in the local institution.

We suggest that, of the many contextual factors identified in this study, the following stand out as especially promising in leveraging the types of change sought by the MSP program:

1. Decision-making bodies and interdepartmental forums;

2. Networks of STEM educators;

3. Academic staff and graduate students;

4. Cultural schemas regarding disciplinary legitimacy and credibility; and

5. Individual sense-making.

We emphasize the effects of individual sense-making on both the implementation processes and the eventual outcomes of STEM education reforms. Consider, for example, the sense-making filters that faculty use when faced with a new situation: workload and attendant recruitment, tenure, and promotion considerations; cultural schemas salient to the topic at hand; availability of resources (fiscal and social); and the structural and technical constraints of the individuals' location in the institution. We suggest that the above factors deserve particular attention by campus leaders and STEM education reformers, since they have the potential to affect a cascade of impacts in a variety of points in the organizational context of an IHE. In so saying, we caution that the above five (as well as other) leverage points should not be viewed as "magic bullets" that can produce fast and enduring reform across the entire university.

We also recommend that future STEM education reformers at research universities, and policy makers at funding agencies such as NSF and the Department of Education who may wish to replicate SCALE successes at UW-Madison, may benefit if they:

- Conduct assessments of the institutional context before planning and implementing a program;

- Marshal existing resources and reforms to collectively target key leverage points;

- Understand and address the constraints facing STEM faculty when recruiting them for reform efforts;

- Focus on developing new cohorts of STEM educators in specific departments;

- Engage and foster community among specific groups of STEM educators in a strategic manner (e.g., high-status individuals, faculty already engaged with preservice programs, academic staff);

- Change dominant cultural schemas for STEM instruction by creating interdisciplinary committees that are focused on high-value tasks and facilitated by a culture broker who understands how to manage diverse groups; and

- Carefully design top-down structural reforms with attention to cultural considerations.

A Final Case Study of SCALE Activities at UW-Madison: The Influence of Institutional Context on a K–20 STEM Education Change Initiative[2]

Matthew T. Hora and Susan B. Millar

I. Introduction

Institutions of higher education (IHEs) play an important role in mathematics and science education by offering undergraduate instruction, operating teacher training programs, and providing in-service training for K–12 teachers. The National Science Foundation (NSF)–funded System-wide Change for All Learners (SCALE) project sought to effect change in its partner IHEs by (a) improving science, technology, engineering, and mathematics (STEM) undergraduate education; (b) improving collaborations between STEM and education faculty on preservice programs; (c) improving collaborations between IHE faculty and K–12 districts on in-service training; and (d) improving the institutional policies and practices that support these activities. As part of the SCALE IHE case studies line of work, this paper provides findings on the effects of the SCALE project at the University of Wisconsin–Madison (UW-Madison) between May 2004 and August 2007. This case study includes two interrelated accounts of SCALE activities: (a) a presentation of evaluation findings for each of the SCALE activities undertaken at UW-Madison and (b) an analysis of how specific aspects of the institutional context influenced SCALE activities.

NSF Math and Science Partnership Program

Background: Declining Performance of U.S. Students in Mathematics and Science

The performance of U.S. students in mathematics and science is an increasingly pressing problem, particularly in light of the implications for the future competitiveness and employability of U.S. residents. As numerous studies and reports attest, the problem is systemic, with challenges that include public policy, funding, and curricular strategies that span the education continuum from K–12 to higher education (Committee on Science, Engineering, and Public Policy [COSEPUP], 2006; National Research Council [NRC], 2001; Project Kaleidoscope, 2006; U.S. Department of Education, 2006b; U.S. Office of Science and Technology Policy, 2006). Most recently, researchers and policy makers are focusing on the importance of a teacher workforce that is more highly trained in science and mathematics (Levine, 2006; U.S. Department of Education, 2005). Indeed, the 2006 COSEPUP report suggested that an appropriate goal to address the eroding U.S. advantages in mathematics and science would be to produce 10,000 qualified teachers annually. This goal addresses the "chronic and growing shortage of discipline qualified K–12 teachers" that researchers have been warning

[2] The authors would like to thank faculty, staff, and administrators from the University of Wisconsin–Madison and the Madison Metropolitan School District for participating in this case study. We also wish to thank Matt Clifford, Joe Ferrare, Eric Osthoff, Laura DeLima, and members of the SCALE Research and Evaluation Team for their support and suggestions, especially Andrew Porter, Norman Webb, Jeff Watson, William Clune, Natalie Tran, and Paula White.

policy makers about for several years (Seymour, 2001). This shortage is illustrated by the fact that in 2000, 93% of students in Grades 5–9 were taught physical science by an instructor who lacked a college major or certification in the physical sciences (National Center for Education Statistics, 2004). The mandate of the No Child Left Behind Act (NCLB; 2002) that all school districts must employ only “highly qualified teachers” further indicates that teacher workforce quality in science and mathematics is a critical national issue.

One of the many challenges in reforming teacher preparation and professional development practices in the U.S. is the complex nature of the preparation process. For example, to qualify for certification to teach at the K–12 level, most future mathematics and science teachers must navigate both teacher preparation programs in schools of education and disciplinary requirements in STEM departments at accredited IHEs. Then, they participate in professional development programs that are governed by state and/or district policies and offered by an array of providers including private vendors, district specialists, and IHE faculty. Thus, individual K–12 teachers obtain their mathematics and science content and pedagogical training from diverse institutions and stakeholders whose programs are governed by diverse policies that operate in isolation and with little coordination (NRC, 2001). As a consequence, the quality of this training often is uneven, if not haphazard (Mundry, Spector, Stiles, & Loucks-Horsley, 1999). In 1998, the NRC addressed this multi-institutional problem by establishing a Committee on Science and Mathematics Teacher Preparation (CSMTP). The CSMTP report (NRC, 2001) states that a significant restructuring of the relationship between K–12 schooling and higher education, including new partnerships to collaboratively design and implement high-quality professional development programs, is required to adequately prepare and train effective teachers.

NSF Math and Science Partnership Program

Growing concerns about improving the alignment of the teacher training continuum are among the reasons NSF has invested substantially in teaching improvement and organizational change in higher education—most recently through its Math and Science Partnership (MSP) program. These concerns reflect development in some national policy makers’ understanding of the role that higher education plays in preparing future teachers, moving beyond long-held critiques of teacher preparation programs to a closer examination of the role of disciplinary faculty in the STEM disciplines.

The NSF MSP program aims to improve the coordination among STEM undergraduate education, teacher preparation programs, and K–12 professional development by fostering mutually beneficial partnerships between IHEs and K–12. Specifically, it hopes to encourage partnerships between STEM disciplinary faculty, education faculty, and IHE administrators and the K–12 districts they serve in “efforts to effect deep, lasting improvement in K–12 mathematics and science education” (NSF, 2002). The MSPs are based on the premise that IHE/K–12 partnerships should draw on the disciplinary expertise of STEM faculty and graduate students and undergraduate STEM (including preservice) students to develop strong math and science content knowledge and pedagogical methods. That is, the MSP program’s theory of change includes the idea that increased involvement of STEM faculty in the teacher training continuum will result in lasting improvements in K–12 student learning (Change and Sustainability in Higher Education [CASHE], 2006; NSF, 2002).

Specific Problems Addressed by MSP Program

STEM undergraduate instruction. Critiques of the quality of teaching in higher education began in the 1980s with *A Nation at Risk*, by the National Commission on Excellence in Education (1983). Since then, we have seen a cascade of criticisms of higher education, culminating in the U.S. Department of Education's *A Test of Leadership* (2006a). Critics note that many STEM undergraduate majors graduate with substantial deficiencies in their content knowledge (e.g., Handelsman et al., 2004). Researchers have identified high rates of attrition among undergraduate science majors as one of the consequences of poor undergraduate instruction and academic assistance (Seymour & Hewitt, 1997). Because in most states students seeking to earn secondary school teaching credentials are among these science majors, and in all states students seeking to earn primary and secondary school teaching credentials take STEM courses, national policy makers are increasingly recognizing and scrutinizing the roles that STEM faculty play in the teacher training continuum by instructing preservice candidates in disciplinary content and modeling pedagogical methods. For example, NSF's *Shaping the Future* report (1996) recognized these roles when it urged STEM faculty to use active learning strategies in their undergraduate courses not only to help students understand disciplinary content more deeply but also to model effective pedagogy for future teachers.

Teacher preparation programs. Teacher preparation programs and the colleges of education that operate them have been subject to criticism for years. In particular, critics charge that college of education curricula for preservice candidates are poorly designed and insufficiently grounded in rigorous content courses and/or pedagogical instruction (Labaree, 2004; Mundry et al., 1999). Policy bodies such as CSMTP (NRC, 2001) and NSF-funded practitioner reformers have urged greater collaboration across departments and colleges within an IHE with respect to teacher preparation. In response to these critiques and recommendations, many initiatives both within and outside IHEs are under way to improve teacher preparation and training (Robinson, 2006). Among these initiatives are several—including NSF's Collaboratives for Excellence in Teacher Preparation and the MSP program—that focus on the role of STEM and education faculty in organizing and delivering a solid curriculum. However, critical gaps remain in our understanding of teacher education program effectiveness, including the effects of subject-matter coursework on teacher knowledge (Cochran-Smith & Zeichner, 2005) and the relative efficacy of different teacher education pathways (Darling-Hammond, Chung, & Frelow, 2002).

IHE participation in professional development programs. In-service training in disciplinary content and pedagogical methods, which authorities suggest should occur on a regular basis (U.S. Department of Education, 2005), is another key venue for enhancing K–12 teacher mathematics and science knowledge. There is a large body of research on the efficacy of professional development programs, and researchers are increasingly questioning the efficacy of the traditional program model, in which IHE faculty or other "experts" deliver "knowledge" to K–12 teachers (Garet, Porter, Desimone, Birman, & Yoon, 2001). This approach is considered ineffectual because it is decontextualized, treats teaching as a routinized and technical activity, and stresses "additive rather than transformative change" (Carlone & Webb, 2006, p. 545). Possible solutions to this problem include paying closer attention to the context of professional development design (Ball and Wilcox, 1989), fusing content and pedagogy by involving both disciplinary and education IHE faculty (U.S. Department of Education, 2005), and more explicitly building on novice teachers' prior experiences or knowledge (Mundry et al., 1999).

Challenges to higher education reform. The MSP program is facing the extremely difficult undertaking of fostering change in higher education, a sector known to be very resistant to change (Cuban, 2000). Researchers cite the persistence and resilience of institutional tradition (Kezar & Eckel, 2002), the decentralized and "loosely coupled" nature of IHEs (Birnbaum, 1988), and the unique elements of organizational structures and autonomous cultures (Schroeder, 2001) as characteristics of IHEs that make them resistant to change efforts. Furthermore, historic divisions between STEM and education faculty, and between higher education and K–12 education, may inhibit collaborative activities between these sectors (Labaree, 2004); Gilroy, 2003). These challenges are pertinent to the MSP program and may limit its effects on STEM faculty and institutional processes. For example, a 2006 review of institutional changes catalyzed by 21 MSP higher education partners found that while curricular changes were occurring at IHEs across the MSPs, a majority of the changes were occurring in preservice programs and in-service professional development, not in STEM departments (CASHE, 2006). Furthermore, changes were at the individual rather than the institutional level, with no department-wide initiatives or collaborative team efforts. An analysis of STEM faculty engagement in the MSP program (Zhang et al., 2007) similarly found little evidence of institutional change, but identified significant individual-level shifts in STEM faculty knowledge of and collaboration with K–12 education. The Zhang et al. study also found that the effect of STEM faculty engagement in the teacher training continuum was difficult to ascertain and that effects on student learning were even more elusive.

SCALE Theory of Change and Goals for IHEs

The MSP project featured here, SCALE, sought to effect change in its partner IHEs by fostering a "transformative culture" through the creation of "cross-cultural working teams" that operated at the intersection of K–12 districts, colleges of education, and colleges of mathematics, science, and engineering (SCALE, 2005). Upon engaging the IHE case studies team, SCALE leaders conveyed their theory of action regarding IHEs by stating that SCALE seeks to achieve the following goals:

1. Reform undergraduate STEM courses;

2. Promote collaboration between STEM and education departments on preservice teacher education;

3. Promote collaboration between IHEs and K–12 districts on in-service professional development; and

4. Improve institutional policies and practices at the IHE level that support faculty engaged in pre- and in-service activities.

However, SCALE leaders did not define or operationalize the construct of *organizational culture* or state measurable objectives for the four goal areas articulated for the IHE case studies team. Unable to measure progress toward a set of clearly defined objectives or evaluate the program according to a set of established criteria, this evaluation design focused on describing program activities, assessing how well subsequently observed effects met stated goals, and analyzing the relationship between the institutional context and program activities.

Methodology of SCALE IHE Case Studies

This section briefly describes the rationale for the research, the theoretical framework guiding the research, and the research design. For a more detailed description of the study's methodology, see the appendix.

Conceptual Framework

To achieve the goal of improving K–20 STEM education, policy makers, funders, and practitioners are placing greater weight on methodological issues in program evaluation, with particular focus on basing decisions about program replicability and expansion on knowledge-based claims (Lawrenz & Huffman, 2006; Mosteller & Lee, 2004; Kelly & Yin, 2007). Programs such as the NSF MSP program entail research and development, requiring high-quality evidence of effectiveness in order to ensure intellectual rigor and broad applicability (NSF, 2002). These requirements further contribute to an interest in evaluation.[3] There is also a widespread pressure to improve the methodological rigor of evaluations of STEM education programs (U.S. Department of Education, 2007). Some researchers note that education research has had a difficult time establishing itself as a science, in part due to the lack of accumulated knowledge, replicable studies, and transparency about methodological issues (Kelly & Yin, 2007). Researchers who study STEM education reform are surfacing difficulties associated with studying change processes in complex institutional environments (Patton, 2006; Clune et al., 1997). A particular challenge found in many evaluation studies is that researchers have tended to focus on discrete elements, such as curriculum or assessment practices. Anderson and Helms (2001) argued that reformers need to "come to grips with the totality of this complex situation" in order to fully understand these complex dynamic systems and the basis for accepting, rejecting, or adapting reform initiatives (p. 4). In response to these concerns, this study of SCALE at UW-Madison seeks to help convince the wider social science community that education research is moving toward evaluation procedures that are high quality and well suited to the research challenges inherent in studying complex institutional environments such as IHEs.

Our methodological approach is to analyze the SCALE project through the analytic lens of organizational culture. We define *culture* as patterns of behavioral norms, beliefs, and values that are differentially internalized and expressed by individuals *and* larger collectives, each operating within the structural and social constraints of different administrative units. In this formulation of culture, neither the institutional context nor individuals are secondary considerations; each is treated as an integral component of an IHE. Our emphasis on culture enables us to situate an intervention within its local institutional context and thus to systematically observe the "black box" of reform implementation. The underlying research paradigm guiding this approach is that of ethnographic research, meaning that we attempt to

[3] The MSP program sponsored a 2008 conference with the theme "Claims-Based Outcomes: What do we know? How do we know what we know? What do we still need to know?"

describe the IHE context and the SCALE implementation in a grounded and multidimensional fashion, based largely on the perspectives and experiences of local participants (Agar, 1996). This approach enables us to provide SCALE leaders and NSF with three types of actionable knowledge:

- Knowledge of the key components of the organizational context pertaining to the SCALE project, their influence on the project's implementation, and key leverage points for future reform;

- Evaluation findings about SCALE activities and their outcomes, including effects on the organizational context; and

- Knowledge of how the organizational context and a specific SCALE activity influenced one another.

Research Design

The research questions for the IHE case studies line of work were informed by the dual need to evaluate the SCALE MSP and to more deeply examine the reasons SCALE did or did not achieve its goals. Hence, we posed these research questions—which mirror the SCALE theory of change—about each IHE studied:

1. How does the institutional context influence STEM instruction, STEM and education faculty collaborations on preservice programs, and IHE and K–12 collaborations on in-service programs?

2. Are SCALE activities contributing to changes in SCALE's primary goal areas? If so, how?

3. Under what conditions are change initiatives, including SCALE, accepted and incorporated at the institution?

This case study used a repeated cross-sectional design, with in-depth interview data collected at Time 1 (T1; February–June 2006) and Time 2 (T2; June–August 2007). Other data collected for this research included official university and SCALE documents and observations of SCALE meetings. Nonrandom sampling procedures were used to identify interview respondents—22 at T1 and 25 at T2, for a total of 47 interviews with 42 unique individuals. Interview transcripts were coded using a scheme we call the *institutional context framework* (ICF), which is based on preliminary analyses of the SCALE IHEs (Hora & Millar, 2007) and includes the following code families: external environment, internal structure, resources (fiscal and social), collective values and beliefs, individual sense-making, and practices. Next, queries of the transcript database were conducted to identify high frequencies of code applications for specific codes and code combinations. These reports were then analyzed inductively, and findings were constantly compared to other sources of data.

Additional analytic procedures included (a) an inductive analysis of the coded interview transcripts using a grounded theory approach (Strauss & Corbin, 1990), (b) a causal network analysis that organized data by time and posited mechanisms of change, and (c) an exploratory analysis of mental models based on the coded interview transcripts and field observations. We used established methods of qualitative analysis to verify our findings, including triangulating sources, actively seeking disconfirming evidence, and member-checking findings to ensure their accuracy.

Limitations

This research is designed to (a) explore faculty sentiments at one intervention site, (b) investigate the initial impact of SCALE activities at that site, and (c) generate a theoretical and practical approach for analyzing STEM education projects. As a result, the sample of respondents interviewed for this research does not constitute a random or representative sample of UW-Madison overall, or of individual UW-Madison colleges or academic departments, and is not intended to be generalizable to other IHEs or even to other IHE faculty. This micro-level analysis builds on the strength of the ethnographic case study approach. The interpretations and claims in this case study go only as far as is warranted by the methods used and the data collected. Since the preliminary IHE case studies were also intended to provide feedback for SCALE administrators and practitioners, it is possible that these case studies influenced the outcomes of SCALE and the findings reported here. Another limitation of this research is that two different researchers conducted data collection at T1 and T2, which potentially resulted in variations in the type and quality of data collected. However, a single researcher conducted the analysis, including coding the interview transcripts in NVivo. Finally, attrition of faculty and program participants at UW-Madison resulted in different populations available for interviews at T1 and T2. As a result, reported changes reflect the views of a variety of respondents at both points in time and do not represent the observations or experiences of a single cohort over time.

II. Snapshot of Intervention Site: UW-Madison

In this section, we feature certain characteristics of UW-Madison that are prominent elements of the “field” in which the intervention was enacted. These characteristics are not just a backdrop to the SCALE MSP; rather, they comprise the technical, sociocultural, and political context within which the intervention operated. Furthermore, an IHE’s culture is grounded in its geographic location and history, its particular structural and social systems, and the unique milieu it inhabits in the world of higher education. Taken together, these factors constitute the broad outlines of the organizational culture as it pertains to the SCALE project. A more intensive analysis of how these factors interacted to influence the SCALE program is the subject of Section III.

Founded in 1848, UW-Madison is the flagship institution of the University of Wisconsin System. It is located in Madison, the state capital and the second largest city in Wisconsin (population 214,098 in 2006; see Figure 1). UW-Madison is one of the largest public universities in the nation.[4] It has an annual total budget of $1.8 billion yet operates in a climate of declining financial support from the state of Wisconsin and increased public scrutiny over its finances. In the fall of 2006, it enrolled some 28,000 undergraduate students and 9,000 graduate students (of whom approximately one fourth were teaching assistants) and employed some 2,000 faculty,

[4] www.wisc.edu/about/facts/

1,500 instructional academic staff, and 4,700 other academic staff. Its teacher education program is relatively small: in 2006–2007, it certified 125 students to teach in elementary education, 15 students in secondary math, and 22 in secondary science.[5]

***Figure 1*. Location of the University of Wisconsin–Madison.**

Mission

UW-Madison is a designated land-grant university and is located in one of the most productive agricultural regions of the country. One of the missions of land-grant universities is to teach agriculture and provide working-class residents of the state with a solid and affordable liberal arts education. This mission led in part to the development of the "Wisconsin Idea," a tradition begun by UW President Charles Van Hise in 1904, who stated that he would "never be content until the beneficent influence of the university reaches every family in the state."[6] The current strategic plan also asserts that the university aims to "vigorously share advances in science and knowledge with the people of the state, the country, and the world" and "to expand university-state relationships in a way that reflects the new global economy."[7]

Institution Type

According to the Carnegie Foundation's influential ranking of IHEs, UW-Madison was formerly classified as a Research I (RI) institution and now is categorized as a Research University with very high research activity (RU/VH; Carnegie Foundation for the Advancement of Teaching, 2006). The RI moniker will be found throughout this report due to its pervasive usage by IHE faculty and administrators. This ranking is considered prestigious and indicative of a top-flight university with active research programs, highly ranked departments, and

[5] www.bpa.wisc.edu/datadigest

[6] www.wisc.edu/wisconsinIdea/

[7] www.chancellor.wisc.edu/strategicplan/

internationally recognized faculty. According to the Program on Measuring University Performance (Lombardi, Capaldi, & Abbey, 2007), in 2003 UW-Madison was ranked fourth in total research funding, eighth in federal research funding, and eighth in doctorates granted.

Organizational Structure

The upper administration of UW-Madison consists of a chancellor (who is considered the chief executive officer of the university), a provost and vice chancellors, and 15 deans of various schools and colleges. The schools and colleges, in turn, are organized into four divisions: biological sciences, physical sciences, social studies, and arts and humanities. However, a defining characteristic of the university is that authority is frequently devolved from the institutional level to colleges and especially to departments, where decisions are ultimately made regarding tenure guidelines, assessment procedures, and the academic program. The critical role that departments play is further accentuated by a cherished tradition of faculty autonomy. Faculty are vested with responsibility for "immediate governance of the university" and have "primary responsibility for academic and educational activities and for faculty personnel matters, including educational policies, establishment of faculty committees, requirements for admission, requirements for graduation, adoption of rules for recruitment and performance reviews."[8] As a result, key decisions are often made at the departmental and individual faculty levels, though interdepartmental committees and individual colleges are also important venues for decision making. The characteristics of the organizational structure that are particularly salient to the SCALE MSP are depicted in Figure 2.

Faculty Workload

Faculty at UW-Madison generally devote the great majority of their effort to research and teaching and allocate a relatively small proportion to professional or community service. Some faculty undertake multiple research projects funded by external grants worth millions of dollars, while many others pursue fewer projects and work without external funding. Teaching responsibilities are established by each department and vary based on tenure status and specialty area, but generally faculty teach one to two courses a semester. Courses differ in format, from undergraduate courses with up to 400 students to 8-student graduate seminars. There is a widespread perception by faculty that their professional lives are overwhelmingly busy with research, teaching, and service responsibilities (Rouse & Sapiro, 2005; Millar, Clifford, & Connolly, 2004).

Faculty Recruitment, Tenure, and Promotion

Faculty life is characterized by attention to the reward and promotion system within departments, also known as the recruitment, tenure, and promotion system. Even after achieving tenure, faculty are subject to promotion policies and are expected to meet departmental needs and expectations. The three primary criteria for achieving tenure in each division are research, teaching, and service. Research is described as an active research program that has "yielded demonstrably significant results," as evidenced by publications, and evidence of external funding

[8] www.secfac.wisc.edu/governance/FPP/Chapter_1.htm

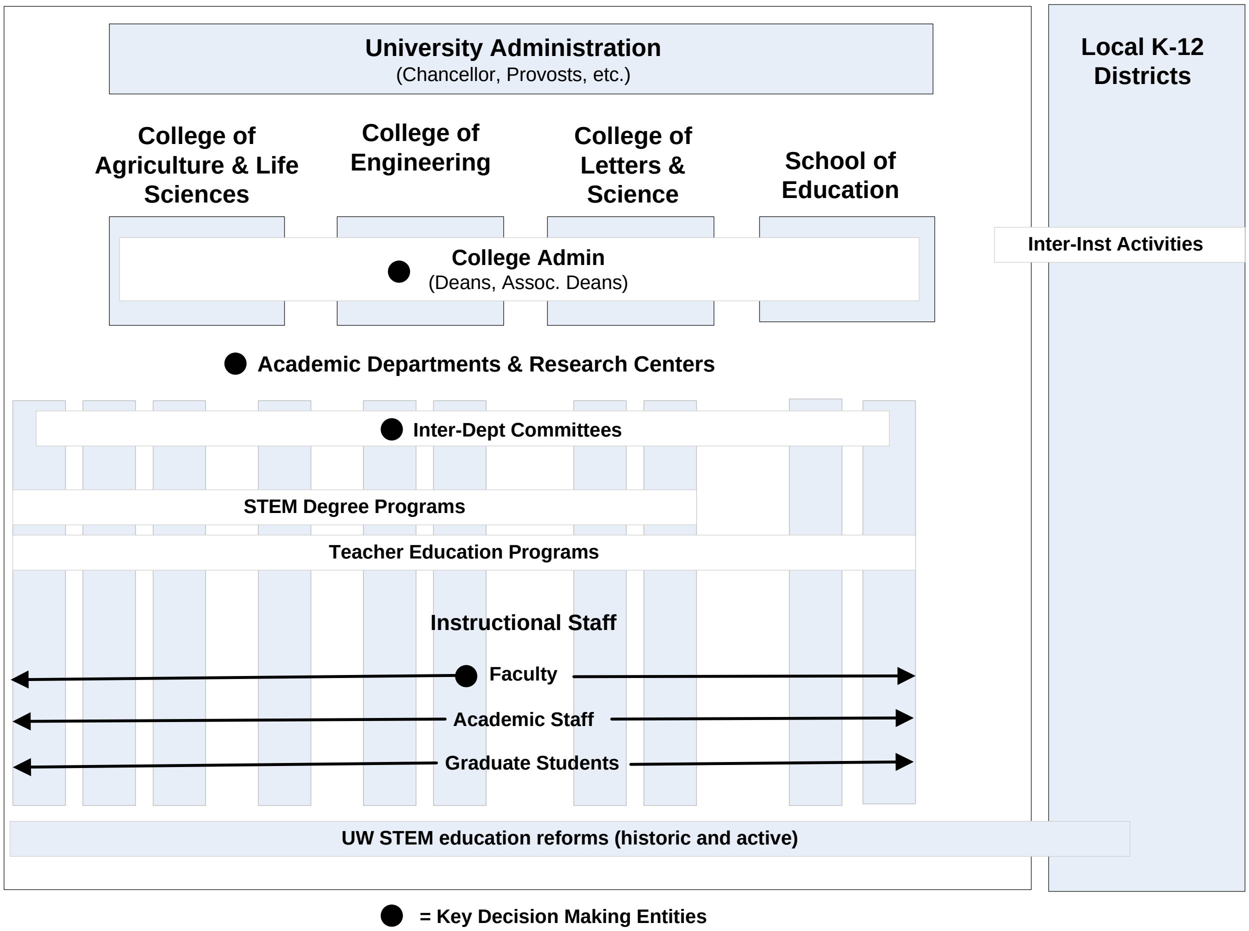


***Figure 2*. Structural characteristics of UW-Madison salient to the SCALE MSP.**

to ensure the viability of the research program is highly valued.[9] Teaching is measured by peer review (at the discretion of the department) and student evaluations. Service is a very broad construct that includes participation in departmental or university committees, professional organizations, government agencies, and professional consultation to the community. It is clearly stated that service alone is insufficient for tenure or promotion.

Local K–12 Districts and Outreach

The Madison Metropolitan School District (MMSD) is the site for numerous UW-Madison outreach activities, faculty research efforts, and collaborative programs. In fall 2006, MMSD's 53 schools or programs enrolled approximately 24,600 students and employed 2,700 teachers.[10] Involvement with K–12 education at UW-Madison has historically been through outreach programs (such as UW-Extension), recruitment efforts, campus-wide initiatives to engage the community in implementing the Wisconsin Idea, or interactions between individual faculty and individual schools or teachers. These latter efforts involve IHE faculty in conducting

[9] www.secfac.wisc.edu/governance/FPP/Chapter_1.htm

[10] www.madison.k12.wi.us/district.htm

demonstrations or field days at schools or public events, inviting K–12 students and teachers to participate in research activities, or conducting education research in individual classrooms or schools.

Education Reform Environment

Institutional change initiatives pertaining to the education mission are part of the institutional history at UW-Madison, notably including the activities of Dr. Alexander Meiklejohn, who created a revolutionary “learning community” in 1927. UW-Madison is nationally recognized as having visible and prominent teaching and learning initiatives that some believe indicate an institutional commitment to improving undergraduate education (Fogg, 2006). The education change initiatives currently under way operate at campus-wide, departmental, and individual faculty levels and are loosely coordinated, if at all. Many of these initiatives are funded by external sources such as NSF and are not internally directed. Some of the NSF-funded initiatives were particularly influential in shaping the SCALE project, as they directly involved the SCALE principal investigator (PI) and other UW-Madison staff; these projects included the National Institute for Science Education (a unique center funded from 1995 to 2000), K-Through-Infinity (a project of the Graduate Teaching Fellows in K–12 Program, funded from 1998 to 2003), and the Center for the Integration of Research, Teaching, and Learning (one of two postsecondary Centers for Teaching and Learning, funded from 2003 to 2011).

STEM Degree Programs

STEM discipline degree programs are offered by departments and centers in the Colleges of Engineering, Letters and Science, and Agricultural and Life Sciences. Based on averages for the years 1996–2005, the relative proportion of total bachelor’s degrees granted in the biological and physical sciences was low (19% and 15%, respectively) relative to the proportion of doctoral degrees granted in those fields (25% and 30%, respectively).[11] As is common at Research I institutions, most UW-Madison STEM faculty place the needs of doctoral students first (Millar et al., 2004). Because the numbers of students graduating with STEM degrees reflect diverse factors—such as student interest and job markets, department reputation, and department efforts to attract majors—we do not provide numbers of degrees granted by specific STEM major. Speaking broadly, the most popular undergraduate STEM majors are in engineering/computer science, followed by the biological sciences.

Teacher Education Programs

The elementary and secondary teacher education programs at UW-Madison are administered by the School of Education. The school is one of the top-rated colleges of education in the country, known especially for its curriculum and instruction, educational psychology, and educational administration programs. It offers teacher education programs in more than 30 subject areas, each of which requires 4 years of coursework. In 1996–2005, the average numbers of bachelor’s degrees granted in elementary education and special education were 119 and 27,

[11] apa.wisc.edu/degrees/FTE_Degrees_AllLevels_Rank_2004.pdf

respectively. Students graduating with certification in secondary math and science are included among students earning undergraduate STEM majors. For the academic year 2006–2007, 15 were certified in secondary math, and 22 in secondary science (UW-Madison School of Education, personal communication, 2007).

The elementary education program has two options: the early childhood/middle childhood option prepares teachers to work at preschool, primary, and intermediate levels, and the middle childhood/early adolescence option prepares teachers for intermediate and middle school levels. Each option includes liberal studies courses, coursework in a focus area, education coursework, and a professional sequence. Also, a dedicated sequence of courses provided by the Department of Mathematics is required for elementary preservice candidates. This sequence, called the *Math 13X sequence*, includes courses called Mathematics for Elementary Teachers, Arithmetical Problem Solving, and Geometrical Inference and Reasoning. The secondary science and math programs require majors in the disciplinary field and additional methods or pedagogy coursework in the Department of Curriculum and Instruction. Options for the secondary science major include broad field science, biology, chemistry, earth and space science, and physics. The broad field science degree option is attractive because it permits individuals to teach courses in middle and high school that are not specific to a particular science field, with titles such as Life Science and General Science.

III. Influence of Institutional Context on SCALE MSP at T1

Underlying this research and evaluation is a desire to conduct an empirical investigation into the relationship between the institutional context of an IHE and the implementation of a math and science education reform effort. Because reform efforts such as SCALE—far from working in a vacuum—interact with various elements of the institution and coexist with extant reform initiatives, it is critical to understand the context in which a reform effort unfolds (Patton, 2006; Katzenmeyer & Lawrenz, 2006; Anderson & Helms, 2001). In addition, researchers in both K–12 and higher education have established that a primary reason instructors do not passively receive policy directives and translate them with complete fidelity to the classroom is that they are inclined—if not required—to attend to contextual features of their organizations, especially the culture of administrative units such as academic departments (Birnbaum, 1988; Gamoran et al., 2003; Coburn, 2001). Insights into the processes by which features of the institutional context dynamically interact in ways that lead actors to resist, adapt, or adopt reform efforts like SCALE can improve our understanding of the relationship between instructional policy and local implementation, and provide actionable knowledge for program planners.

In our approach to evaluating the effects of culture on the SCALE project, both the institutional context and individual actors are considered integral components of the context of an IHE, with neither subordinated to the other. This case study shows that the factors that affected how the SCALE reform effort played out include not only degree programs and governance structures, but also material and human resources, group identities fostered by structured interactions, and individual dispositions and practices—all of which were influenced, in turn, by external factors. Analysis of these factors enables us to understand the often nonlinear and sometimes unpredictable interactions between a reform effort, an institution, and its members. With this focus, we emphasize the importance of situating an intervention within its local organizational context in order to systematically observe the “black box” of reform implementation.

Factors Relevant to SCALE in UW-Madison Context

This section presents findings on how organizational context factors at UW-Madison interacted with the SCALE MSP. Upon analyzing interview transcripts, documents, and field notes from observations and interviews, we identified key factors within the organizational context that were salient to the SCALE intervention and played either a supporting or an inhibiting role. We assigned a valence to each factor—*supporting* (+) or *inhibiting* (-)—based on respondent views or our own interpretation of the relationship. We organized these findings by the institutional context framework (ICF) categories. This section is organized by these categories, as is Figure 3, which summarizes the key findings. (See the appendix for more information on the analysis used to derive the findings discussed in this section.)

External Environment

Factors external to UW-Madison with an impact on SCALE include institution type, national and state education policy, academic training of faculty, economic forces affecting education, and local K–12 characteristics.

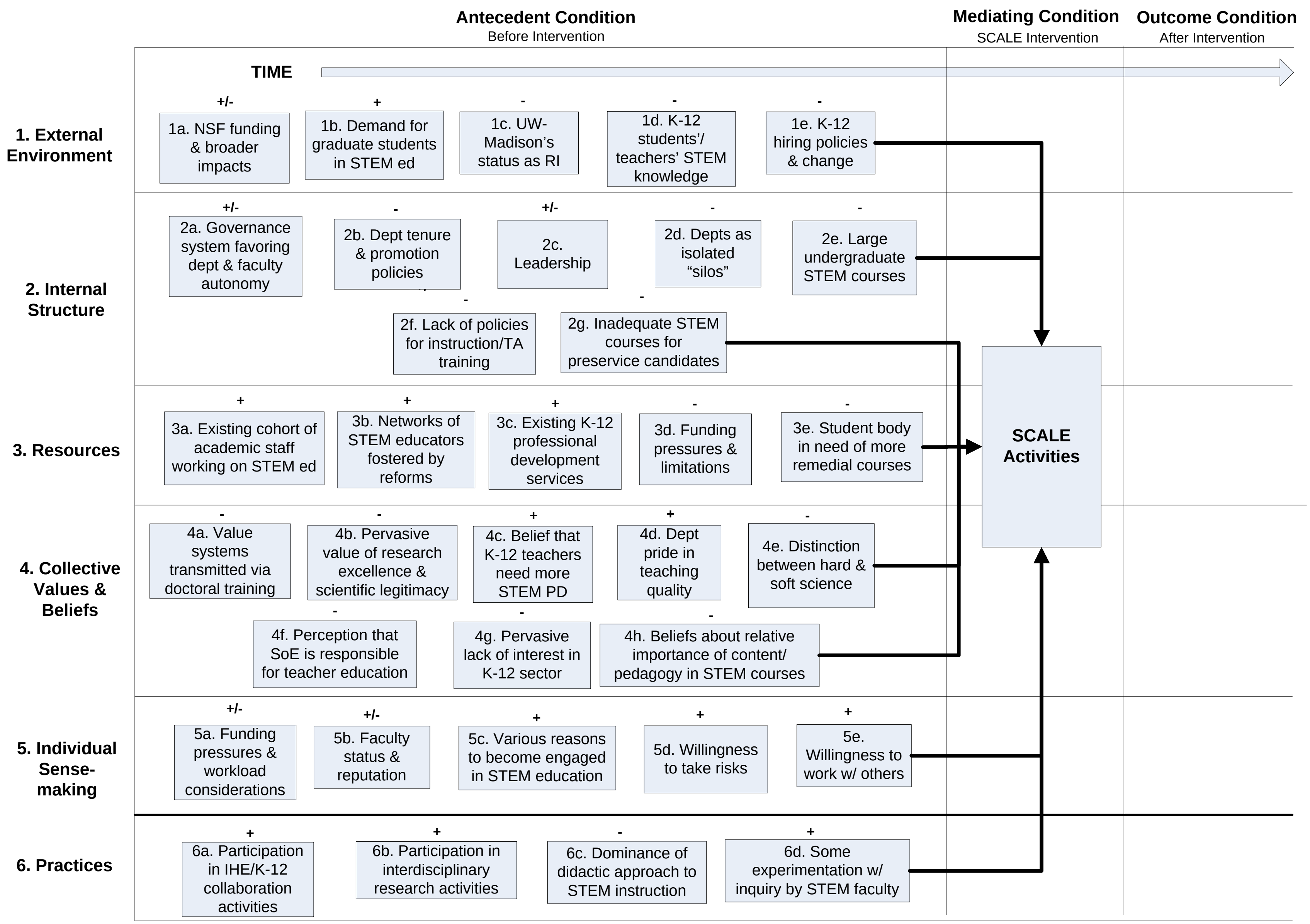
NSF funding requirements lead faculty to consider broader impacts (+/-). NSF funding is a significant source of revenue to UW-Madison and its faculty and academic staff. By requiring that grantees consider the “broader impacts” of their research, NSF funding is leading faculty and staff to consider if and how their research could affect the general public. While some faculty may pay lip service to this criterion, others are genuinely committed to the effort, and some of these seek opportunities to engage the K–12 sector or the general public. In this sense, NSF funding requirements may play a role in supporting SCALE goals. However, they may also play an inhibiting role, as some of those we interviewed strongly emphasized that the broader impacts criterion attached to NSF funding was an “annoyance” and that some colleagues rarely follow through on it, since it is viewed as detrimental to the primary goals of their careers. As one STEM faculty respondent explained, “In fact, someone who is trying to launch an internationally known research career cannot go to inner city Chicago and be trying to take their research to the masses.” In any case, SCALE participants’ uncertainty about whether this policy will negatively or positively affect how IHE/K–12 partnerships evolve emerged as a significant external factor that they attempted to take into account while designing their action strategies.

Demand is growing for graduate students in STEM education (+). The job market for newly minted PhDs is very competitive.

> They [the faculty] look at industry as a perfectly acceptable option. They look at teaching as an acceptable avenue. They are training you to be Research I researchers, but they understand that’s not for everybody. And then there are not enough of those jobs to go around anyway. (Graduate student)

In this context, it is of note that some respondents said that students with experience in some aspect of math and science education are highly sought after. This is assessed as a theme

Figure 3: **Factors in the organizational context activated by the SCALE Intervention.**



supportive of SCALE's goals because it entails new awareness for some faculty that their students, particularly those who are not focused on becoming faculty at research universities, should acquire a broad skill set that may include additional teaching experience or expertise in STEM education.

UW-Madison's status as a Research I institution prioritizes research (-). In considering the influences on faculty and academic staff professional lives, respondents repeatedly cited how the Research I status of UW-Madison deeply influenced their professional identities and workload prioritization. This status manifests itself in respondents' lives through an unquestioned focus on research activities and their role in substantiating the university's reputation and status. Respondents also exhibited a keen awareness of the hierarchy of higher education in the U.S., their place and that of UW-Madison in that system, and the implications that had for their own careers and institutional context. As a result, this factor inhibited achieving SCALE goals by establishing workload expectations that were primarily focused on research accomplishments and only secondarily on pedagogical improvement.

K–12 students and teachers lack STEM knowledge (-). Another salient external influence is that both K–12 teachers and students are perceived to have limited knowledge of STEM fields. Respondents from both STEM and education disciplines made this observation, with explanations ranging from poor teacher education programs to the ways in which the lecture method used in STEM courses inhibits learning. These perceptions are based on personal experience in professional development and research activities and, for parents, on interactions with teachers of MMSD students. Yet, it should be noted that respondents familiar with the secondary science program at UW-Madison felt strongly that students in that program were being adequately trained and prepared for K–12 careers. The concerns expressed focused on students in the elementary education program and incoming UW-Madison students.

K–12 hiring policies, STEM curriculum, staff turnover, and policy changes pose challenges (-). K–12 hiring policies, challenging STEM curriculum, and frequent changes in policy and personnel were identified as factors in the K–12 sector that posed challenges for SCALE. In both interviews and meetings about revising the preservice sequence for elementary education majors, respondents cited hiring policies as a challenge because K–12 districts often prefer teachers without a specialization in math or science, so that they can place teachers wherever needed. This preference deeply affects hiring practices and works against efforts to introduce new, more demanding STEM course requirements for preservice teachers. In addition, the MMSD math curriculum, Connected Math, while in alignment with the pedagogical philosophy of SCALE, poses significant problems if teachers do not adequately understand the content. Since some teachers do not have adequate content mastery, particularly at the elementary and middle school levels, this means that additional professional development is required to ensure that students' classroom experiences are not compromised. The turnover of key administrators and curriculum specialists guarantees that the political atmosphere and key stakeholders are constantly in flux at the district level, which makes it more challenging for the STEM educators at UW-Madison to achieve continuity in their interactions with MMSD leaders. Some respondents also noted the cyclical nature of education policy and expressed the opinion that "We're in one of those flare-up periods now" in regard to cross-institutional collaboration and math and science education. Some STEM faculty expressed skepticism about this phenomenon, suggesting that it may reflect not a response to research findings on the efficacy of these collaborations, but rather the rapidly changing nature of the field of education and political and societal trends. Taken together, these factors exert an inhibiting influence on the achievement of SCALE goals.

Internal Structure

Factors pertaining to the internal structure of UW-Madison that have an impact on SCALE include organizational structure (governance, teacher education programs, STEM degree programs), student body composition, instructional workforce composition, personnel policies, leadership, and active and historic reform initiatives.

Governance system and autonomy exert strong influence on faculty (+/-). The governance system of UW-Madison, with its emphasis on departmental and faculty autonomy, was cited as a factor that strongly influences faculty practices at the university. This system favors departmental and faculty control over decisions regarding academic programs and related policies. Coupled with a strong tradition of academic freedom, this factor can serve as a supportive influence to SCALE goals by allowing faculty significant leeway in how they prioritize their professional lives and make instructional decisions. However, this autonomy is constrained by institutional pressures such as workload and tenure and promotion policies that serve to limit the possible range of actions available to faculty in these areas.

Departmental tenure and promotion policies discourage teaching innovation (-). As previously noted, research and teaching activities are the primary considerations for tenure, with professional service playing a minor role. In practice, respondents reported that recruitment and promotion committees generally emphasize research over teaching, noting that this is not surprising at a Research I institution. One respondent was actively discouraged from focusing on improving her teaching, due to the risk that her student evaluations—a key component of the review process—would be poor during the period when she was making changes.

STEM education leaders are in the minority (+/-). Respondents emphasized the importance of leadership in the success or failure of STEM education reform at campuses as large and complex as UW-Madison. Several stated that STEM education leaders, who include both official leaders and high-prestige faculty, must effectively marshal resources and personnel to further the goals of reform at strategic leverage points within the university. These leaders range from administrators at the college level to individual faculty members who are deeply committed to STEM education reform. The ongoing commitment of these leaders to STEM education reform is a factor that strongly supports the goals of SCALE. However, these leaders operate as a minority at UW-Madison and perceive themselves as “swimming against the tide” on campus. Given the marginalization of education reform efforts, respondents noted that it is particularly important to engage high-prestige faculty as colleagues on campus, since research accomplishments are the “currency of the realm” at UW-Madison.

Departments are isolated “silos” that discourage collaboration (-). Academic departments in higher education tend to operate as isolated “silos” within the institution, a pattern that is exacerbated at UW-Madison by the governance model that emphasizes departmental and faculty autonomy. One respondent succinctly summarized how decentralized governance plays out at the departmental level:

> Well, our department and pretty much the university at large doesn't really believe in leadership. We have this tradition that's called faculty governance. So it basically means that everything is decided from the bottom up. It's all committee-driven and everything is processed. The upside of this is that it really helps people get along, and [helps] with morale and makes people feel like they are involved. But it's a monumentally inefficient way to accomplish anything. It's just the way things are done around here. (STEM faculty)

While this factor may inhibit interdepartmental collaboration, it is worth noting that faculty autonomy and the continuing rise in interdisciplinary research in the STEM disciplines may mitigate its deleterious effects.

Large undergraduate STEM courses encourage didactic instruction (-). Many introductory undergraduate courses in the STEM disciplines are taught in large lecture halls (with as many as 300 students) by a rotating staff of faculty, including tenure-track professors, adjunct faculty, and graduate students. These lower division courses are a major source of the criticism leveled at higher education, since the structure of the courses thwarts efforts to use teaching methods designed to engage students and thus affords students little opportunity to interact with their instructors or fellow students.

> Unfortunately, too many of the classes I teach here are giant lectures. I just finished a lecture with 276 students, and therefore [the students] do not get much chance to interact with me, and [active learning] is just not going to work and I don't see any way to make it work. I have a few things in mind, but their only chance to interact with a human is in their recitation section that they have twice a week with a [teaching assistant (TA)]. (STEM faculty)

Since many preservice teacher candidates' only exposure to the STEM disciplines is in these introductory courses, the quality of the teaching and the pedagogy that is modeled was of particular concern to several respondents. In addition, because these courses are designed to cover a large amount of content, faculty focus on the more efficient lecture approach to instruction and let their TAs "pick up the pieces."

Lack of policies for instructional practice and TA training results in high variability in teaching quality and style (-). Respondents noted that instructional practices are generally left to the discretion of individual faculty or graduate student TAs, which results in a high degree of variability in teaching quality, pedagogical style, and in some cases the content emphasized. Although some STEM departments require specific textbooks for introductory courses, few mechanisms are in place to ensure that the core course content is consistent from one semester to the next. Further contributing to this situation is the often limited scope of TA training, which commonly focuses on the technical requirements of the position. Some departments attempt to provide more formal training for their doctoral students, but the value of this training is undercut by the constant pressure on students to pursue research and complete their doctorates.

STEM courses required for elementary teacher candidates are considered inadequate (-/+). While respondents generally felt that students enrolled in the secondary education program were acquiring adequate STEM pedagogical content knowledge through their coursework in both STEM departments and the College of Engineering, doubts often were expressed about the adequacy of the elementary education program. In that program, students are required to take relatively few STEM courses, and some STEM respondents considered the quality of these courses to be poor. Respondents also noted that the courses are generally introductory or survey courses that do not adequately convey the breadth or depth of knowledge that they believe K–12 teachers should have about their discipline. One reason offered is that the state of Wisconsin has low requirements for its elementary and middle school teachers, in contrast to other states. In addition, College of Engineering faculty—who have no oversight of these courses and rarely interact with the faculty who teach them—questioned the quality of instruction that both secondary and elementary education students receive in STEM courses.

Resources

This ICF category includes factors pertaining to material resources (e.g., time, funding) and social resources (e.g., networks).

Existing cohort of permanent academic staff works on STEM education (+). In 2006, there were 4,663 non-instructional academic staff at UW-Madison who were engaged in a variety of activities, including research, administrative support, and outreach with the general public. For example, the Center for Biology Education employs a cohort of academic staff who work exclusively on STEM education issues related to both higher education and K–12. Many of these staff are doctoral-trained scientists, and some feel that they are uniquely qualified to design and implement professional development programs because they can effectively interact with faculty and bring a professional scientist's perspectives to the K–12 sector. As academic staff, they have less status and often less security, but they also do not experience the pressures that faculty face to teach, publish, and continually develop their reputations as researchers.

Active and historic reform efforts foster networks and lay groundwork (+). UW-Madison has a strong history of participating in education reforms in the STEM disciplines, and these active and historic efforts have fostered networks of STEM educators and laid the groundwork for future projects such as SCALE. The funding and employment opportunities afforded by these projects played a significant role in developing the readily identifiable cohort of faculty and academic staff (as noted above) who are particularly active and experienced in STEM education. This community is recognized by K–12 personnel as a valuable resource when they need collaborators or expertise pertaining to STEM education. Personnel at UW-Madison recognize that people on campus have experience working with pedagogical issues and in the K–12 sector. It is worth noting that these networks in many cases extend beyond the confines of UW-Madison, as many personnel have extensive personal networks within their disciplines and specialty areas. These networks provide a resource for idea sharing and knowledge building, particularly through professional meetings and electronic communications.

Other supportive factors for SCALE are the existing organizational structures and initiatives with goals similar to SCALE's, such as the School of Education–sponsored Teacher Education as an All-University Responsibility project. College leaders initiated this project to address perceived problems with the curricular requirements of the elementary education program and the detrimental effects of little or no interdepartmental collaboration. This council—composed of representatives from the School of Education, the College of Letters and Science, and local public schools—is responsible for discussing issues related to teacher education on campus.

K–12 professional development services already exist at UW-Madison (+). Members of the previously mentioned cohort of academic staff devoted to STEM education often design and facilitate professional development programs for K–12 teachers. Organizational units such as the Center for Biology Education and Science House provide these services on a regular basis and thus serve as a resource for K–12 districts and UW-Madison personnel seeking expertise in this area. These entities, their skilled staff, and their positive reputation in local K–12 districts all serve as a supporting factor to the SCALE project.

Funding pressures limit resources (-). There is a consistent financial pressure on all UW-Madison personnel to compensate for declining state funds by obtaining external funding to sustain or even enhance current teaching programs and research capacity. One way in which declining resources affect faculty is the lack of additional staff and other resources available to adequately instruct undergraduate students. Under pressure to increase enrollment, one respondent noted that departments often respond by just "churning out undergraduate students," who are largely taught and mentored by graduate students so that faculty can devote more time to seeking external funds to build research programs, developing a track record for fundraising, and accomplishing other tasks for which college and departmental funds are not available.

Student body requires more remedial courses (-). Respondents reported dissatisfaction with the preparation of many incoming students in the STEM disciplines. Some observed that anxiety about STEM courses is not uncommon, particularly among preservice candidates, and that this problem does not bode well for their future careers as K–12 teachers. One respondent noted that the mathematics preparation of incoming freshmen was "sad" and that students lack even "sub-high school skills" such as addition of fractions or basic geometry. As a result, increasing numbers of students require remedial courses, which respondents felt drain departmental resources and further increase the teaching challenges they face.

Collective Values and Beliefs

This category of the ICF includes factors pertaining to the beliefs, values, and tacit assumptions operative among groups at UW-Madison, including the institution as a whole, colleges, departments, and smaller communities or subcultures.

Dominant value system in STEM disciplines conveyed during doctoral training prioritizes research over teaching (-). Once students are granted entry to a discipline through the awarding of a PhD and subsequent measures of achievement, the discipline becomes the primary source of their identity as a professional academic. Respondents noted that this identity is related not simply to the content of the discipline, but also to value systems that help differentiate disciplines from one another. In regard to the relative value of research and teaching, the fact that no STEM respondents received training in pedagogy during their graduate education clearly conveys the higher value placed on research and the acquisition of expertise in a specialty area of their field. The lack of pedagogical training often results in a reliance on teaching "the way I was taught," which was described as a practice that "was taken for granted." The instructional method that STEM respondents relied on was generally the didactic, lecture-based approach, with little direct engagement with the students outside of labs.

The value placed on research excellence and scientific legitimacy influences faculty priorities and instructional decisions (-). UW-Madison is a research institution whose primary focus is excellence in research, notwithstanding the teaching and service aspects of its mission.

> The nature of the culture here is so powerfully embedded in the socialization of the faculty to be successful and survive. The whole process of tenure, tenurability [*sic*], research, research proposal writing, and the culture that supports that—success in that culture—almost negates that these people can take time [for things like SCALE]. (STEM faculty)

One respondent noted that—given the focus on research—many faculty are "not going to be going out looking for [pedagogical] information." Junior faculty, who are particularly subject to the pressures of the recruitment, tenure, and promotion process, are often advised to spend their time "thinking about how to solve a problem in my research area, instead of a solution to my problem in teaching." Lack of interest in pedagogical improvement does not necessarily mean STEM faculty are not committed to teaching or are not good instructors. Nonetheless, lack of training and interest in teaching sometimes results in an uncritical approach to instruction. Furthermore, respondents stated that a combination of factors—including faculty commitment to research, the persistence of the transmission-of-content approach to teaching, and an aversion in the "hard" sciences to the "soft" sciences—contribute to a widespread sentiment that teaching is simple, secondary, and in no need of further attention or improvement.

Interestingly, the pressure and desire to conduct research apply to both STEM and College of Engineering faculty.[12] The achievement of legitimacy and credibility in a particular discipline is viewed as a critical ingredient of academic success in general, and of interdepartmental collaboration in particular. Competence in a discipline and specialty area is made legitimate and credible by a faculty position, publications, and an active research program. Moreover, legitimacy in a STEM discipline often is more highly valued than legitimacy in education. This is evident from statements indicating that STEM faculty and academic staff who are engaged in educational activities need impeccable STEM credentials in order to shore up their legitimacy with their disciplinary colleagues. The high value placed on STEM disciplinary credibility also is evident in the fact that STEM faculty often question the STEM disciplinary credentials of faculty who specialize in math and science education in the School of Education. Another key element of legitimacy is faculty status, as evidenced by respondent statements indicating that academic staff, even those with impressive academic background and achievements, do not fit into the established hierarchy of higher education achievement and thus may be less desirable than faculty for projects such as SCALE.

[12] A consequence of this pressure for College of Engineering faculty is that training teachers may be viewed as a secondary activity, or at best as only one of several faculty responsibilities.

A practical corollary is the departmental practice of separating teaching and research activities. For example, one STEM department hired a faculty member specifically to focus on outreach and education—in effect, to not pursue research in the discipline. Some respondents emphasized that even though colleagues may not be particularly interested in STEM education themselves, they still "want to have somebody around who is"—for example, to address the broader impacts criteria as required by NSF and other funders and to help ensure that a department's contribution to the university's teaching mission is "in good shape."

Respondents believe that many K–12 teachers need more STEM professional development (+). There was a widespread recognition among our respondents that K–12 teachers would benefit from professional development to improve their STEM content and pedagogical knowledge. For education faculty, this conviction is based on their professional understanding of K–12 education and the perceived shortcomings of STEM undergraduate instruction and teacher education programs. For STEM faculty, this perception is based on their impressions from their own children's experiences in a K–12 classroom, their experiences facilitating a professional development workshop, or from messages in the media. In addition to improving K–12 teacher STEM content knowledge, respondents noted the importance of ameliorating K–12 teachers' math and science anxiety, which was viewed as a significant problem. These sentiments predispose UW-Madison faculty to sympathize with the goals of SCALE, if not to engage in actual professional development activities.

Departments take pride in teaching quality (+). As previously noted, conducting high-quality research and being committed to excellence in teaching are not mutually exclusive. Some respondents noted that their own departments took pride in the quality of their undergraduate and graduate instruction and provided several mentoring and/or professional development opportunities for their faculty. Some departments focus on providing support and training for incoming faculty because "they're walking in and none of them know how to deal with [teaching]." However, it must be noted that this mentoring extends to "protecting" new faculty from overwhelming teaching, advising, or service commitments so that they can focus on developing a research program. In any case, the apparent pride that some departments have in their faculty's teaching abilities indicates that pedagogical excellence is not a foreign or undesirable concept.

The distinction between "hard" and "soft" sciences fuels long-standing tension between departments in the School of Education and some STEM departments (-). A widely reported division between the School of Education and STEM departments has both structural and sociocultural dimensions. Structurally, faculty have few reasons or officially sanctioned venues in which to collaborate across these disciplinary boundaries. (Exceptions include intercollege committees for the mathematics sequence for elementary education students—Math 13X—and for the liberal studies program.) Respondents reported that there is just no reason for interaction, as is the case for many departments on campus. The sociocultural dimensions of this divide, however, are arguably unique to, and especially salient in, the dynamics between School of Education and STEM departments.

One factor contributing to the divisive nature of these dynamics is a perception by many STEM faculty that the quality of education research is substandard. As one respondent noted, most STEM faculty think that education is a good thing but have a negative feeling about researching how people learn. This perception is expressed in both subtle and not so subtle ways and is linked to the perceived higher status of “pure” over “applied” research and of “hard” over “soft” sciences. One STEM faculty member clearly admitted holding the view that education faculty are involved in altruistic, and thus inferior, research and other activities. The institutional context of UW-Madison, where research activities in the STEM disciplines are viewed as a priority, reinforces a predisposition to rank “pure” research activities over teaching and even research on teaching. While this in itself does not necessarily translate into a denigration of education, respondents felt that the research orientation exacerbates existing stereotypes of and divisions between the School of Education and the College of Letters and Science.

Another perspective noted by respondents is that education faculty pay insufficient attention to content mastery. A STEM faculty member felt that content-based pedagogy was over-designed by “methodologists” and noted his displeasure with curriculum developed through an NSF grant by education specialists. He found it unwieldy and believed that it “over-complicated” the content. A related point made by another respondent is that people tend to turn to content specialists on issues in math and science education because there is a societal and academic bias toward “pure” scientific research. These views imply that education faculty have relatively little to contribute to STEM education. Some education faculty expressed dislike for this bias and noted that it is evident in the NSF Math and Science Partnerships, including SCALE, which involved relatively few education faculty in project planning or implementation.

However, some respondents downplayed or even denied a divide between the two colleges, citing a tradition at UW-Madison of interdepartmental collaboration and historic examples of STEM faculty involvement in teacher preparation. Others noted that the divisions between the School of Education and STEM departments are complex, encompassing structural issues that separate departmental oversight and more sociocultural factors. One of these differences is based on the discipline-based identities of the participants, which are very difficult to negotiate effectively. One person explained this point in this way:

> Okay, scientists think one way about issues and education people think a different way, and sometimes they can’t see eye to eye about issues. And preparation of teachers might be one of those things. (STEM faculty)

For a more in-depth analysis of the differences in how STEM and education faculty “think,” and their implications for the SCALE project, see the analysis of cultural schemas in Section V.

Respondents perceive the School of Education as responsible for teacher education (-). There is a widespread perception among respondents that teacher education is the responsibility of the School of Education. Since preservice students are in courses with a variety of other majors and are rarely identified as preservice teachers, instructors in STEM departments are often not attuned to the presence of these students, much less to unique needs they may have in preparing for their future careers. At one extreme, one respondent was not even aware that future teachers were trained at UW-Madison. A respondent from the School of Education stated that the delegation of preservice teacher content instruction to STEM departments is “just the way things are” and expressed the view that the institutional context that supports this arrangement is relatively intractable. This said, the context for mathematics differs from that for science because there has long been a sequence of math courses (the 13X sequence) specifically designed for preservice teachers. Thus, math faculty are generally aware that they play a role in teacher education at UW-Madison.

STEM faculty lack interest in the K–12 sector (-). Respondents noted that there is a lack of interest in K–12 issues among many STEM faculty. As one STEM faculty member put it, since UW-Madison is a research university, it makes sense that people focus on research and not K–12. He observed that the education faculty should work on education issues, just as physicists focus on physics and chemists focus on chemistry. In another case, a STEM faculty member stated that very few people in his department cared about K–12 education “in any overt way,” and those who did worked “behind the scenes and that’s the way it works.” In fact, some respondents noted that involvement with K–12 and/or teaching reform efforts can serve to alienate faculty members from and make them “suspect” in the eyes of their colleagues. Although some STEM respondents were conversant with K–12 issues, several admitted that they knew little about the needs of K–12 educators other than what they read in the news or heard about from their children and other parents. As a result, recruiting STEM faculty for reform activities while minimizing the likelihood that those recruited will exhibit offensive opinions or behaviors toward their K–12 colleagues may be particularly challenging.

Faculty hold conflicting beliefs about the importance of content and pedagogy in preservice STEM courses (-). Respondents made clear that there is major disagreement about the courses required to effectively train a K–12 teacher and the approach the university should take in designing and offering these courses. This issue is particularly touchy in math. For example, some STEM faculty expressed discomfort that few “professional” (STEM) researchers are consulted in the development of K–12 curriculum. Some STEM faculty have responded to this perceived problem by advocating an increase in the number of “content” courses required for preservice teachers and a decrease in the number of methods courses. However, the selection of the appropriate content for preservice teachers is not a simple matter. Furthermore, some respondents observed that relying on the “core” content courses as currently taught in STEM departments is a mistake, since research indicates that accumulating courses in a major does not automatically make someone a good teacher. Respondents identified the problem as a lack of connection between the content preparation and the pedagogy. Because agreement on these matters is required before effective action can be taken, we assess this disagreement as exerting a negative effect on SCALE efforts.

Individual Sense-Making

This category of the ICF includes various IHE-related elements of an individual’s sense-making process, including workload considerations, personality, background and training, views on instruction, and status.

Funding pressures and workload exert strong pressures on faculty time (+/-). As previously noted, demanding faculty and academic staff workloads present a major barrier to participation in a STEM education project such as SCALE. This is a particularly important issue for junior faculty who are under pressure to “publish or perish.” Faculty responsibilities include research and publishing, teaching, advising, service, and miscellaneous duties including writing proposals. Academic staff are also extremely busy with the demands of their current projects.

This results in an overall lack of availability of most faculty and staff to participate in STEM education reform activities, unless a person has a grant that can buy out teaching responsibilities, holds a position that requires participation in STEM education, or is extremely motivated. However, faculty or academic staff whose workload entails involvement with STEM education may consider programs such as SCALE a boon. Thus, one way or another, workload demands are a critical interpretive frame used by UW-Madison personnel when assessing participation in STEM education activities.

Faculty values status and reputation (+/-). Respondents noted that status and reputation are important in shaping the way individuals, departments, and the entire university are perceived. High status can endow individuals with credibility and respect, whereas low status can diminish the likelihood that a person's views or participation in projects will be sought. Respondents indicated that faculty in high-prestige departments should uphold the status of their administrative home, usually by conducting world-class research. As noted elsewhere, most UW faculty and academic staff place high value on their positions at a major research university. Faculty with sufficiently high status may be more apt to join a reform effort such as SCALE, as they are relatively immune from colleagues' disapproval and, if tenured, have ample time to pursue such activities. Conversely, faculty without high status must be attentive to the opinions of their colleagues who may one day sit on their tenure review panel. As a result, status is an extremely important sense-making frame that UW-Madison personnel use, sometimes without realizing it.

Diverse personal reasons lead faculty to become engaged in reform efforts (+). Respondents identified a variety of personal, political, and practical reasons for becoming involved in K–12 activities. Many School of Education faculty were former high school teachers and were predisposed to involvement in pre- and in-service activities. In addition, some of these faculty were directly engaged in K–12 education through their research or their teaching responsibilities in the secondary or elementary education program. In contrast, most STEM faculty participated for more personal reasons, including having children in a local school district or an intellectual curiosity about a controversial K–12 curriculum. In any case, respondents indicated that they become engaged in programs like SCALE for diverse personal reasons.

Willingness to learn and take risks spurs faculty to become engaged in reform efforts (+). Willingness to learn and go outside one's "comfort zone" emerged in interviews as an important element of personal disposition that affected willingness to engage in a K–20 education improvement activity. Among the reasons expressed for participating in SCALE and similar projects was personal desire to learn about a new topic, whether the K–12 curriculum, STEM pedagogical content knowledge, or departmental policies governing teacher education.

Faculty express willingness to work with others on teacher training (+). Respondents from both the STEM disciplines and education recognized that content expertise alone is not sufficient for teacher training, but that students also need specialized pedagogical knowledge. While they recognized that the distinctions between "content specialists" (STEM faculty) and "methodology specialists" (education faculty) are sometimes detrimental to collaborative activities, they also acknowledged that these distinctions serve to demarcate areas of expertise that should be brought to bear on the complex issue of teacher education.

> You can't just have content experts designing teacher preparation, ignoring everything we know about teacher learning and so on. And you can't have people who don't know the content knowledge deeply making those decisions either. So you really need the engagement, a broader engagement in the act of teacher education. (School of Education administrator)

Significant differences of opinion remain over curriculum content and methods of delivery. Nevertheless, respondents agreed that all parties have unique strengths and talents that should inform the process of improving preservice training. We assess this consensus as a positive factor.

Practices

This category of the ICF includes factors pertaining to an individual's classroom instruction (e.g., planning and delivery) and task-based collaborative activities with both IHE and K–12 partners.

Faculty actively participate in K–12/IHE collaborations (+). Respondents reported numerous collaborative activities between UW-Madison and local school districts and noted that these support SCALE efforts. These activities included both structured and unstructured collaborations. Unstructured collaborations included informal faculty interactions with MMSD schools, usually in the form of math or science outreach efforts. Above, we mentioned the many structured outreach activities through which the UW-Madison interacts with local districts. We assess this factor as having a positive effect on efforts such as SCALE. However, some respondents expressed a tendency to use the "throw it over the wall" approach to K–12 professional development, whereby materials would be designed and disseminated without attention to the needs or unique characteristics of K–12 participants. Another characteristic of this approach was a focus on the "1% of teachers who are exceptional" and who exhibit a particular talent for learning and teaching science.

Participation in interdisciplinary collaboration improves communication and enhances trust (+). Some respondents stated that there was a tradition of interdisciplinary collaboration at UW-Madison that was distinctly different from other IHEs. This interdisciplinary collaborative spirit extended beyond partnerships among colleagues in the same specialty area to teacher education and K–12 outreach. These collaborations are both unstructured and structured. Examples of structured cross-departmental relations include interdisciplinary research collaborations, especially in the life sciences, and institutionalized committees such as the Math Preservice Committee. Less structured collaborations involve individual faculty as part of research interest groups or personal networks. From these relationships come improved lines of communication and mutual trust, which are important and resource-intensive assets to efforts to build from the ground up. Respondents noted that while this tradition did not influence all faculty equally, it is an important aspect of UW-Madison. Based on these comments from respondents, we assess this factor as supportive of projects such as SCALE.

Didactic approach to STEM instruction dominates (-). Some respondents expressed the view that their approach to pedagogy is informed and influenced by their own pedagogical training, or lack thereof, and in many cases replicates the approach of their mentors. Many respondents observed that the traditional teaching model used in IHEs is the transmission of content, in which the instructor conveys a body of information, usually through a lecture, with the expectation that the students will absorb the information. In light of research on learning, we assess this factor to have a negative effect on projects such as SCALE. We also note that this model is supported by the dominant ethos of the university as a top-tier research institution, which focuses on training the best in the field. Evidence for this observation is based on various respondent comments. For example, one respondent noted that what students expect to get from UW-Madison is not the best teaching methodology, but rather the opportunity to be around "great researchers who have some kind of aura that you try and soak in."

Some STEM faculty experiment with an inquiry approach (+). An extension of the presence of a STEM education cohort at UW-Madison is that some STEM faculty were conversant with or at least are sympathetic to pedagogical reform in math and science. Although these faculty vary in their relative levels of expertise with specific theories and methods for inquiry-based instruction, we assess their reported teaching practices as a factor that is supportive of projects like SCALE.

Summary

The factors described above influenced the SCALE implementation in many ways. Here, we briefly illustrate how some of these factors interact. The demanding faculty workload and prioritization of research accomplishments at UW-Madison made it challenging to recruit STEM faculty for the project. Fortunately, the STEM education community at UW-Madison is extensive, and previous grants had fostered an active and supportive community of faculty and academic staff, many of whom became involved in SCALE. Furthermore, as a STEM faculty member and administrator, the SCALE PI had extensive contacts and institutional knowledge, which deeply influenced how SCALE was designed, implemented, and perceived at UW-Madison. For example, capitalizing on the high value placed on research accomplishments and prestige, the SCALE PI purposefully recruited well-known faculty with significant clout and visibility. Also, given the size of the university and its many decentralized and autonomous units, the SCALE theory of change focused on planting small seeds of change at strategic points in the system, building on existing efforts, and working with committed individuals at all points in the continuum of teacher training and professional development.

In our view, the factors discussed above constitute a collection of disparate yet interconnected features that, taken together, reinforce the notion that UW-Madison is a large, complex institution with many moving parts that operate according to a variety of political, structural, and sociocultural rules. This notion was expressed by one respondent who considered it reasonable that SCALE might ultimately fail to effect any lasting changes at UW-Madison:

> If you didn't understand universities and didn't understand that what we're dealing with here is a very complex, cultural issue, it would be fair to say, "You spent $35 million and you did what at UW?" (STEM faculty)

Into this organizational culture, SCALE introduced a multifaceted intervention that was intended to have an impact on the teacher training and professional development process at multiple points.

IV. Findings on SCALE Intervention

This section presents a summative evaluation of SCALE activities at UW-Madison, consisting of descriptions of the activities from January 2005 to August 2007, observed outcomes of these activities, analyses of the longer term consequences of each intervention, and consideration of how each outcome of SCALE is situated within the institutional context of UW-Madison. This latter step more realistically links project outcomes with contextual factors, thereby avoiding the problem of presenting outcomes as if they were independent of their institutional context (Anderson & Helms, 2001). The evidentiary base for the findings presented in this section includes 47 semistructured interviews, documents, and field observations (see the appendix for more details).

Background

This section discusses the local precedents and the theory of change for the SCALE project.

Origins of SCALE and Local Precedents

As with many STEM education reforms, the SCALE project built upon previous efforts that cultivated experienced and motivated personnel, established a track record for involvement at UW-Madison, and in some cases led to changes in the institutional context. As previously noted, the history of STEM education reform at UW-Madison is extensive and has fostered an active and supportive community of faculty and academic staff that the SCALE PI tapped when writing the proposal. The NSF-funded K-Through-Infinity (KTI) project, which focused on graduate training, and the National Institute for Science Education (NISE) most directly laid the groundwork for the SCALE proposal. These initiatives fostered a cohort of faculty and academic staff engaged in STEM education, helped support a variety of spin-off programs that further advanced the field, and built extensive local and national networks for UW-Madison participants. The SCALE PI was directly involved in these programs. These contacts and the extensive institutional knowledge developed in his STEM faculty and administrator roles enabled him to play an instrumental role in designing and implementing SCALE. The significance of his role in the design, implementation, and perception of SCALE at UW-Madison should not be underestimated.

Local Theory of Change and Implications for Program Evaluation

SCALE is a systemic reform initiative that involves IHEs and K–12 partners to improve math and science teaching and learning through the entire educational spectrum. The SCALE theory of change posits that the entire continuum of teacher training and professional development must be improved, with particular attention to improving the role IHE faculty play in designing and implementing preservice curricula and in-service programs. The SCALE theory of change is based on a systemic understanding of the educational systems that inform and support K–20 math and science education. *The SCALE theory of change pertaining to IHEs* holds that, if improvements in IHE participation in teacher preparation and professional development are to be sustainable and significant, then it is necessary that:

1. STEM faculty improve their approaches to teaching and learning;

2. STEM and education faculty collaborate effectively to improve teacher preparation; and

3. Leaders at different levels of the institution work to overcome the conservative nature of the IHE by supporting faculty participation in teacher preparation.

It also is important to consider the *broader theory* of change held by IHE actors generally, including SCALE leaders. Since IHEs, and particularly large decentralized institutions such as UW-Madison, are notoriously resistant to change, it is not realistic to expect SCALE to effect a sea change throughout the entire institution. One respondent observed that, even if the provost or chancellor decided to implement significant reforms, most likely little would change because departments would go on with “business as usual.” This dynamic contributed to how SCALE was designed and implemented at UW-Madison, which was based on the following implicit theory of change: *Plant small seeds of change at points in the system deemed most likely to eventually yield large changes, and do so by building on and collaborating with other change initiatives (at UW and other institutions) that complement SCALE goals, and by identifying and working with individuals already interested in these goals*.

This approach is known as the *campaign approach to change* (Hirschhorn & May, 2000), which involves mobilizing people around a strategic theme that has staying power at a particular institution. The strength of this approach is that the main actors are able to identify strategic opportunities for leveraging resources. These may include combining resources with those of other change efforts or institutions to achieve like goals or seizing an opportunity, such as the appointment of a sympathetic new department chair or dean, to promote a reform agenda. This approach also presents a number of challenges, including the need for leaders to have a deep understanding of the institutions involved and constantly adjust to the changing situations facing their K–12 and IHE partners. In addition, leaders may find it difficult to know if and when a project is meeting its own criteria for success because goals, objectives, and strategies are not clearly stated prior to implementation.

This latter aspect of the campaign approach presents a challenge for program evaluation that was evident in the beginning of the SCALE MSP; at that time the goals for IHE involvement and the intended outcomes were unclear, and specific objectives and strategies for achieving any goals at UW-Madison were not articulated. Indeed, some of the strategies described in this section have only recently been initiated, and because they were developed “on the fly” as opportunities presented themselves, they cannot be assessed in terms of carefully designed plans and theories of action. As a result, a key goal of this evaluation is to assess the efficacy of the campaign approach to change at UW-Madison and the extent to which SCALE addressed effective and high-leverage points in the institutional context.

Evaluation Criteria

The outcomes reported in this evaluation are limited to the activities involving UW-Madison faculty, academic staff, and other personnel. As a result, some SCALE activities that occurred in the city of Madison that did not involve UW-Madison personnel are not included (e.g., University of Pittsburgh professional development activities in MMSD). Nor do we include activities involving UW-Madison personnel in other cities and states (i.e., LAUSD science immersion unit design). Evaluators increasingly recognize that interventions in complex environments such as education, public health, and research management often result in a variety of outcomes beyond those originally envisioned by the program designers (Patton, 2006; Connick & Innes, 2001). Researchers argue that a mechanistic view of evaluation, as embodied in the commonly used linear logic model, will “fail to identify many of the most important results of these processes” (Connick & Innes, 2001, p. 1). Accordingly, instead of focusing on the outcomes as delineated by program designers at the outset of an intervention, evaluators need to view the context of the intervention as a complex system, in order to identify a wide array of possible outcomes (Patton, 2006). Using this approach, we find there is little precedent in the evaluation literature for categorizing types of outcomes that may result from an intervention in a complex environment such as UW-Madison.

Lacking precedent, we choose to organize program outcomes according to their location in the ICF framework. In addition, we organize outcomes in terms of:

1. First-order outcomes, which were those that program implementers articulated and anticipated; and

2. Second-order outcomes, which were those that program implementers did not anticipate.

Changes to the organizational context most often emerge as second-order outcomes. Evidence for both types of outcomes is based on second-party evaluations, documentary evidence, or reports of changes by at least three respondents. In cases where only one or two respondents considered a particular change to instructional practice or behavior important, these changes are reported and the number of respondents claiming the change is specified. It is interesting to note that most of the first-order changes are in the external influences, internal structure, and practices categories, while most of the second-order changes are in the resources, collective values and beliefs, and individual sense-making categories.

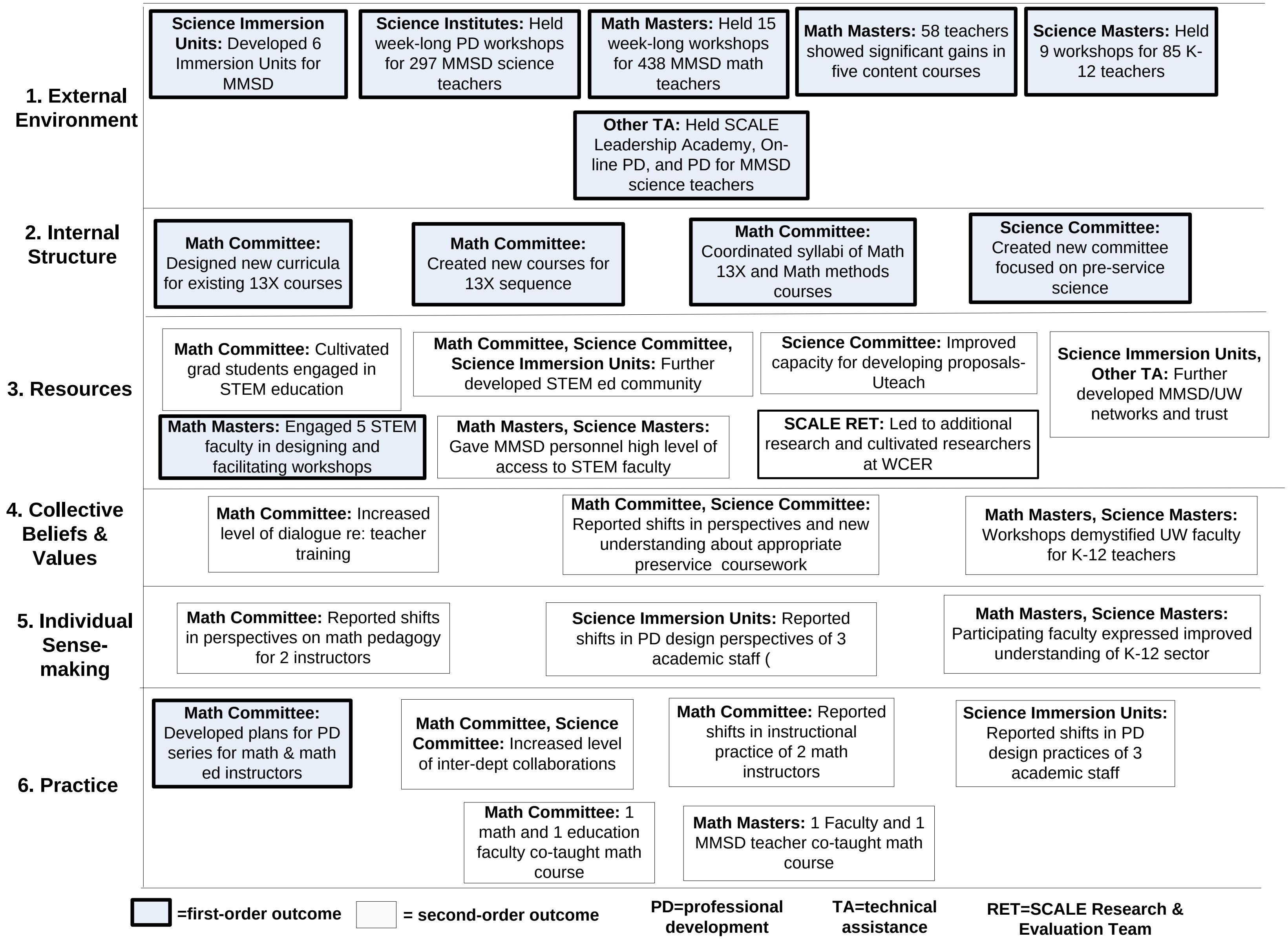
SCALE Activities: May 2004 to August 2007

During the period from May 2004 to August 2007, SCALE implemented the activities described below. In presenting the outcomes of each activity, we indicate the relevant category within the ICF with an italicized phrase. The first- and second-order outcomes, organized by the ICF categories, are summarized in Figure 4.

Elementary and Middle School Math Preservice Committee

Background. The Mathematics Department has long hosted a committee, in collaboration with the School of Education, to discuss and plan for its sequence of required courses for preservice candidates (known as the Math 13X sequence). This committee, the Math Preservice Committee, was described as mostly ineffective and increasingly acrimonious in recent years. In December 2005, a newly constituted committee began meeting, with impetus from the associate dean from the School of Education. This committee became known as the Elementary and Middle School Math Preservice Committee. One reason this dean took action was that members of the Mathematics Department had identified as problematic the fact that elementary and

Figure 4: **First- and second-order outcomes of SCALE activities.**



secondary teachers receive the same content preparation. The SCALE PI was instrumental in organizing and providing leadership for this committee, particularly for a subgroup that was very active.

Goals and objectives. The Math Preservice Committee attempted to redesign the preservice elementary and middle school math sequence and hoped to engage other UW campuses and eventually the Wisconsin Department of Public Instruction in changing and strengthening the credential requirements for middle school mathematics teachers. The committee outlined four objectives to improve the current course structure:

1. Create an optional minor in mathematics and another subject area to provide opportunities for preservice students to develop a deeper understanding of the knowledge necessary for teaching mathematics at the middle school level.

2. Design current and proposed mathematics courses to better reflect educational theories of mathematics teaching and learning.

3. Build connections across the mathematics content and methods courses through continued collaboration of course instructors and the development of joint projects for students.

4. Develop a professional development course for mathematics instructors for the Math 13X course sequence.

Activities. The committee began meeting in December 2005 to discuss its goals and objectives. In the summer of 2006, SCALE funded an effort to research other IHE math preservice courses and innovative curricula. Based on findings from this research, subcommittees composed of faculty members from the Mathematics Department and the Curriculum and Instruction Department (C&I) and graduate students from their respective programs began assessing each course in the Math 13X sequence and providing recommendations for changes and updates. Related activities included discussions about coordinating the Math 13X courses with the math methods courses taught in C&I and developing professional development workshops for faculty and graduate students in these courses.

Participants. Accounting for the participants in this activity was challenging for two reasons: (a) committee member participation varied over the course of the grant and (b) given the historic presence of the committee, participants had varying ideas about when they were members of the committee. As a result, the following participant count is limited to those active in efforts to revise the Math 13X courses during the SCALE grant. Participants included seven math faculty (one from Ithaca College), three math education faculty, five math graduate students, four math education graduate students, and five MMSD staff.

Outcomes: First and second order. The first-order outcomes for the Math Preservice Committee, and the category in which they are positioned in the ICF framework (see Figure 4), are as follows:

- *Increased levels of committee activity.* Since this committee was in existence prior to SCALE and is an institutionalized feature of the Math Department, it will continue beyond the SCALE grant. Further, funding support from the School of Education and recognition of the importance of these efforts further increase the chances that this committee will continue to operate into the future (*Practices*).

- *New course curricula*. The committee's work resulted in the design of new course curricula for the Math 13X sequence and created new courses that may constitute an optional minor in mathematics. These courses have become part of the Math Department's course offerings and thus will also likely continue into the future (*Internal Structure*).

- *Coordination of syllabi*. The committee coordinated the syllabi of Math 13X and C&I math methods courses (*Internal Structure*).

- *Professional development*. The committee developed plans for a professional development series for math and math education instructors (*Practices*).

The second-order outcomes for this activity include:

- *Team teaching.* Two faculty participants team-taught one of the Math 13X courses in spring 2007 with support from the School of Education (*Practices*).

- *Increased level of dialogue between the Math and C&I Departments regarding preservice training.* The work of the committee enhanced relations and collaboration between the Math and C&I Departments. However, faculty and graduate student attrition may undermine the sustainability of this outcome. For example, the relatively small math education cohort in the C&I Department (four faculty) was reduced to two faculty in 2007. As participants move in and out of these committees, relationships must be continually redeveloped, which makes the future of the committee more dependent on the quality of interactions among the more permanent members (*Collective Values and Beliefs*).

- *Reported shifts in instructional practices (n = 3 math instructors).* Three math instructors reported small shifts in how they design and teach their lessons. This outcome should be considered in light of questions that some School of Education respondents raised about the ultimate efficacy of the committee's work as long as the Math 13X courses are managed by the Math Department, because the quality of the courses depends heavily on the particular skills and attributes of the participating math faculty and graduate students (*Practices*).

- *Community*. The committee further cultivated the community of STEM educators at UW-Madison by engaging faculty and graduate students who had not previously been engaged in such activities (*Resources*).

Middle School Science Committee

Background. In early 2006, the SCALE PI worked with a School of Education associate dean to organize and recruit the Middle School Science Preservice Committee. The committee was then appointed by the associate dean. The committee is assessing the science requirements for students in the UW-Madison elementary education program who have selected the middle school preparation option.[13] Current requirements for these middle school teacher candidates are the same as those for elementary candidates and thus are considered by many to constitute insufficient content preparation for middle school. Students are currently required to take nine credits in the biological and physical sciences as part of the liberal studies requirement. Most of the allowed credits are for introductory courses in various STEM departments.

Goals and objectives. This committee is still in the early stages of development and thus has not yet formulated its goals and objectives. However, it appears that the committee hopes to review and revise the credential requirements for middle school science teachers at UW-Madison. A required core, multidisciplinary sequence is a possible outcome of this committee's work.

Activities. In the summer of 2006, the SCALE PI began gauging interest among various STEM faculty, administrators, and K–12 partners in an attempt to develop a new course sequence for preservice middle school science teachers at UW-Madison. This committee has met three times (November 2006, January 2007, May 2007). Initial suggestions included new interdisciplinary courses, a dual focus on improved content and pedagogy, and an investigation of numerous resources available for interdisciplinary science education at UW-Madison. One of the participants contributed three courses that were developed for another interdisciplinary program as an example of a new approach to middle school science preparation.

Participants. Participants in this SCALE activity include a core group of nine STEM faculty, four College of Engineering faculty, one STEM academic staff, and three MMSD staff.

Outcomes: First and second order. The single first-order outcome for this SCALE activity, and its location in the ICF framework, is:

- *New interdepartmental committee on preservice teacher training in science where before there had been no forum for dialogue.* Respondents noted that the committee would have limited effects on teacher education unless the Wisconsin Department of Public Instruction changed its requirements for teacher licensing. Despite this barrier, this committee will most likely continue past the SCALE grant with support from the School of Education and a high level of interest among participants (*Internal Structure*).

The second-order outcomes for this activity include:

- *Community*. The Middle School Science Committee further developed the STEM education community at UW-Madison, particularly for faculty with high status in the STEM disciplines (*Resources*).

[13] Students in the UW-Madison elementary education program must select a concentration in either early childhood/middle childhood (EC/MC) or middle childhood/early adolescence (MC/EA). The latter prepares students to teach in middle school settings and is the target of this SCALE activity.

- *Grant seeking.* The committee increased UW-Madison capacity to develop new research proposals, as evidenced by the rapid development by several members of this committee of a proposal to the UTeach program at the University of Texas at Austin (*Resources*).[14]

Science Immersion Unit Design and Institutes

Background. One of the primary goals of the SCALE project was to develop high-quality professional development for K–12 teachers in the form of "immersion units" (SCALE, 2005). An immersion unit is a carefully selected and designed learning opportunity in which students are engaged in the scientific inquiry process over an extended period (4 weeks), focusing intensely on a particular concept or big idea in the content area (Lauffer, 2004). Each immersion unit provides a coherent series of lessons designed to guide students in developing deep conceptual understanding that is aligned with key science concepts and the essential features of classroom inquiry specified in the state standards of the district for which each unit is designed. In each unit, students learn academic content by working like scientists: making observations, asking questions, doing further investigations to explore and explain natural phenomena, and communicating results based on evidence. The immersion units were delivered to K–12 teachers through an intensive weeklong professional development session that took place during the summer break.

Goals and objectives. In the original SCALE proposal, the overarching goal for the science immersion units was to "develop and implement immersion STEM learning experiences to ensure that every student in our partner districts experiences the process of engagement in an extended (e.g., 4-week) scientific investigation at least once a year" (SCALE, 2005). The specific benchmarks for this goal included developing and piloting immersion projects at different grade levels, developing professional development materials for unit implementation, conducting professional development sessions across the partnering K–12 districts, and facilitating the institutionalization of the units into district curricula.[15]

Activities. The immersion unit design process involved teams of SCALE staff, MMSD personnel, and UW academic staff who collaboratively developed grade-specific science immersion units for kindergarten, third, fourth, sixth, seventh, and ninth grades. Each of the units was designed to address the MMSD science standards. These units were then introduced to MMSD science teachers through 5-day professional development institutes. The institutes were designed to introduce the concept of immersion to K– 12 teachers by engaging them as "learners" in a scientific inquiry, and to model the unit implementation as if it were occurring in a K–12 classroom.

Participants. Two groups participated in this activity: the unit designers and the recipients of the professional development institutes. Although the unit designers varied depending on the grade level of the unit, the core group comprised four SCALE academic staff,

[14] UTeach was established in 1997 as a new way of introducing undergraduate math and science majors to secondary school teaching. This new pathway to teacher certification is streamlined to allow completion of both the bachelor's degree and teacher certification in 4 years.

[15] Other studies by the SCALE Research and Evaluation Team (RET), including the district case studies, have conducted more in-depth analyses of the immersion units.

seven MMSD staff, and three UW academic staff. STEM faculty were minimally involved in the immersion unit design process and served primarily as consultants to ensure the accuracy of the STEM content. A total of 297 K–12 teachers participated in the professional development institutes.

Outcomes: First and second order. The first-order outcomes for this SCALE activity, and their location in the ICF framework, are as follows:

- *Immersion units*. Six science immersion units were developed for MMSD and incorporated into the MMSD K–12 grade-level science standards (*External Environment*).

- *Science institutes.* Science institutes were provided for 297 MMSD science teachers (*External Environment*).

The second-order outcomes for this activity include:

- *Community*. The activity resulted in further development of academic staff engaged in STEM education at UW-Madison (*Resources*).

- *Networks and partnerships*. The activity further developed MMSD and UW-Madison networks and partnerships. The newly fostered relationships among individual UW academic staff and MMSD personnel will likely continue, given the mutual benefits and positive relationships that have been cultivated over the years (*Resources*).

- *Professional development*. The activity reportedly changed the perspectives and practices of professional development designers at UW-Madison. These reported changes will likely endure as they appear to be substantive and transformative (*Individual Sense-Making; Practices*).

Math Masters K–12 Professional Development

Background. SCALE leaders developed the initial Math Masters project (2004–05) in response to student learning and teacher training needs identified and documented through a needs assessment conducted by the project partners. The program was designed to support the implementation of a research-based mathematics curriculum—Connected Mathematics Project (CMP)—in MMSD and two nearby districts.

Goals and objectives. The goal of the Math Masters project was to expand K–12 teachers' subject matter knowledge of deep mathematics linked to state and national standards. In seeking funds for the project from the U.S. Department of Education under Title IIB of NCLB, the proposal writers articulated three objectives for achieving this goal: (a) use of classroom observations, (b) provision of in-class support, and (c) use of reflective analysis. They also clearly articulated strategies for achieving these objectives, which they closely linked to MMSD practices and objectives for teaching and learning. Key among these strategies was that UW mathematics professors should model constructivist approaches in Math Masters courses so that "teachers experience firsthand, as learners, the instructional approaches they will be using with their own students" (Math Masters proposal). This said, the proposal writers were less specific about the goals and objectives for the math faculty who were to be involved. An implied objective was that, through co-facilitating the workshops, the faculty would learn about, and learn to model, the active learning pedagogies required for teaching the Connected Math curriculum.

Thus, while the primary and explicit goal of Math Masters was professional development for K–12 math teachers, the program was also designed to provide informal professional development for math faculty in the hopes that they would institute a content-based pedagogical approach in their own undergraduate courses. The IHE SCALE leaders also stated in the proposal that a spin-off goal of Math Masters was to build the capacity of UW-Madison to "offer appropriate content-based courses to both pre- and in-service middle school mathematics teachers." Thus, the Math Masters project and the Math Preservice Committee can be viewed as complementary efforts.

Activities. Funded by a one-year state-administered U.S. Department of Education (Title IIB) grant during 2004–05, UW-Madison mathematics professors and MMSD math educators collaborated to design and facilitate 15 one-credit (20-hour) courses. This activity was referred to as Math Masters 1 (MM1). These courses focused on five of the "big ideas" in middle school mathematics (number operations, geometry, measurement, algebra, statistics and probability) and on the ways in which students learn that content. In addition, MMSD leaders offered optional, parallel one-credit courses in pedagogy. A second Title IIB Math Masters award (2005–06) enabled this group to provide six two-credit courses centered both on content and pedagogy (Math Masters 2, or MM2).

Some faculty participants in these activities reported surprise at the weak STEM content knowledge, and attendant anxiety, exhibited by the K–12 teachers in their workshops. Participants also noted that modeling a new pedagogical approach was not easy for them.

> So, we [math faculty] were supposed to be modeling the pedagogy that they [teachers in a professional development session] were to be teaching in their class. Modeling the first time around for me was something I had never done before. It was kind of mentally taxing. It was really hard. I had to work extremely hard the first time, even when [an MMSD leader] was running it. [It was hard] for me to do things right and learn and also be a model for something I'd never done before. It's completely insane if you think about it. (Math faculty)

Participants. This activity involved two groups of participants: the workshop designers and the recipients of the professional development workshops. Although the workshop designers varied depending on the specific unit, the core group included two MMSD staff and six UW math faculty. A total of 438 teachers attended the workshops, with an average 18.5 hours of professional development per person.

Outcomes: First and second order. The first-order outcomes for this SCALE activity, and their location in the ICF framework, are as follows:

- *Workshop participation.* The Math Masters project engaged a total of 438 K–12 teachers in 15 math professional development workshops. Unfortunately, the project will not, at least in the near future, be institutionalized or continued under external funding because external funding ended as of summer 2006 and MMSD-based professional development funding was cut back at the same time (*External Environment*).

- *Gains in content knowledge*. For MM1, middle school teachers took one or more of the five content-related courses and three pedagogy courses that the Math Masters project offered. Pre- and post-test results showed that participating teachers had statistically significant gains in all five content courses. Each course enhanced teachers' learning, with effect sizes ranging from .58 to .91 (*External Environment*).

- *Design and facilitation of workshops*. The project engaged five math faculty in designing and facilitating the workshops (*Resources*).

The second-order outcomes for this activity include:

- *Co-teaching*. A math faculty member and an MMSD teacher co-taught a lower division mathematics course designed for preservice elementary teachers (*Internal Structure*).

- *Collaboration between MMSD and faculty*. MMSD personnel now have an unprecedented level of access to some faculty at UW-Madison, particularly in the Mathematics Department. The new collaborations among UW math faculty and MMSD personnel resulted in a new project called Extending Math Knowledge (*Resources*).

- *Demystification of faculty*. The project served teachers by demystifying UW faculty, which was particularly important given the past history of acrimony between the UW Mathematics Department and MMSD (*Collective Values and Beliefs*).

- *Faculty understanding of middle school mathematics*. Participating UW faculty expressed better understanding of middle school math experiences, which makes them more informed when engaging in K–12 discussions at the IHE level. The shifts in math faculty's understanding of middle school math are likely to continue influencing how these individuals perceive and interpret math teaching and learning at the K–12 level (*Individual Sense-Making*).

> [SCALE did not change] the way I teach, but [helped me] recognize that if these teachers [in professional development workshops] don't understand this, then their students don't understand this, which means that they're coming in here [UW-Madison] not understanding this, so I better make sure that they understand this before they leave. (Math faculty)

Extending Math Knowledge K–12 Professional Development

Background. Based on the Math Masters experience, SCALE created a program model for elementary teachers, Grades 3–5, through the Extending Math Knowledge (EMK) project. This program was implemented in 2007. The key difference between MM1/MM2 and EMK is that the latter extended content knowledge development beyond 20-hour summer institutes by holding twice-monthly seminars throughout the school year. This change was driven by the literature on what elementary teachers need to know to successfully teach math, which tends to agree with the conclusion of Russell et al. (1994) that “the new mathematical understandings teachers must develop and the teaching situations they must negotiate are too varied, complex, and context-dependent to be anticipated in one or even several courses” (p. 289)

Goals and objectives. The goal of EMK was to increase student achievement in math in Grades 3, 4, and 5 by strengthening the quality of math instruction through content-based professional development linked to state content and teacher standards. Specific objectives included increasing the math content knowledge of at least 180 K–12 teachers, improving teachers’ understanding of student learning, and expanding teacher knowledge of standards-based mathematics curricula.

Activities. The professional development plan for mathematics in the elementary school included training for in-school facilitators who were provided by Title I funding. The training involved summer workshops, release time for school-day workshops, online learning modules, and/or regional workshops. The facilitators were trained to use MMSD’s Learning Mathematics in the Primary Grades document.

Participants. At the time of writing, participant data are not yet available.

Outcomes: First and second order. At the time of writing, outcome data are not yet available.

Science Masters K–12 Professional Development

Background. The Science Masters project was modeled after the Math Masters grants and is focused on improving K–12 teachers’ knowledge of science and student learning through intensive professional development workshops. A proposal to support a Science Masters Institute (SMI) was funded in November 2006. This project was developed in collaboration with 10 regional school districts and UW-Madison.

Goals and objectives. Over the 3-year grant period (November 2006–August 2009), SMI will provide intensive professional development to 120 middle school teachers of science, and thus roughly 18,000 middle school students will be affected. The specific objectives of SMI are to increase teachers’ content knowledge; improve teachers’ understanding of how students learn science; enhance implementation of standards-based science curricula; raise middle school student achievement; and reduce the achievement gap in science among all NCLB subgroups.

Activities. A project coordinator from MMSD led the design of each of the nine SMI courses held in 2007 and worked closely with STEM faculty on the facilitation of each individual course. Of these courses, one (Motion & Forces) was offered in the spring, four (Earth in the Solar System, Properties & Changes in Matter, Cellular Structure & Function, and Transfer of Energy) were offered in the summer, and three (Earth’s History, Structure of Earth’s Systems, and Natural Selection & Evolution) were offered in the fall. One summer course (System Interactions & Regulation) was canceled due to insufficient enrollment.

Participants. As of September 2007, 85 middle school teachers had participated in SMI, 52 of whom were teachers in MMSD. Workshop facilitators included the MMSD project coordinator and UW-Madison faculty from the fields of engineering (2), astronomy (1), chemistry (2), botany (1), and geology (1).

Outcomes: First and second order. Although insufficient data are available for this analysis at the time of writing, it is worth noting that Science Masters was one of the most successful SCALE activities in engaging STEM faculty.

MMSD Math Task Force

Background. In the fall of 2007, the MMSD Board of Education established the goal of forming a Math Task Force made up of national experts in math education in order to provide recommendations for future math curricular decisions.

Goals and objectives. The goals of the Math Task Force were to (a) analyze mathematics achievement data for MMSD K–12 students, (b) analyze performance expectations for MMSD K–12 students, (c) provide an overview of mathematics curricula including MMSD's mathematics curriculum, (d) provide a discussion of how to improve MMSD student achievement, and (e) make recommendations on measures to evaluate the effectiveness of MMSD's mathematics curriculum.

Activities. The Math Task Force was formed in January 2007. As of August 2007, the task force had met twice (April 13–16, June 12–13) to discuss how best to address the goals set forth by MMSD. Subcommittees had been established to address each of the goal areas, and task force members had begun preliminary work in each area. Initially, these efforts were supported by a combination of SCALE and MMSD funds, and the principal organizers of the Math Task Force unsuccessfully sought external funding from NSF to continue these efforts. Subsequently, the task force was awarded funding through UW-Madison's Baldwin Foundation, and MMSD and SCALE have committed financial and staff support to continue this activity.

Participants. The participants in this SCALE activity include five UW-Madison School of Education faculty, two UW-Madison math faculty, two faculty from other IHEs (University of Nebraska–Lincoln; California State University, Northridge), four UW-Madison administrators, one graduate student, and one academic staff.

Outcomes: First and second order. Insufficient data are available for this analysis at the time of writing.

Other Technical Assistance to MMSD

Background. In addition to the aforementioned activities, SCALE provided a number of technical assistance services to MMSD that were largely unanticipated at the time of the original proposal.

Goals and objectives. Since these activities emerged as the partnership between UW-Madison and MMSD developed, no specific goals or objectives were articulated. The activities fell within the larger mandate of SCALE to foster the internal capacity of K–12 districts to improve professional development and math and science teaching and learning.

Activities. The activities in this category include the SCALE/WestEd Leadership Academy for K–12 teachers, support for MMSD online professional development, and professional development for MMSD teachers of freshman science.

The *SCALE/WestEd Leadership Academy* was initiated by SCALE leaders who are UW academic staff. These UW leaders invited leaders from WestEd (a professional development company) to help them produce and hold training sessions based on a SCALE-developed professional development model. This model is designed to help district leaders develop their capacity to train other leaders in how to structure and use professional development resources in ways that are well aligned with the district theory of action. This effort engaged a team of 12 MMSD staff, including instructional resource teachers in mathematics and science, the mathematics coordinator, and the executive director of teaching and learning. These individuals participated in two 2-day sessions in the spring of 2007 (January 31–February 1 in Madison, and March 7–8 in Providence) to build capacity toward a "leader of leaders" professional development model.

In response to a district budget crisis, MMSD began in 2005 to shift from an in-person to an *online professional development model*, and SCALE staff provided technical assistance to ensure that this process was aligned with the SCALE and MSP goals. An online New Science Teacher Support Course was completed in fall 2007. The course provides new teachers with critical information to introduce the K–8 science standards, inquiry-based instruction, and assessment. The introductory course was to be evaluated in 2007–08 to assess whether all new teachers were provided with adequate instructional and content support to teach science effectively in their first year.

Five full-day *professional development seminars* were conducted in 2006–07 for 25 teachers of freshman science. The school year 2006–07 marked the second year of focus on equity and excellence at the high school science level. These seminars centered on building capacity in instructional skills and differentiation strategies to enable all students to participate in heterogeneously grouped science classes at the ninth-grade level.

Participants. These efforts involved at least four SCALE personnel. Accurate data on district-level participants were not available at the time of writing.

Outcomes: First and second order. The first-order outcomes for this SCALE activity, and their location in the ICF framework, are as follows:

- *Leadership Academy*. SCALE engaged a total of 12 MMSD staff in the SCALE Leadership Academy (*External Environment*).

- *Online professional development*. SCALE provided technical assistance for the development of MMSD online professional development. These efforts have been incorporated into the design and implementation of MMSD's professional development offerings (*External Environment*).

- *Professional development for science*. SCALE provided professional development for 25 MMSD science teachers (*External Environment*).

The second-order outcome identified for this SCALE activity is as follows:

- *Networks and partnerships*. SCALE technical assistance further developed MMSD and UW-Madison networks and partnerships. The newly fostered relationships among individual UW academic staff and MMSD personnel will likely continue, given the mutual benefits and positive relationships that have been cultivated over the years (*Resources*).

> It used to be [that] we'd have the university coming after us for everything under the sun, this person has an interest in this and that, and "Let's do this cute little thing and that cute little thing." That still happens to some extent, but with SCALE we now have some people at the university who understand that, unlike the university, the district is, in fact, a system. And that it has goals for kids that are very specific. And that we are standards-based, [although] I don't know if they understand the standards yet. But [they understand that] we're trying to move everybody in the same direction and that [university people] get in the way when they just take a shot in the dark. (MMSD personnel)

WCER Research and Evaluation Team

Background. While the SCALE Research and Evaluation Team (RET) did not directly implement SCALE activities, its work affected the organizational context of UW-Madison. The RET was housed at the UW-Madison Wisconsin Center for Education Research (WCER) and provided both formative and summative evaluation services to the SCALE project.

Goals and objectives. The goals of the RET were to evaluate the SCALE MSP and provide formative and summative evaluations of its activities. Thus, the RET was indirectly involved in helping SCALE achieve its stated goals for institutional change at UW-Madison by providing formative evaluation findings. This was primarily accomplished through the preliminary UW-Madison IHE case study (Hora & Millar, 2007) and the study reported here.

Activities. The RET was involved in four distinct lines of work: analyses of the participating K–12 districts; documentation of the partnership-building process; case studies of participating IHEs; and a study of student outcomes. In carrying out these research and evaluation activities, RET members regularly interacted with SCALE personnel and partner organizations, including other researchers in K–12 districts and IHEs.

Participants. The RET included one faculty member located at another university, one UW emeritus faculty member, seven academic staff at WCER, one faculty member at another university, and several UW graduate students. There was some turnover in the academic staff and substantial turnover in the graduate students, who generally held one-year appointments with the RET.

Outcomes: First and second order. The first-order outcome for this SCALE activity, and its location in the ICF framework, is as follows:

- *Research, evaluation, and dissemination*. The RET conducted a variety of research and evaluation activities and disseminated formative and summative findings to local and national audiences, including those at professional meetings (e.g., the American Educational Research Association annual meetings) and NSF (*External Environment*, *Resources*).

The second-order outcomes for this activity include:

- *Grant seeking*. The activities of the RET led to additional proposals submitted for funding by WCER for projects building on SCALE activities, including an NSF-funded large-scale implementation and research study of a SCALE immersion project currently under way in LAUSD. As these activities will continue past the end of the SCALE grant, this outcome will have a lasting influence on UW-Madison (*Resources*).

- *Research opportunities*. The RET provided a cohort of WCER researchers (including graduate students) with opportunities to conduct high-quality research in STEM education. Since many RET members will continue on at WCER in another capacity, this outcome will likely continue to influence UW-Madison into the future (*Resources*).

SCALE Participant Data

Data on the participants in SCALE—including faculty, academic staff, and K–12 personnel—are presented in Table 2.

Table 2
SCALE Participants by Position and Activity (January 2004–August 2007)

	Math Comm.	Science Comm.	Science Immers.	Math Masters	Science Masters	EMK	Math Task Force	Other TA[a]	SCALE RET	Undupl. totals
STEM faculty	8	10	0	6	7	N/A	2	0	0	25
Educ. faculty	3	3	0	0	0	N/A	5	0	0	8
Graduate students	9	0	0	0	0	N/A	1	0	6	15
Academic staff (SCALE)	0	0	4	0	0	N/A	1	4	7	11
Academic staff (non-SCALE)	0	3	3	0	0	N/A	0	0	0	3
Admin.	0	1	0	0	0	N/A	4	0	0	4
District staff	5	2	7	2	1	N/A	2	0	0	11
K–12 teachers	0	0	297	438	85	47	0	N/A	0	867[b]
Total	25	17	311	446	93	47	11	4	13	

[a]TA = technical assistance. [b]K–12 participant-level data were not available for this analysis at the time of writing so it is not possible to verify if these are unduplicated counts in this column total.

Major Effects of SCALE on UW-Madison Organizational context

Without measurable objectives with which to evaluate the SCALE project's activities and progress towards accomplishing its goals, it is difficult to make a definitive statement about the relative success or failure of the project. That said, the effects of the SCALE project—in relation to the size and complexity of UW-Madison—must at this point be considered modest. It is also fair to say, however, that the SCALE project resulted in a wide array of outcomes pertaining to the organizational context of UW-Madison that address the four goals of the project. Of note, SCALE focused its efforts on relatively small and discrete points within the UW context—redesigning STEM courses for preservice teachers and engaging faculty and academic staff to support K–12 teacher professional development. For example, a substantial amount of energy was focused on math courses for preservice students in the elementary education program. This approach is consistent with the perspective of a respondent who noted that once you identify a leverage point or a program, "you have a laser allocation of resources," and some people will follow while others will "complain about it for 50 years." SCALE not only targeted specific leverage points in such a manner, but also engaged multiple leverage points (e.g., decision-making bodies, interdepartmental forums, graduate students) in carrying out a single activity that resulted in both first- and second-order outcomes.

Below, we summarize the key accomplishments of the SCALE project in terms of specific elements of the UW-Madison organizational context.[16] By providing an account that situates the projects' outcomes within the complex institutional environment of UW-Madison, as opposed to a decontextualized list of project accomplishments, we hope to provide a more realistic and useful evaluation for program leaders and policy makers. Figure 5 presents these outcomes in terms of the ICF, depicting relationships based on a causal network analysis.

External Environment

- SCALE provided high-quality professional development in math and science to 867 K–12 teachers in order to improve their pedagogical content knowledge in the STEM disciplines.

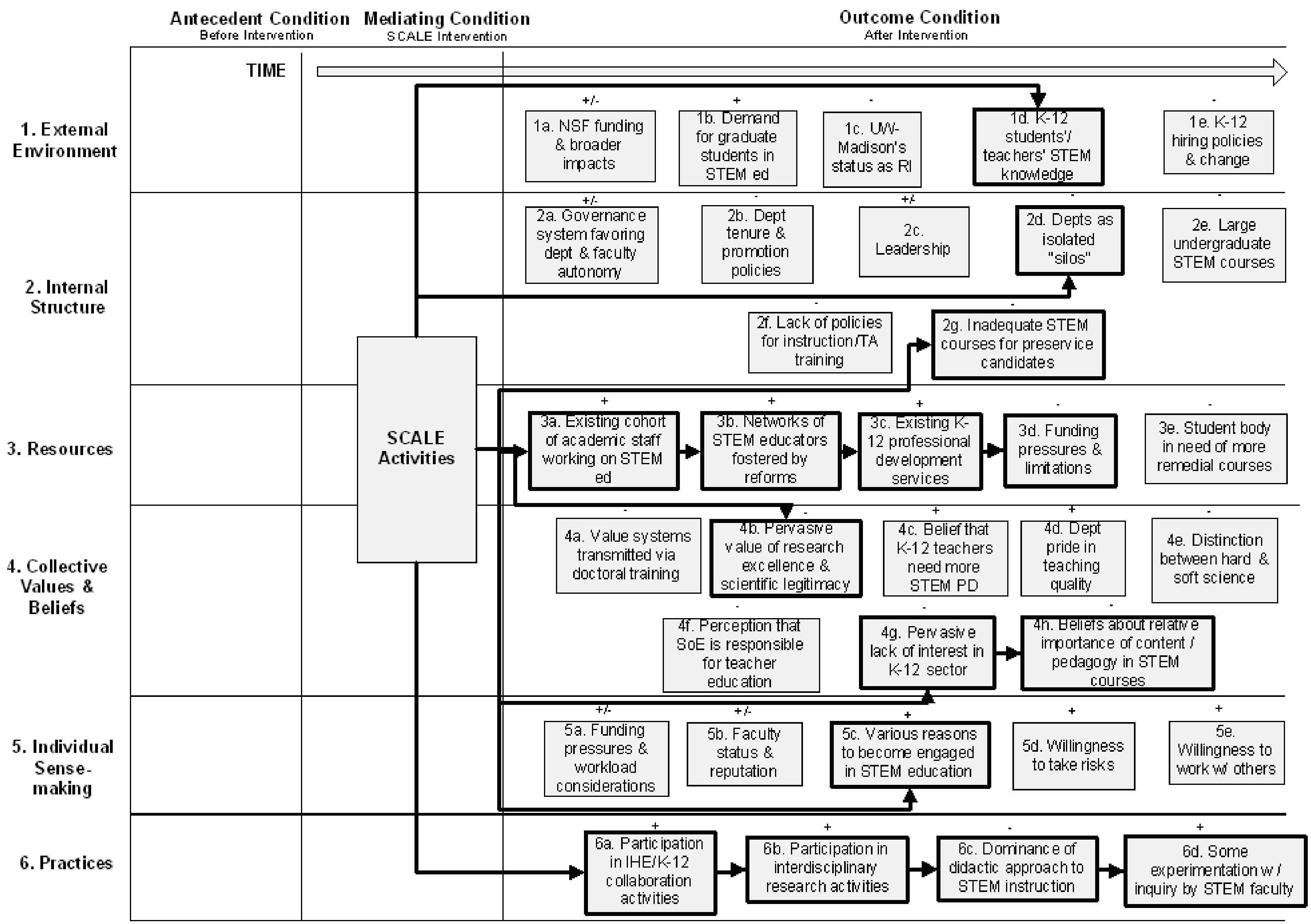
Internal Structure

- SCALE helped to create one interdepartmental committee focused on preservice training in science and reinvigorated an existing committee in math. Prior to SCALE, there was no perceived need for formal interactions between STEM and education departments on preservice training issues. As a result of the committee meetings, the science committee participants increased their understanding of which of their departments' courses were required by education students.

- The Math Preservice Committee successfully redesigned existing math courses and created new courses that are more closely aligned with the pedagogical philosophies of math educators and the practical considerations of local K–12 district leaders.

[16] Professional development outcomes for K–12 personnel are not included in this analysis as they did not directly or substantively affect UW-Madison personnel or institutional processes.

Figure 5: **Major effects of SCALE on the organizational context of UW -Madison.**



Note: We do not claim that changes to factors apply to all faculty or staff at UWMadison, but only to SCALE participants.

Resources

- SCALE effected changes in how some academic staff designed K–12 professional development materials. Some respondents had expressed a tendency to follow a "throw it over the wall" approach to K–12 professional development, whereby materials would be designed and disseminated without attention to the needs or unique characteristics of K–12 participants. Through their experiences with SCALE, they moved to an approach that involved the co-construction of materials, active cultivation of local K–12 capacity to deliver professional development workshops and train other personnel, and explicit attention to K–12 standards.

- The influx of SCALE and related funds in the form of faculty release time, professional development materials and workshops, and other support was very important in a resource-limited environment. This said, it must be noted that some respondents expressed skepticism about whether this major influx of funding would result in any substantive changes at UW-Madison.

- SCALE further enriched and developed a cohort of STEM educators at UW-Madison, including STEM faculty, education faculty, and academic staff who are engaged in or otherwise interested in improving K–20 STEM instruction. It is important to note that other reform efforts on campus, particularly the NSF-initiated (now campus-funded) Delta Program,[17] are continuing to foster the development of these networks of STEM educators.

Collective Values and Beliefs

- SCALE linked the existing collective value of scientific legitimacy and reputation to STEM education reform. SCALE leaders accomplished this by specifically recruiting faculty who were highly respected within their fields or departments. For example, a respondent noted that a colleague who exhibited greater understanding of middle school challenges as a result of SCALE was an important success for the project, because "he is a respected researcher, somebody who can get listened to."

- Participants in the Math Preservice and Middle School Science Committees reported shifts of opinion and newfound understandings of how preservice programs were designed, which altered a pervasive lack of knowledge about the K–12 sector.

- Through interdisciplinary working groups, participants developed a better understanding of the other discipline's beliefs about the relative importance of content and pedagogy. For example, one education faculty member learned more about "where STEM faculty were coming from," which led to a new understanding of the language and concepts underlying their instructional practices. In another case, a STEM faculty member who co-taught a course with an education faculty member observed his colleague elicit students' expectations for

[17] The Delta Program (www.delta.wisc.edu/index.html) is a research, teaching, and learning community for faculty, academic staff, postdocs, and graduate students. The program seeks to help current and future STEM faculty succeed and improve student learning in the changing landscape of STEM higher education.

learning and explained that this was “a wake-up call for me,” as he hadn’t considered asking students what they hoped to gain.

Individual Sense-Making

- Participation in SCALE activities led individual faculty to a renewed commitment to improving STEM education, as they became more aware of the lack of comfort and ability among K–12 instructors and the inadequate status of existing preservice course requirements in math and science. This commitment is particularly important as faculty must negotiate a demanding workload and recruitment, tenure, and promotion considerations, which generally do not reward or encourage K–12 or pedagogy-related activities. We note that, while it is important that the Wisconsin Idea validates such activities, individual faculty must be convinced of the value and importance of their involvement in projects such as SCALE.

Practices

- As a result of the Math Masters and Science Masters programs, the science immersion units, and other technical assistance efforts provided through SCALE, the relationship between UW-Madison and MMSD became more collaborative and mutually enriching than it had been previously. K–12 personnel indicated that while there had been existing collaborations before SCALE, it was refreshing that IHE faculty came to the K–12 venue with professional development materials tailored to K–12 participants’ unique needs and constraints.

- SCALE facilitated new interdepartmental collaborations between individual faculty, which led to new channels of communication between departments regarding preservice courses requirements in math and science.

- SCALE led to minor changes in the instructional practices of STEM faculty and graduate students. One respondent observed that a STEM faculty member who had participated in a SCALE activity was spending more time listening to students and had created innovative activities within a previously established syllabus. Another respondent admitted that it was difficult to learn how to use the instructional techniques employed in SCALE activities, but that she nonetheless was actively trying to incorporate specific pedagogical techniques into her STEM lectures.

V. Faculty Cultural Schemas and Sense-Making in Math Preservice Committee

To better understand the specific mechanisms of cultural processes associated with SCALE activities and the ways in which contextual factors interacted with a particular SCALE initiative and influenced the outcomes, it is instructive to investigate a single effort closely. For this case study, we analyzed the Math Preservice Committee, focusing on how collective values and beliefs were expressed in individual participant behaviors and views of this SCALE activity. We also assess how SCALE attempted to change collective values instantiated in individual instructor practices, and the results of this effort.

Value of Cultural Perspective for Evaluating STEM Education Reforms

Research on reform implementation in both higher education and K–12 has found that policy directives are frequently adapted and transformed by individual agents at the local school or IHE level (Coburn, 2001). The process of interpreting policy interventions and adapting them to a local situation is sometimes called *sense-making*, where institutional actors "make sense" of their environment and select appropriate actions (Birnbaum, 1988). Increasingly, researchers are recognizing the importance of this process and of the way in which local contextual factors such as organizational structure and leadership shape the sense-making process (Coburn, 2001; Spillane, Reiser, & Reimer, 2002).

Of particular interest is the role that organizational culture—the constellation of pervasive values and behavioral norms collectively held by groups within an institution—plays in shaping individuals' sense-making processes and ultimately their behaviors and interpersonal relationships (Siskin, 1991; Becher & Trowler, 2001; Van Maanen & Barley, 1984). As one respondent who has been a student in both math and education departments put it, "the cultural differences between the School of Education and the Math Department are vast and substantial." When placed within the crucible of an interdisciplinary working group or an intervention activity, these differences are not mere curiosities, but instead hold important implications for STEM education reforms.

> When a K–12 teacher says none of our students would understand what you're saying in Math Masters professional development, it may be about fancy mathematical language, or it might just be that they're coming at this with a different mindset, that they're thinking a different way. For language difficulties, somebody can be a translator, but in this case the whole approach is different. (STEM faculty)

If it is true that differences in values, beliefs, and tacit assumptions play an important role in reform implementation, then it is extremely important to understand precisely *how* culture manifests during the implementation process, and if it influences the observed outcomes of the reform. Further, as this case study demonstrates, pervasive values and beliefs do not exist in a vacuum, but instead are shaped by the technical and social constraints of the institutional context. Thus, a cultural account of the implementation process must also attend to the recursive relationship between culture and the institutional context.

Finally, if this "black box" of cultural influences on reform implementation is better understood, it may be possible to identify specific aspects of the organizational context as outcome measures for evaluation purposes. Given the widespread interest in changing the culture of schools and IHEs, such an advance would give program planners and policy makers the tools to better understand their institutions and the ultimate effects of investments in reform.

However, there are significant shortcomings in the dominant approach to understanding and analyzing organizational culture—in particular, its tendency to produce static and homogenous sets of vaguely defined values, beliefs, or artifacts (Bate, 1997; Van Maanen & Barley, 1984; Knight & Trowler, 2000). Many studies fail to address the degree to which group members adhere (or not) to the dominant knowledge in their organization (Ross, 2004). Moreover, some studies of organizations ignore the role of time in cultural process, thereby obscuring the origins and evolution of commonly held beliefs and values and, ultimately, our understanding of the actual processes of cultural change within organizations. This section includes a discussion of these issues and a way of understanding and analyzing cultural processes within IHEs.

Distributed Theory of Cultural Analysis from Cognitive Anthropology

In contrast to a commonly used theory of culture that seeks to establish a unitary and stable set of cultural norms for a specific group of people (e.g., the Math Department), we employ here a *distributed* theory of culture. This approach focuses on the distribution of knowledge and beliefs across and within groups, with particular attention to the underlying dynamics of agreement patterns and the relationship among these patterns and individual cognition (Atran, Medin, & Ross, 2005). The idea that an individual's cognitive processes shape how information (e.g., visual or aural stimuli) is processed and interpreted is an old concept in psychology and the cognitive sciences (Rumelhart, 1980; Schank & Abelson, 1977). Schema theory—one of the core ideas in cognitive psychology—posits that incoming information must be reduced in its specificity (e.g., color, context) and "chunked" into more simplified units that can be stored in short-term memory (Craik, 1943). The schemas that individuals internalize constitute "unconscious mental structures that underlie molar aspects of knowledge and skill" (Brewer, 1987, p. 188). As individuals internalize information and experiences from their physical and sociocultural environment—or "schematize" them—they become deeply embedded in the cognitive processes of the brain through repetition, reinforcement, and attachment to key life events or emotions (Shore, 1996).

Cognitive psychology makes an important distinction between schemas as underlying knowledge structures and their *episodic* representations, generally called mental models, which are formed in active engagement with environmental stimuli (Brewer, 1987).[18] These episodic representations are more complex "global knowledge structures constructed at the time of input" that may be composed of various interlocking schemas (Brewer, 1987, p. 189). Further, different types of mental models serve different purposes for individuals as they interact with their technical, social, and cultural surroundings (Shore, 1996), including orientational models (e.g., spatial models, social orientation models), diagnostic models (e.g., checklists), conceptual models (e.g., theories, classificatory models), and task models (e.g., scripts for specific task completion).

Some cognitive anthropologists suggest that mental models consist of combinations of schemas, which collectively comprise explanatory structures that are used by actors in a filtering process to omit or transform environmental stimuli (D'Andrade, 1995; Strauss & Quinn, 1998). Some schemas can be considered cultural since they are internalized from instantiated cultural forms that are "part of the stock of shared cognitive resources of a community" such as the "Star-

[18] The use of the term *mental model* is ubiquitous and has been critiqued for its lack of conceptual clarity and definition, particularly in organizational science (Lakomski, 2002). The term is more precisely defined in cognitive psychology, especially in its relationship to schema. However, the construct still suffers due to lack of attention to variability, change, and distinctions between constituent schema that are idiosyncratic and those that are internalized from cultural forms. We use the term here as a bridge to discussing different types of schema and the cultural model construct.

Spangled Banner" or tacit food habits pertaining to specific mealtimes and holidays (Shore, 1996, p. 47). However, individuals differentially internalize these shared beliefs, values, and norms, and thus, cultural communities are always "internally differentiated and cultural models are characterized by different degrees of sharing" (Shore, 1998, p. 1). Not only may the cultural schemas of a group be internalized differently by particular members of the group; the schemas may be tacitly held and never actually surface in everyday interaction.

An individual's mental model is activated in response to environmental stimuli, which in educational settings consists largely of the unique context of the organization. As a result, mental models must be viewed as simultaneously situated within and influenced by the organizational context (organized in terms of the ICF in this study), and shaped by the individual's unique personal experiences and social position in that context. In sum, we believe that this approach—by accounting for how individuals variously interpret, internalize, and instantiate organizational values, attitudes, and knowledge—enables us to develop a more adequate understanding of organizational culture than an approach that presents knowledge as uniformly shared and distributed across a complex organization.

How mental models and their constituent parts are instantiated into an empirically observable form is a critical issue for researchers in management, education, and industry who wish to understand how cognitive processes unfold in complex environments (Lakomski, 2001). Researchers working in laboratory settings can observe schemas or other aspects of cognition through experiments that ask research subjects to make causal judgments (Proctor & Ahn 2007) or that compare subjects' recall of critical events over time (Hamilton & Fagot, 1988).[19] It is considered more challenging to observe cognitive processes in non-laboratory settings, as there are more variables to account for and thus there is less control over the stimuli affecting a research subject. Some researchers have focused on highly standardized workplace environments in order to analyze how the mental models required for completing a task, such as navigating a battleship, can be decentralized among a group's members and how critical information can be embedded within artifacts (Hutchins, 1995). However, for researchers interested in cognitive processes in nonstandardized environments where cognitive processes may not be easily instantiated or embedded in physical form, discourse and narrative play an important role (Quinn, 2005).

Methodology for Identifying Cultural Schema at UW-Madison

Researchers seeking to empirically observe cognitive processes commonly analyze dialogue in interview transcripts (Brewer, 1987; Quinn, 2005). In this portion of our case study, we build on and extend this methodology by explicitly linking mental models and cultural schemas to specific factors in the local institutional context and by attempting to develop knowledge that can guide local program planners and policy makers. Specifically, we assess the content and contextual underpinnings of cultural schemas within groups, identify their role in an intervention activity, and assess if and how they changed over time. *We strongly emphasize that this is an exploratory effort to identify cultural schemas, undertaken in order to understand the*

[19] These are only two selected examples of lab-based research on cognition.

role of cultural models in STEM education.[20] (See the appendix for more details on our methodology.) Working within the interpretive tradition of Strauss and Quinn (1998), which uses natural discourse to identify cultural models, we identified the cultural schemas exhibited by at least three individuals within a group of math educators (N = 6) and a group of mathematicians (N = 8) who participated in the Math Preservice Committee. It is important to note that our sample draws heavily on faculty and graduate students who are conversant with education-related topics and thus likely represent a subgroup within their respective departments. *Further, cultural schemas are not cognitive structures that all group members exhibit; rather, individuals may hold multiple and even competing mental models and schemas for a given topic.* To illustrate this point, one respondent noted that there is "no unified voice in the Math Department" about education issues.

We looked for statements about a respondent's approach to math instruction, the origins of this approach, and ways in which the local context shaped the approach. We then focused on statements that expressed a core value, belief, or knowledge about STEM pedagogy, paying particular attention to its origins (i.e., from outside or inside the institutional boundaries). Next, using the causal network analysis method, we identified contextual factors that were related to the cultural schemas. We then analyzed how the 14 respondents who were engaged in this single SCALE activity described the activity and its influence on their approach to teaching and learning. Last, we identified those schemas or contextual factors that we believed held the greatest promise for leveraging change at UW-Madison. We asked respondents to review our findings to affirm or challenge their accuracy (D'Andrade, 1995), an approach common in cultural model research.

As a result, this study does not present an account of the culture of an entire organization or even its administrative subunits, but instead presents the pervasive cultural schemas held by group members in a specific domain under consideration. Researchers have long argued that over time multiple individuals with similar mental models can alter institutional structures and traditions (Clark, 1998). We posit that this distributed approach to culture is particularly suitable for evaluating systemic reforms (like the ones that SCALE is attempting in higher education) for two reasons: (a) faculty are particularly autonomous agents who exhibit high degrees of variability and independence and thus may hold cultural schemas that are not evenly shared across their departments and other groups; and (b) SCALE can be thought of as attempting to introduce into the environment new cultural schemas that individual faculty may internalize in various ways. We hope this provides an approach to the study of organizational culture in IHEs that is more nuanced and empirically sound and thus of value to the STEM education community.

[20] Future research should be undertaken to build upon this exploratory effort. This research may involve the additional use of methods developed specifically for identifying agreement, such as free listing and cultural consensus analysis. For the analyses presented here, we identified cultural models using data from two code categories in the ICF: *collective values*, where respondents were prompted to speak about their group's tacit assumptions, and *individual sense-making*, where respondents expressed personal perspectives.

Cultural Schemas Held by Mathematicians

Here, we present the cultural schemas held by the mathematicians ($N = 8$) who participated in the Math Preservice Committee: schemas related to math instruction and STEM education reform. Again, it is important to note that we do not claim that all respondents uniformly exhibit these cultural schemas. Instead, the schemas represent cognitive structures whose parts individuals may or may not exhibit and employ in a given situation.

Mathematicians' Cultural Schemas for Math Instruction

Teaching math is a straightforward and relatively easy task. Respondents indicated that they and most of their colleagues felt that math instruction is a simple instance of transmitting facts to a group of students, some of whom will excel and some of whom will not. This "wheat from the chaff" model is pervasive, and largely attributed to the fact that most faculty were themselves trained in this model as doctoral students. In their experience, being a highly accomplished researcher was a sufficient criterion for being an effective math instructor.

> They [math faculty colleagues] tend to have a lot of confidence that just by being good research mathematicians they have some innate ability to effectively teach a good student, and that may or may not be based in reality.

Some respondents indicated that their approach to teaching is more nuanced than this comment suggests, with differences in how they approach teaching graduate versus undergraduate and major versus non-major courses.

Content considerations are more important than pedagogical concerns. One of the most consistent sentiments expressed by math respondents was the primacy of content considerations. While some respondents noted the importance of acknowledging the unique instructional needs of certain student populations—such as preservice teachers, whose math anxiety or future careers may require a different type of instruction than that required by math majors—these concerns were secondary to those of first identifying the actual math content that should be covered in a given course.

> For a mathematician, content drives pedagogy. First you decide what you want to teach, and then you decide how to teach it. There are people, to my amazement, in math education who disagree with that. (STEM faculty)

This schema is in large part driven by the conviction that a math course is designed to "cover" a specific set of mathematical procedures or principles, usually contained within a selection of chapters within a textbook. For some math faculty, it is difficult if not impossible to discuss pedagogical issues for a given course until the specific math content has been identified. Furthermore, for most mathematicians a focus on content expertise has generally been the primary concern in their own work, careers, and classrooms. This singular focus on content and the straightforward "delivery" of this content through a lecture-based approach to teaching may have implications for the pedagogical approaches of math instructors at UW-Madison. As one respondent noted, "there are no role models [for alternatives to lecturing], and it is hard to control the impulse to just stand at the board and explain it and tell them everything they need to know.” In our view, mathematicians’ lack of exposure to the learning sciences and pedagogical training is a critical feature of this particular schema.

Teaching preservice teachers is different. Respondents indicated that teaching courses for non-majors—including general “service” courses for students majoring in fields such as engineering and chemistry—and courses for preservice teachers is qualitatively different from teaching courses for math majors. They observed that high-performing students in their math courses tend to go into industry or research, not teaching, and that those who are “ambivalent or negative” about math disproportionately end up becoming teachers, due in large part to their own negative experiences in school, creating a vicious cycle.

> The content is deemphasized to some extent in favor of changing attitudes and changing outlook on math. I think it is generally acknowledged that teachers who hated math end up teaching students who themselves end up hating math. If that isn’t changed somewhere along the line, we’re just perpetuating the same old mistakes of beating them on the head, teaching them “This is what you need to know,” telling you how to do it. (STEM faculty)

The mathematicians in the Math Preservice Committee expressed this model by designing courses for preservice teachers that attempt to integrate group work and other learning strategies to a greater extent than courses for majors. One noted that these strategies are adopted in view of preservice teachers’ math anxiety and the fact that they will ultimately end up teaching in that format in elementary or middle schools.

Mathematicians’ Cultural Schemas for STEM Education Reform

These cultural schemas are examples of schemas held only by a subset of a larger group. In this case, respondents clearly indicated that most math faculty are not interested in pedagogical reform or K–12 activities, and thus either do not have a schema for pedagogical reform, or if they do, it is minimized to the point of inaction.

> It’s still the case that we think of ourselves as first and foremost a research department. A very large part of our status in the pecking order of mathematics departments has to with our stature as researchers and that tends to drive salaries and hiring and retention and all this kind of stuff. So it’s a small subset of the faculty who really are interested in K–12 issues in any identifiable way. (STEM faculty)

As this respondent pointed out, the marginalized state of this subculture is due in large part to the “pecking order” of the department at large, which represents a larger cultural model of mathematical accomplishment and expertise.

Mathematicians have a role to play in K–12 math curriculum and teacher training. Respondents from the Math Department expressed the sentiment that, while most of their colleagues in other STEM departments at UW-Madison “just do not think about educational issues” very often, mathematicians have an important role to play in math education at the K–12 and IHE levels. This sentiment is shaped in large part by the opinion that professional mathematicians and their content expertise are needed to balance out the influence of math educators.

> I do think that there's a role for professional mathematicians in effectively focusing on what's important in a mathematics curriculum, and it's distressing to me how little professional mathematicians are consulted in the development of K–12 curriculum. The curriculum at the K–12 level tends to be overwhelmingly designed and implemented by [math educators], and that's too bad. Because those folks are overwhelmingly interested in methodology, and they are not that interested in concept. People in this building definitely think that content should drive [curriculum] and not the other way around. (STEM faculty)

A critical sentiment underlying this schema is a sense of ownership of the discipline. That is, mathematicians feel that conversations about math education are essentially about their own field, and there is a sense that they have an obvious role to play in determining how the general public is exposed to their discipline.

Mathematicians are the content experts, and the School of Education faculty are the learning experts. Related to the schema discussed above, mathematics respondents emphasized that in discussions about math curriculum and pedagogy, they are the experts in mathematics, and math educators are the experts in teaching and learning. Respondents conveyed that the fields of mathematics and math education are mutually exclusive in many ways and that each group of faculty should play roles appropriate to their expertise in discussions of math curriculum.

Math education as a discipline has some problems with rigor. Respondents expressed the view that math education is perceived as a lower tier field of inquiry in the broader discipline of mathematics. This sentiment is based on the conviction that "pure" mathematics research is a rigorous discipline that demands a high level of intelligence and mathematical aptitude and that math education is less intellectually demanding and rigorous and more akin to the "soft" social sciences. For example, one respondent noted that a graduate student who had decided to do a thesis in math education was told "you are smart enough to do a math thesis." One of the primary reasons mathematicians hold this sentiment is their perception that math educators generally do not have adequate training in mathematics and that their research is therefore questionable due at least in part to this weak mastery of mathematical content.

> Mathematicians often feel, and sometimes rightfully so, that the math educators may know how to teach but they don't know what to teach—they don't know the math. (STEM faculty)

Also underlying this schema is the perception that research and funding in math education are subject to fads—what one respondent described as putting a "new spin on things and it is a little too much like Paris fashion."

Other respondents noted that most mathematics faculty just do not think about these issues and thus have no active animosity toward math education. However, this lack of animosity does not negate a widespread notion that math education is a second tier pursuit, in terms of academic and intellectual hierarchies.

Problems in mathematics and education are very different. Further reinforcing the distinctions between mathematicians and math educators is the notion that problem solving is fundamentally different in the two fields. Some respondents pointed out that in math there are different ways to solve problems and construct proofs, but that ultimately problems have solutions. In education, by contrast, there is often less definitiveness and sometimes “more mystery” and interpretation.

> Pedagogical research does not work the same way as mathematical research. People don’t prove theorems in pedagogy, so the conclusions are not set in stone the same way mathematical conclusions are. (STEM faculty)

Some STEM faculty pointed out that because education research often lacks “crisp clear results,” their colleagues sometimes jump to conclusions about solutions in education, because they are “obvious” and require little intellectual exertion.

Cultural Schemas Held by Math Educators

Here, we present the core cultural schemas held by the math educators (N = 6) who participated in the Math Preservice Committee: schemas for math instruction and for STEM education reform.

Math Educators’ Cultural Schemas for Math Instruction

Math is a human endeavor and not an objective set of rules. Math educators pointed out that they hold a different view of the epistemology of math than mathematicians, and that this has profound implications for their views on math instruction. This view was summarized by a respondent as follows:

> I believe that math is a human endeavor, that mathematics is constituted of people’s understandings and is tied to culture, context, and history. I do not hold a Platonic view of math, so I do not believe that math is something out there that exists independent of human thought that we have to access somehow or teach students how to access. So I do not believe that it is this independently existing entity or set of relationships and roles that can be handed to anyone. (School of Education faculty)

We propose that this schema is extremely important in shaping how math educators interact with mathematicians, and is the foundation for their entire cultural model for teaching and learning.

Mathematics instruction should be driven by both content and learning theory. Another key schema for math educators is the conviction that math instruction is not simply “transmitting content,” but is a complex combination of content and method. Regarding her approach to instruction, one respondent emphasized that she “could not imagine teaching methods in a way that didn't build on content." This schema also has implications for math educators' beliefs about what future teachers need to know in order to become effective teachers.

> It strikes me that there's just a different philosophy or perspective about what one needs to know to be a good teacher. [For mathematicians,] it's that you have an appropriate amount of content expertise and you're ready to teach. [However,] lots of research suggests that there's a lot more to teaching than just knowing the content. (School of Education faculty)

Math Educators' Cultural Schemas for STEM Education Reform

In contrast to the cultural schemas of mathematicians, math educators' schemas for STEM education reform appear to be applicable to the larger group of math educators in the School of Education. In this case, respondents indicated that most of their faculty colleagues are interested in pedagogical reform and K–12 activities.

Math educators are the learning experts, and mathematicians are the content experts. This schema is identical to the mathematicians' sentiment about relative areas of expertise. Mathematicians feel strongly that the knowledge base of mathematicians is about math content and that their primary role in math education is therefore to strengthen the content knowledge of preservice teachers. In contrast, math educators see their area of expertise as being in the learning sciences, and pedagogy and teaching in math education are their specialty.

> There is a lot that we know about what teaching is, which is not just transmitting knowledge, and we know how teachers learn and what they need to learn, that education can bring to complement content expertise. (School of Education faculty)

Interestingly, some math educators qualified this schema with an acknowledgment that since mathematicians are not experts in math education, it is understandable that they use an instructional style in which they "just do their normal thing." Further, this lack of pedagogical expertise informs math educators' expectations of mathematicians' ability to participate in discussions about pedagogy and implement any subsequent changes in pedagogical practice.

> It would be a lot of work to develop the knowledge base that is necessary to teach those courses well, and I don't think anybody in the Math Department is qualified to do that. (School of Education faculty)

Mathematicians need to become reflective practitioners. Math educators expressed the sentiment that improving the content knowledge of preservice teachers requires that mathematicians become reflective practitioners. In other words, math educators view the didactic approach taken by many mathematicians as a significant reason students' knowledge of math content does not improve. This sentiment is fueled in part by the feeling that some mathematicians at UW-Madison have had an antagonistic approach to education. Some math educators are aware that this schema places them in a somewhat adversarial, if not condescending, stance. They explained that if the mathematicians are not willing to become more reflective about their own practice, then "we are just imposing ourselves upon them externally, and it just doesn't seem fruitful or helpful."

Problems in mathematics and education are very different. This schema is essentially the same as that for mathematicians and is based on the conviction that solving problems in math is fundamentally different from solving problems in education. This leads to a difference in each discipline's approach to research and education. One respondent noted that this difference is also expressed in the temperaments of faculty and students and the way they approach problem solving.

> There is a definitiveness to [solutions in math, while] in education, if I grade a paper, a student could get all worked up because she thinks that her way is just as valid as another way and there's this sort of fear of judging anything ever. That fear sure does not exist over in the math world. (School of Education faculty)

Social Transmission of Cultural Schemas

Faculty respondents identified two key ways that these cultural schemas were socially transmitted in both groups: doctoral training programs at their alma maters and academic departments at their current institution. For example, in their doctoral training programs mathematicians experienced a pedagogical approach exclusively focused on lecture and a didactic method, which is the source of the cultural schema for math instruction. Mathematics training also implicitly conveyed a value system that placed scholarship in the "hard" sciences much higher than that in the "soft" sciences. This perspective was conveyed through a disdain for the social sciences in general, and education in particular, and was exacerbated by an almost complete lack of interaction with colleagues from these other disciplines. The cultural schemas were then reinforced within the Math Department at UW-Madison, with its explicit emphasis on high-quality mathematical research and its marginalization of pedagogy-related activities such as K–12 outreach. As a result of this recurring reinforcement, these cultural schemas appear to be particularly rigid in terms of their "taken-for-granted" nature.

Relationship Between Cultural Schemas and Institutional Context

The primary contextual factor that respondents cited as pertinent to STEM education reform is not obviously related to the cultural schemas discussed above, yet it exerts an unmistakable influence on faculty's sense-making process. This factor is the demanding faculty workload in a setting that gives relatively low priority to teaching excellence. As a result, the workload is the primary contextual factor through which the cultural schemas (and STEM education reforms) must be viewed.

Activation of Schemas by Math 13X Activity

A cultural analysis of STEM education reform provides insight into how individuals interpret the reform initiative itself, and if and how they choose to participate in the reform activity. Since the subject matter addressed by SCALE was not new to UW-Madison personnel, given the history of K–12 outreach and pedagogical reform activities, we speculate that the information processing activities of our respondents were schema-driven, as opposed to requiring individuals to create interpretive frameworks "on the fly." That is, respondents interpreted the SCALE project through their existing cultural schemas.

As previously noted, mental models are a combination of cultural and idiosyncratic schemas, and many respondents pointed out that one idiosyncratic schema in particular played a very important role for mathematicians.

> I think it's fair to say that the main source of interest for professional mathematicians tends to be when they have children in the public schools. Then suddenly they get very interested. (STEM faculty)

The important role that faculty's children play in how reform activities are interpreted and then acted upon points to the unpredictable nature of the sense-making process. In this case, the schema pertaining to faculty's children appears to mostly shape their motivations for involvement in reform. Once "inside" the reform, other aspects of their cultural models play a more prominent role. Thus, while idiosyncratic schemas may be more important in motivating participation, the cultural schemas based on each member's respective disciplinary home figured most prominently in the Math Preservice Committee's process.

Based on observation of one meeting and various respondent accounts, we review the early stages of the Math Preservice Committee's development and provide an analysis of how the two cultural schemas described above and SCALE actors and resources influenced its activities.

Agreement on Problem and Complementary Cultural Schemas

At the outset, most participants in the Math Preservice Committee expressed a high degree of willingness to collaborate and deal with the problem at hand, which was notable given the acrimonious history of the predecessor committee. In fact, acute awareness of the tensions between the math and math education groups fostered a modicum of civility.

> It's going very well. I would say the rapport in this group is excellent compared to certain times in the recent past when various personality clashes made reaching a consensus much more difficult than it seems to be for this particular group. So far we have been trying to inform ourselves mainly about what the typical education program and state requirements are for middle school certification at peer institutions and other states in the Midwest. (STEM faculty)

A key aspect of this rapport was agreement on the problem facing the committee: that the Math 13X courses were in need of revision in order to improve the unsatisfactory math content knowledge of many elementary and middle school teachers. In response, SCALE provided funds to examine requirements for preservice teachers at peer institutions. The resulting study found that the university and state requirements were "substantially lower" than those of other IHEs, and this finding intensified the committee's conviction that things needed to change at UW-Madison. Although the committee as a whole did not hold identical cultural schemas, we believe that the commonly held schemas—which identify each group's area of expertise—provided a foundation of agreement upon which the committee was able to build. This acknowledgment that both parties had a role to play in determining the future direction of the Math 13X courses helped create at least the semblance of a collaborative atmosphere.

Disagreements, the Surfacing of Cultural Schemas, and Understanding of the "Other" Group

Despite committee members' good intentions, it did not take long for disagreements about math education to surface. Of note, it was primarily through these conflicts that elements of the cultural schemas were made visible. In particular, when committee members felt the need to make clear that the "other" group simply did not understand the experiences or perspectives of "their" own group, they were likely to make their schemas visible. For example, at an early meeting of the committee, an MMSD participant who had many years of teaching experience stood up and stated outright that the current courses are "not what people need to go and teach in elementary school." In this case, some mathematicians present understood: they realized that until that moment they had not considered what math content elementary school teachers actually teach. In other cases, cultural schemas surfaced not through disagreement but through the opportunity the committee provided for respectful interaction. This opportunity enabled members to at least become aware of, if not fully understand or agree with, the kinds of ideas and practices that informed the other group's work. One mathematician, in describing his experiences with the committee, made it clear that such interdisciplinary contacts were extremely rare, yet welcome.

> It was wonderful to listen to them. There were two or three people from Curriculum and Instruction, and their ideas were so different from what I was used to hearing. It was a learning experience to hear people that have studied the learning question itself. We study math and want to know math. We are not as well trained in how to think how their [the students'] brains are actually working. (STEM faculty)

Some points of disagreement and contention that emerged in the committee are particularly important to understand, as they remained a persistent challenge throughout the duration of the SCALE grant. Some respondents noted that each group's lack of expertise in the other's discipline made communication and achievement of mutual understanding difficult. In particular, even though members of the math and math education groups recognized that the other group's expertise was valuable, each group's commitment to its own areas of expertise proved to be more a barrier to than an enabler of learning within the group. Probably the most contentious issues pertained to the relative importance of math content and pedagogy. For example, a math faculty member rejected a recommendation to show 13X students the work of K–12 students so that they could start thinking about concepts the way their students would, reportedly stating: "That's a methods issue, and we're only talking about content." One respondent felt that this type of disagreement, which represented the implicit and deep-seated nature of each group's beliefs and values, potentially was a fatal flaw that would thwart achievement of the committee's aspirations. This person explained:

> The major disagreements are so fundamental, and they have not been made explicit by us together as a committee, [so] it's hard to point to them. But I believe that the disagreements surround our belief about what it is to do mathematics. I think that [math faculty member] thinks that math is something different from what I think math is. (School of Education faculty)

As is common for interdisciplinary groups, another source of frustration and misunderstanding was differences in language used by each group. As one mathematician put it, "It's somewhat frustrating because we speak a totally different language, so it took me awhile to understand what they were even talking about." Another respondent reported that the terms *understand*, *explain*, and *apply* were particularly subject to differing interpretations. For example, mathematicians expected an explanation to be very clear and detailed and include conventional notation. For a math educator, explanation included the act of explaining and reasoning, and entailed the idea that students should take up the practice of really understanding what they were doing rather than just listing steps. Finally, the views that each group held about the other emerged as a significant issue, and sometimes were at the root of personal conflicts and disagreements. For example, the views that math education is not a rigorous discipline and that some math educators had inadequate mathematical background emerged in both subtle and not-so-subtle ways.

Cultural Schemas Conveyed by SCALE

We speculate that the cultural schemas conveyed by the SCALE intervention had more similarities with the math educators' cultural schemas than the mathematicians', as math educators generally had few disagreements with the intent and design of the committee, whereas some mathematicians had some significant disagreements. This has important implications for how participants perceived the intent of the reform, and if and how it will be allowed to permeate the existing practices and cultural models of the Math and C&I Departments.

Outcomes of Math Preservice Committee

In analyzing the outcomes of this SCALE activity, we identified self-reported changes to specific schemas, the extent to which these changes shaped the translation of the reform message to concrete action, and changes to contextual factors that are particularly salient to the formation and reproduction of cultural schemas. We identified only minor shifts in specific cultural schemas.

Influence of SCALE Participation on Cultural Schemas

While the SCALE project did not explicitly seek to change the cultural schemas held by groups of faculty, both the MSP program and SCALE do have "culture change" as one of their primary goals. Since this evaluation takes a distributional rather than a categorical view of culture, we now examine the evidence for changes to the cultural schemas held by Math Preservice Committee members. This evidence is based entirely on respondent self-reports of changes in their own perspectives and behaviors. We report only minor shifts in perspective and understanding, which is consistent with the research on the difficulty of effecting behavioral change in education, changes in fundamental conceptual knowledge, and the resiliency of culture (Stensaker & Norgard, 2001; Strike & Posner, 1985; Tobias, 1992).

Changes to "content considerations are more important than pedagogical concerns." Some mathematicians (n = 3) exhibited small shifts in this schema related to math instruction. These three came to appreciate that teaching mathematics is not a simple or "obvious" practice.

> I've changed my mind a little bit about [classroom practice]. I realize that it's more important to have [students] come up to the board and explain stuff to other people, which I couldn't do in any other class, right? Because they're going to have to teach stuff later on, so they need to be a lot better at clearly explaining what I would consider very simple mathematics. There are some fine points there too, which I didn't appreciate a couple years ago. To me it seemed obvious, but now I realize that there are actually (pause) there are some points to be made. (STEM faculty)

This respondent had worked closely with a K–12 teacher and expressed a newfound appreciation for understanding student expectations and goals for their education.

> [K–12 teacher] has given me help on how to present certain things and very good feedback. One time [K–12 teacher] conducted a whole class just trying to find out what the students wanted out of this class. What were their expectations? It was a wake-up call for me. (STEM faculty)

We note that perspective shifts of this type may alter individual mathematicians' mental models pertaining to teaching and learning, and the potential importance of such changes should not be underestimated. Understanding the rationale for one's teaching practice is an important step in becoming a reflective practitioner (Schön, 1983). At the same time, we are cautious about assuming that attitude shifts of this type automatically translate into changes in classroom practice: the literature on learning indicates that the relationship between teacher thinking and classroom practice is unclear (Kane, Sandretto, & Heath, 2002).

Changes to conceptions of and appreciation for the "other." At least one cultural schema within each group referred to the "other" group: (a) math education as a discipline has a problem with rigor (mathematicians) and (b) mathematicians need to become reflective practitioners (math educators). While we observed no changes to these schemas, individuals from both groups exhibited an improved understanding of the "other" discipline and its positions on math instruction. Becoming informed in this manner is an important precursor to minimizing the inimical effects of stereotypes and assumptions that people hold about one another and to developing an awareness of one's own tacit assumptions (Spillane et al., 2002).

Some mathematicians expressed an increased understanding of math education and the positions of their colleagues as a result of their participation in the Math Preservice Committee. These faculty and graduate students read education research and engaged in lengthy discussions with math educators, which led to an improved understanding of their positions on math education. One respondent expressed the view that a significant source of disagreement between the two groups was ideological in nature and not related to specific issues pertaining to the Math 13X courses.

> I think we understand better where we're coming from, and I think we may be converging just slightly. If you get down to the nitty-gritty, there's probably a little more agreement than there might be if you look at just the ideological fluff. (STEM faculty)

By contrast, most other respondents argued that the ideological positions held by both groups were inextricably intertwined with specific issues that they hammered out in redesigning preservice courses and that it was impossible to disentangle these positions from the curricular decisions they made. In any case, the mathematicians' increased understanding of the position of math educators was a critical step toward establishing a mutually agreeable and collaborative working atmosphere.

Some math educators also exhibited changes in their perspectives about their colleagues in the Math Department.

> I started to understand the mathematicians' perspective, where we might be misinterpreting each other. Especially how they perceive what constitutes math learning, what's important to them, especially in K–1—and their perspectives on who can learn math. (School of Education faculty)

Interestingly, one respondent also noted that she had been "reminded of the rigor of the discipline" through her participation in SCALE. Both of these changes indicate that it is not only mathematicians who have room for improvement in terms of their conceptions of the "other." We note that this observation about the rigor of mathematics highlights differences in each discipline's relationship with mathematics. Some math educators are somewhat removed from intensive mathematical research and activity, and essentially all are interested in how learners approach mathematics. That these scholars are once removed from the day-to-day mechanics of the discipline and its possible implications for their depth of understanding may be a major reason some mathematicians question the qualifications of their colleagues in math education.

Changes to Contextual Factors in Which Cultural Schemas Are Situated

It is important to remember that the Math Preservice Committee had been in existence for a long time prior to SCALE. One respondent indicated that he had been involved in the course sequence for over 40 years. As such, this committee did not exist in a sociohistorical vacuum, separate from the constraints and influences of the institutional context and cultural forces described earlier in this case study. Similarly, the cultural schemas held by individual faculty and graduate students operate within and are shaped by this very specific institutional environment. With this in mind, we turn to an analysis of the institutional context specific to the Math 13X courses at T2 and its implications for the cultural schemas that mathematicians and math educators hold for STEM education.

Creation of a cross-cultural venue pertaining to the Math 13X sequence. The Math 13X courses are located in the Math Department. This is a structural factor that influences critical matters such as course design, syllabi, and the appointment of instructors. While the interdepartmental Math Preservice Committee existed to involve School of Education faculty in this decision-making process, at T1 there was little evidence that a collaborative process was in place. Furthermore, respondents described the influence of the School of Education faculty as minimal, and of K–12 participants as practically nonexistent. Thus, there was little if any opportunity for the values, beliefs, and perspectives of these other groups to play a role in the Math 13X courses. As a result of the dominant influence of the Math Department on the Math 13X courses, the primary cultural schema in place at T1 was that of Math Department faculty. Individual faculty and graduate students drew from these values and beliefs within the department, and their own individual background and experiences, to construct their own personal mental models for STEM education.

While the courses are still offered by the Math Department and thus are subject to departmental practices such as instructor designation, the Math Preservice Committee has become far more involved in critical decisions that were previously the sole domain of the department. These include the design of the course syllabi, the selection of textbooks, and the instructional practices employed in the classroom. The committee fostered dialogue between members of the Math and the Curriculum and Instruction Departments, with several results: some members of each department reported new appreciation for members of the other; two math professors reported changes in their instructional practices; and new networks were cultivated among STEM faculty and graduate students at UW-Madison. By introducing a different set of pervasive values and beliefs, primarily from the C&I Department and MMSD, SCALE created a forum in which the cultural schemas of each group came into contact—and sometimes conflict—with one another. This would not have been possible without some sort of structural venue in which these groups could meet. This type of "infiltration" was also made more likely because the SCALE PI was a faculty member of the Math Department and thus had an entrée into the department's decision-making bodies. As previously stated, the observed changes in the cultural schemas of the participants were relatively minor, but their possible impacts should not be underestimated.

Impact on graduate students: Shaping the social transmission of cultural schemas. Prominent among the committee members who reported developing a new appreciation of the other group were the graduate students. Because they were in the early stages of socialization into their disciplines, they exhibited a certain emotional and intellectual distance from the schemas discussed above. Interestingly, a faculty respondent noted that graduate students "were the backbone of the collaboration" and that, since they were less affected than faculty by the historic strife between departments or the associated personal issues, their communication was "much more fluid." Furthermore, some graduate students exhibited a very strong interest in the work of the committee and contributed a significant amount of time and energy to carrying it out. In most cases, this amount of effort was neither feasible nor (in our view) desirable for the faculty participants. Given the fact that the graduate students were in the process of being socialized into their respective disciplines and were quite involved in the committee's work and that a fertile exchange of ideas across disciplines took place, we speculate that this SCALE-initiated activity influenced the cultural models of the participating graduate students. Even if this influence consisted only of improving their understanding of the "other" discipline and of K–12 math education, this would be an important accomplishment, particularly at a prestigious Research I IHE where these types of activities are uncommon.

Conclusions

This analysis demonstrates the resilience of cultural schemas and the ways in which the local context serves to reinforce and reproduce them. We believe that the SCALE PI hoped (although he did not express it this way) that the Math Preservice Committee would foster among faculty the kind of changes it fostered among the graduate students—an "updated" cultural schema of math instruction that at least partially integrated key schemas from both groups. However, the available evidence shows that while some faculty participants exhibited a greater understanding of pedagogical issues in math, their core cultural schemas of math instruction did not substantively change. We also note that the committee engaged in what we call the *accidental model of culture change*, where changes to cultural schemas are not explicitly integrated into the activity's design and implementation. This approach is in contrast to a guided model of culture change, in which a skilled facilitator or "culture broker" leads a group through an in-depth exploration of a new set of ideas, practices, and theories in order to reshape their existing notions and knowledge structures.

In our analysis of SCALE activities at the California State University, Dominguez Hills, we found that a series of faculty professional development workshops had a strong impact on STEM faculty's cultural schemas for instruction (Hora, 2007). In cases where faculty are unlikely to commit to professional development, the accidental approach may be the only option.

This analysis suggests that "shaping" the culture of an organization may include efforts to change or alter the structural, social, and symbolic milieu in which individuals operate, but the actual cognitive processes that constitute individuals' "habits of mind" are much more difficult to change. It is especially important to realize that cultural schemas operate according to a logic that is most likely inaccessible to leaders and change agents (unless they are insiders to that cultural group), which may require leaders to employ a flexible and multifaceted toolkit of "frames" through which to analyze their organizations (Bolman & Deal, 2003). The enduring lesson from SCALE activities at UW-Madison is that efforts to change the culture of teaching and learning in STEM departments should focus on illuminating and then shifting the pervasive cultural schemas that faculty hold for teaching and learning. One strategy for doing so is to create officially sanctioned venues where individuals from different disciplinary backgrounds can focus on commonly shared pedagogy-related challenges, while also being acutely aware of and sensitive to the deeply entrenched nature of cultural schemas and their embeddedness in the local institution.

VI. Conclusions and Recommendations

Assessment of SCALE Strategy at UW-Madison

To understand the impact of SCALE on UW-Madison, it is necessary to bear in mind the relationship between the key contextual factors and institutional change processes identified in this study. Research universities like UW-Madison are large, complex institutions made up of many loosely coupled colleges and departments that largely operate according to their own logics, rules, and norms. The disparate yet interconnected contextual factors identified in this study operate in dynamic interaction such that a change in one may yield unpredictable and even imperceptible movement in others. It is evident that SCALE did effect some substantive changes to the organizational context of UW-Madison in a few key areas. The goal of this final section of the case study is to understand the implications of these multiple and seemingly disjointed points of impact.

Based on our findings, we propose that SCALE's enacted theory of change was that in order to produce improvement that is sustained over time change must be pursued simultaneously on structural, sociocultural, and individual levels. Based on research on organizational change, we postulate that an approach that addresses a plurality of factors is an effective—possibly a necessary—strategy at institutions such as UW-Madison, because such an approach is commensurate with the complexity and multidimensionality of the organizational context of the institution. We therefore consider the enacted SCALE theory of change to be promising, as long as its implementation is guided by a sophisticated understanding of the multifaceted nature of the barriers and supports within an IHE.

While SCALE did not create a revolutionary change at UW-Madison, it set in motion an array of initiatives that resulted in several small pockets of change. Some of these changes were relatively one-dimensional and engaged only a few aspects of UW-Madison (e.g., immersion units), while others were more comprehensive and engaged multiple aspects of the university (e.g., the Math Preservice Committee). To effect substantive change at UW-Madison, a comprehensive strategy is, if not necessary, at least commensurate with the complexity and multidimensionality of the leverage points within the institution.

Role of Reform Leadership

The SCALE reform strategy was informed by the project PI's astute insight into the key mechanisms for change at UW-Madison, which was developed through his years of experience as an administrator and STEM faculty member. He had acquired a significant fund of institutional knowledge and memory to draw upon in designing the reform effort. While this approach yielded some impressive results, there are limitations to relying on a single leader. First, these leaders may focus on a very particular piece of their local institution and in the process fail to engage a wider range of programs, administrative units, and personnel. For example, focusing on a specific sequence of courses in a single department, such as the Math 13X sequence, may reflect the strategic leveraging of scarce resources, but a significant consequence is that other courses and personnel may be left out of the project. That this limitation applies to SCALE was made evident through criticism that the project failed to engage a broader range of STEM and education faculty in the planning and implementation of its activities. Second, in the case of multi-institutional reform efforts such as SCALE, it is unlikely that the local leader can be sufficiently informed about and active at each partner institution, or that each institution will have equally strategic and effective leaders. While SCALE was fortunate in engaging local leaders in K–12 districts (e.g., MMSD) and some IHE partners, local leadership was lacking in other partner institutions. This suggests that multi-institutional reforms should pay attention to cultivating local leaders instead of relying on a top-down strategy that relies on a single leader.

Key Leverage Points for Institutional Change at UW-Madison

We judge that five of the contextual factors at UW-Madison were especially promising in leveraging the types of change sought by the MSP program. We identified these factors by focusing on (a) factors that were directly linked to the first- and second-order outcomes of SCALE activities and (b) factors that had particularly strong "downstream" effects on the organizational context of UW-Madison. The multidimensional framework used in this case study shows that these factors, which we refer to as *leverage points*, include, but are not limited to, factors commonly cited in the change literature, such as policy initiatives, school leadership, and professional community. Furthermore, we note that the leverage points identified in this study should not be viewed as isolated “magic bullets” that can produce fast and enduring reform across the entire university. Rather, they must be understood as operating in dynamic interaction, such that a change in one may yield unpredictable and even imperceptible movement in others.

> The university is quite dynamic. It just has some fundamental rhythms. Those rhythms are not much affected by point charges, even if they’re large, $10 million point charges, like [the Center for the Integration of Research, Teaching, and Learning]. But if you start to get the “pings” in unison and you do it long enough, you can start to change, I think, the fundamental modalities by which this organism, this complex dynamic organism, vibrates. So I think for anything like a Research I, or even K–12 education, if you don’t take a long view, you’re going to not be real satisfied. (STEM faculty)

Based on our analysis of the SCALE project, we speculate that by engaging the key leverage points described below in a substantive and sustained manner, it is possible that a “tipping point” may be reached within a particular organizational unit, such that a previously rare practice or behavior becomes widespread (Gladwell, 2000). This analysis is intended only to identify the key leverage points for change in this system, and no claims are made regarding the ultimate outcomes on instructional practices or student learning. We suggest that the above factors deserve particular attention by campus leaders and STEM education reformers, since they have the potential to effect a cascade of impacts at a variety of points in the organizational context of an IHE.

Decision-Making Bodies and Interdepartmental Forums

Certain decision-making bodies at UW-Madison are critical to a reform effort focused on curricular or policy change. Hence, we classify them as a leverage point. For the proposed changes to the Math 13X sequence, at least three such bodies are involved: (a) the Math Preservice Committee, (b) the Mathematics Department, and (c) a college-level divisional committee. These organizational units strongly influence the structural factors that shape undergraduate education in the Math Department and make up the policy environment that individual instructors (faculty and graduate students) may need to acknowledge when planning and teaching math courses for preservice teachers. It appears that any STEM education reform effort at UW-Madison aimed at effecting lasting policy changes would need to engage this leverage point.

Furthermore, at a campus as large and decentralized as UW-Madison, the status quo is that faculty in different departments do not interact in a sustained, goal-directed manner unless individual faculty (or possibly academic staff or graduate students) initiate interdepartmental forums. We consider such forums as the Math Preservice Committee important decision-making bodies. In the case of SCALE, the PI believed that in order to make headway on the challenge of improving the quality of teacher education, members of math, science, and education departments would need to share ideas, pool resources, and combine expertise. And to enable this interaction, formal structures were needed. Hence, he activated this leverage point by supporting a rejuvenation of the Math Preservice Committee and supporting the creation of the Middle School Science Committee.

Networks of STEM Educators

Faculty and academic staff belong to a variety of professional and personal networks, which in some cases can become professional communities if they involve meeting regularly and addressing common problems and tasks. These networks and communities are a key leverage point because through them ideas can spread rapidly, resources can be accessed, and collegial support for new endeavors can be obtained. Particularly important members of these STEM educator networks are faculty and academic staff who have positions focused on STEM education, which is quite common at UW-Madison. In the case of SCALE, an example is the Math Preservice Committee. STEM faculty who are already engaged in education activities as part of their normal workload are another key leverage point for reform, as they are well placed to enact change and do not have to negotiate their workload to focus on STEM education issues. Further, these faculty and academic staff often have extensive networks and access to STEM education resources that can be utilized to achieve the goals of a reform initiative. It is important to maintain contact with these faculty and staff—and to understand the dynamics of their particular departments in relation to STEM education—in order to avoid inadvertently jeopardizing their reputations or careers.

Academic Staff and Graduate Students

Academic staff at UW-Madison do not have the same workload considerations that faculty do (i.e., classes, publication pressure) and thus may be more available for STEM education reform efforts. Since many academic staff have PhDs and thus are respected and valued by both K–12 partners and faculty, they may be particularly key leverage points for STEM education reform. SCALE engaged and influenced this leverage point by hiring several academic staff, some of whom were STEM education specialists.

> We've had some stellar academic staff. I realize that there is a [technical] difference [with faculty], but I don't think that this difference has impeded the impact and the value that MMSD has gotten from SCALE. (MMSD personnel)

Graduate students are part of this leverage point for a variety of reasons, including their importance in undergraduate education, their future roles as faculty, and their purported distance from departmental and campus politics. In particular, since TAs are the "one human interaction" that many undergraduate students will have with a UW instructor, they are extremely important leverage points for STEM education reform. However, a problem with graduate students as leverage points is their relatively short time at UW-Madison, which raises questions about the longevity of outcomes achieved through projects like SCALE.

Cultural Schemas Regarding Disciplinary Legitimacy and Credibility

Achieving legitimacy and credibility in one's field has two positive benefits for those wishing to engage in STEM education activities. First, it affords safety from colleagues' criticism and gives a strong sense of confidence that is important when departing from the traditional workload of a STEM faculty member. As one respondent stated, if faculty members' research credentials are solid, then they can "dabble" in less prestigious issues such as education.

Second, once faculty achieve tenure and are under less pressure to publish and conduct research, they may have more time to explore other ideas and activities.

> Now you go back and you say, "Well, how did it happen to me?" Well, I was a senior [faculty] and in my profession successful. I was getting the necessary rewards, but then this insight came [that engaging the public was important] and I took this course. [But] parallels of that sort are very rare. (STEM faculty)

Further, respondents noted that, with the "currency of the realm" at UW-Madison being research accomplishments, it is particularly important to engage high-prestige faculty since colleagues on campus and around the world "listen to them." We argue that professional legitimacy and credibility must be recognized and exploited by leaders of reform initiatives, and the SCALE leaders were adept at directing their resources at these strategic leverage points. In the process, SCALE raised the profile of some of these leaders at UW-Madison and changed the complexion of STEM education reform on campus.

Individual Sense-Making

As individual faculty members and administrators operate within their institutional context at UW-Madison, they "make sense" of their environment and make decisions about how to act. This view of practice in higher education holds that individuals' behaviors are governed first by their own sense-making processes, as informed by their personal background, disposition, and motivating structures, and second by the objective rules and policies of the institution. The factors that ultimately shape behavior can be aligned with the pervasive values and institutional policies of an IHE, but they can also be highly idiosyncratic and unpredictable. Why is sense-making so important when considering STEM education reform in higher education? Even though faculty are autonomous agents with significant control over their professional lives, they also exist in a highly structured social and technical system that they must continually interpret and negotiate.

Based on our analysis we strongly emphasize the impact of individual sense-making on the implementation process and eventual outcomes of STEM education reforms. For interventions such as SCALE, the importance of understanding the nature of these constraining systems—and the ways in which individuals and groups of faculty (i.e., a particular discipline or department) make sense of them—cannot be overstated. Based on the data from this case study, we speculate that when faced with a new situation, faculty use the following four sense-making filters (listed in order of importance): (a) workload and attendant recruitment, tenure, and promotion considerations; (b) cultural schemas salient to the topic at hand; (c) availability of resources (fiscal and social); and (d) structural and technical constraints of their location in the institution.

Recommendations for UW-Madison Leaders and NSF

This case study reveals mechanisms of change initiated by a STEM education reform effort at an IHE and, in the process, illuminates an enacted theory of change that appears to have achieved at least some of its intended outcomes. We consider this theory of change promising, with the caveat that effective implementation of the theory requires a sophisticated understanding of the multifaceted nature of the barriers and supports within an IHE. We suggest that the following specific strategies may benefit both future STEM education reform efforts at UW-Madison and policy makers at funding agencies such as NSF and the Department of Education who may wish to replicate SCALE successes at UW.

- *Conduct assessments of institutional context prior to program planning and implementation*. We propose that change efforts should begin with an institutional needs assessment in order to identify the local contextual factors that may provide barriers and opportunities to reform (Tobias, 1992). Treisman (2007) has suggested that this is important so that change leaders obtain a "clear sense of the idiosyncratic features of the environment" (p. 2).

- *Marshal existing resources and reform projects to collectively target key leverage points*. Reform leaders should conduct an institutional scan to identify specific leverage points best suited to fostering institutional change. The many STEM education reform leaders and existing projects at UW-Madison represent a significant pool of resources and institutional knowledge that could be more effectively marshaled. At the present time, these projects are loosely coordinated, if at all, due to their different missions and the size of the university. However, this should not keep reform leaders from meeting on a regular basis to share notes, combine resources when advantageous, and when appropriate, collectively leverage existing political, social, and fiscal capital to exert pressure on strategic points in the system of STEM education.

- *Understand and address constraints facing STEM faculty when recruiting them for reform efforts*. Reform leaders should pay careful attention to addressing and acknowledging the current activities, constraints, and pressures facing STEM faculty when recruiting them to and engaging them in reform efforts. For example, when presenting a recruitment pitch, one might begin by acknowledging the successes and present conditions of a particular department and then present the challenges that the reform effort hopes to address. This strategy could help reform leaders avoid appearing adversarial or out of touch regarding the day-to-day concerns of many faculty. This "meet them where they are" stance could also prove useful during project implementation.

- *Focus on developing cohorts of STEM educators in specific departments*. We also recommend that clusters of faculty with STEM education expertise be recruited in specific departments in order to achieve critical mass and minimize departmental resistance to pedagogical change. Whereas an individual change agent working in a hostile or disinterested institutional environment is unlikely to convince colleagues to change policies or practices, a small group of colleagues amenable to reform may be more successful. Furthermore, the STEM education experts would benefit from having a supportive community of colleagues with whom to share ideas and resources.

- *Strategically engage and foster community among specific groups of STEM educators, including STEM faculty, education faculty, and academic staff*. Instead of focusing exclusively on engaging STEM faculty, which is the wont of current reform initiatives such as the MSP, we recommend an even more deliberate focus on specific groups of faculty and staff. The following four groups represent particularly rich opportunities for programs such as the MSP: (a) STEM and education faculty who are already engaged in educational activities; (b) academic staff who already are engaged in educational activities; (c) STEM and education faculty who occupy key administrative positions relevant to STEM education; and (d) STEM and education graduate students.

We cannot emphasize enough the importance of academic staff to STEM education reforms at large research universities. SCALE leaders were fortunate in that the existing cohort of academic staff with expertise in STEM education was available for hire or consultation. By contrast, STEM faculty, the primary target of the MSP program, have much more stringent constraints on their time and energy, and in many cases they have no experience with STEM education. Reform activities also must take care not to alienate education faculty, who not only are experts in the learning sciences, but also may hold important decision-making positions pertinent to preservice or in-service programming. We recommend that future STEM reform efforts more explicitly support these cohorts of STEM educators by engaging them as a professional community. This effort would, in turn, enhance the influence of this community on the university at large and increase its chances of being sustained as a community.

- *Illuminate then challenge dominant cultural schemas for STEM instruction by creating interdisciplinary committees that focus on high-value tasks and are facilitated by a culture broker*.[21] A critical leverage point in altering faculty members' cultural schemas of teaching and learning may be accessed by surfacing their assumptions about teaching and encouraging them to "think like novices"—processes likely to be accomplished through skillfully facilitated professional development experiences. A critical aspect of this type of change is the creation of interdisciplinary forums where STEM and education faculty can meet in neutral and relatively safe territory to exchange ideas and, ideally, work on tasks relevant to their department-based teaching responsibilities.

- *Carefully design top-down structural reforms with attention to cultural considerations*. Campus leaders should consider potential policy "levers," such as requiring faculty to assess student learning outcomes, as leverage points to support campus-based efforts. Research on the implementation of reforms fostered at the top shows that these efforts fail largely due to resistance of local agents, whose interests, needs, and cultural norms run counter to the perceived intent of the reform (Spillane et al., 2002). Thus, reform leaders would be wise to first understand the schemas with which faculty are likely to interpret external pressures for policy change. An institutional needs assessment focused on identifying the cultural conditions of administrative units most likely to be affected by policy change can provide this type of understanding.

Next Steps

This line of work for the SCALE project includes case studies of two other IHEs, the California State University, Dominguez Hills, and the California State University, Northridge, plus a final cross-case analysis for all three sites. This cross-case analysis of SCALE activities at

[21] We suggest that the kind of attention paid to the cognitive processes underlying the math and science learning of K–12 students should also be applied to the learning processes and identity formation of IHE faculty.

its IHE partner sites will focus on further developing a diagnostic approach to evaluating STEM education interventions in complex organizations. In particular, this analysis will explore the prospects for linking changes in the institutional context to changes in instructional practices and ultimately student learning outcomes.

Appendix
Methodology

This research used a repeated cross-sectional qualitative case study design. The qualitative case study design was selected due to its utility in conducting empirical inquiry into a "contemporary phenomenon within its real life context, especially when the boundaries between phenomenon and context are not clearly evident" (Yin, 2003, p. 23). This design seemed particularly appropriate for highlighting contextual factors that affect an MSP project's implementation processes and outcomes. Moreover, its focus on how and why is expected to yield valuable information for program funders and planners (Owen & Lambert, 1998). We selected this design—in contrast to a longitudinal design that would follow a single cohort who participated in a single intervention—because of the emergent nature of the SCALE project and the reality of participant attrition in projects of this nature. We decided to capture the effects of a large number of project activities and their varied participant populations, understanding that we were sacrificing the ability to attribute program effects to a specific intervention in a robust fashion.

Sampling Procedures

The primary unit of analysis for this research is the individual, and the sampling universe included all UW-Madison and MMSD personnel. We then used two sampling frames to identify participants in the study: (a) participants in any SCALE activity and (b) personnel in administrative units that were the focus of SCALE, including those in STEM and education departments, academic staff, and K–12 personnel. Nonrandom sampling procedures were used to identify SCALE participants, and snowball sampling was used to identify nonparticipants who differed with regard to their experience with STEM education reform. *Nonparticipants with little experience in STEM education reform were included to test and/or confirm findings from the SCALE participants, as the latter may constitute a biased sample regarding their perceptions of the institutional context.*

Data collection took place at two points: Time 1 (T1; February–June 2006) and Time 2 (T2; June–August 2007). A total of 22 interviews were conducted at T1, and 25 at T2 (see Table A1). Due to respondent unavailability and faculty turnover (at both UW-Madison and within SCALE), only five SCALE participants were interviewed at both T1 and T2.[22]

Sources of Evidence: The Data

The data collected for this study included in-depth interviews, documents, and field observations of meetings and informal settings. The interviews were semistructured using a standardized interview protocol for different types of respondents (i.e., STEM faculty, education faculty, administrators, etc.). Documents related to the university were also collected and

[22] At T1, another researcher conducted seven interviews in early 2006. A similar interview protocol was used by both researchers.

Table A1
Number and Role of Respondents at Time 1 and Time 2

	T1 (early 2006)		T2 (mid-2007)		Repeat respondents	
	Total respondents	SCALE participants	Total respondents	SCALE participants	Total repeat respondents	Repeat SCALE participants
STEM faculty	9	5	12	4	2	2
Educ. faculty	3	2	4	2	1	1
Administrators	1	0	1	0	0	0
Academic staff	4	3	2	2	1	1
STEM doctoral students	0	0	1	1	0	0
Educ. doctoral students	0	0	3	3	0	0
MMSD personnel	5	2	2	2	1	1
Subtotals	22	12	25	14	5	5
Total respondents	22		25		5	

analyzed, including reports from the university's Office of Budget, Planning, and Analysis; strategic plans; external evaluations of related programs; and recruitment, tenure, and promotion policies. Documents were identified by both respondents and researchers and were analyzed at both T1 and T2. Field observations of the research site were also conducted, including three SCALE-related meetings, respondents' work environments, and public presentations of the SCALE project. Finally, the preliminary case study of SCALE activities at UW-Madison (Hora & Millar, 2007) provided the analytic foundation for the present study.

Data Analysis

The analytic approach for this research draws on established procedures of qualitative analysis. These include inductively coding interview transcripts using a grounded theory method (Strauss and Corbin, 1990), causal network analysis that graphically organizes the data by time and sequence (Miles & Huberman, 1994), and an exploratory analysis of cultural schemas (Strauss & Quinn, 1998).

Coding of Interview Transcripts Using a Grounded Theory Approach

Using the findings from preliminary analyses of data from all three IHEs—UW-Madison and California State University at Northridge and Dominguez Hills—we developed a coding paradigm called the *institutional context framework* (ICF). A coding paradigm is a structured coding scheme used to analyze data and identify discrete themes and patterns (Strauss & Corbin, 1990; Ryan & Bernard, 2003). A coding paradigm was especially necessary in this instance in order to categorize and reduce the multidimensional data we had collected. The ICF is organized into six broad categories that include more specific topics that are subcodes used in our analysis (see below). It is important to note that the categories used to code the data are derived from analyses of complex institutional environments that are exclusively focused on STEM education, teacher preparation, and IHE/K–12 partnerships (Hora & Millar, 2007). As a result, it is possible that the framework adequately models only categories and topics related to SCALE goals.

The six broad categories of the ICF are listed below:

1. *External influences:* Institution type, national and state education policy, academic training of faculty, economic forces affecting education, and local K–12 characteristics.

2. *Internal structure:* Organizational structure (governance, teacher education programs, STEM degree programs), student body composition, instructional workforce composition, personnel policies, leadership, and reform initiatives.

3. *Resources:* Material resources (e.g., time, funding), and social resources (e.g., networks).

4. *Collective values and beliefs:* The beliefs, values, and tacit assumptions operative among groups at UW-Madison, including the institution as a whole, colleges, departments, and smaller communities or subcultures.

5. *Individual disposition and sense-making:* The primary elements of an individual's sense-making process, including workload considerations, personality, background and training, views on instruction, and status.

6. *Practices:* An individual's classroom instruction (e.g., planning and delivery) and task-based collaborative activities with both IHE and K–12 partners.

We developed a three-step coding system that consisted of the following: (a) the ICF categories; (b) topics considered barriers or enablers to SCALE as identified by either the respondent *or* the analyst; and (c) changes attributed to SCALE activities. This coding structure was designed to facilitate later data queries that would identify relationships among factors, particularly if a category in the ICF was considered a barrier or an enabler to SCALE goals. We then coded both T1 and T2 interviews using NVivo qualitative analysis software and conducted queries of the coded interviews as a first step in identifying the themes for the case study.

Queries were conducted based on high frequencies of code sources and references (as seen in Table A2) and analyst judgments regarding the importance of the topic based on field notes and analytic inference. In this paper, *sources* refers to the number of interview transcripts that include the code, and *references* refers to the actual number of codes applied to the transcripts.

Table A2
Frequency of Code Sources and References in Interview Transcripts

	Sources	References
External environment		
Local K–12 characteristics	33	154
Institution type	28	48
Field of higher education	19	51
Alignment	8	21
Education policy	13	24
Economics	12	19
Doctoral training		
Individual sense-making		
Learning and pedagogy	32	101
Workload considerations	29	87
Legitimacy and credibility	25	73
Colleagues	22	64
Family	26	58
Teacher education	18	53
K–12	21	35
Epistemology of discipline	16	38
Home institution	16	40
Background and training	14	29
Student body	21	32
Internal structure		
Teacher education programs	39	187
Change processes	22	114
Hiring and personnel policies	33	112
Workforce topics	26	83
Governance and autonomy	24	69
Reform initiatives	27	69
Centers and units	17	51
STEM degree programs	24	61
Leadership	19	41
History	17	34
Practices		
Rationale behind instruction	35	158
Lesson delivery	33	97
Intercollege collaboration	36	146
Interinstitutional collaboration	27	100
Research and publishing	26	80
TA training	9	24

	Sources	References
Engagement with preservice	24	43
Committee work	19	31
Resources		
STEM education community	36	139
Funding	25	50
University-wide colleagues	14	38
Time	10	15
Collective Values and Beliefs		
Department norms	46	303
Distinctions between groups	29	84
Shaping influences	41	119
University norms	23	64
Individual in relation to group	19	39
Subgroup norms	14	29

Next, we conducted matrix queries to search the coded interviews for specific combinations of codes; in this instance, we were most interested in text that had been double- or triple-coded with ICF categories, the second step (barriers/enablers), and the third step (changes attributed to SCALE). Coarse category results are presented in Table A3.

Table A3

Sample NVivo Matrix Query for First-Step (Internal Structure) and Second- and Third-Step Codes

	Enablers to SCALE	Barriers to SCALE	Changes attributed to SCALE
1 : Teacher education programs	19	26	16
2 : STEM degree programs	14	22	6
3 : Governance	7	17	3
4 : Instructional workforce	14	20	8
5 : Personnel policies	9	29	7
6 : Leadership	9	9	5
7 : Student body topics	8	14	3

Note. The darkest cells indicate larger numbers of references to the indicators at left.

It is important to note that frequencies alone were not sufficient for identifying key factors or findings, as the codes were sufficiently broad as to allow for a range of perspectives. It was necessary to conduct a more in-depth analysis of the coded text in order to ascertain the specific nature of the factor under consideration, which we did by reviewing all of the coded text and actively seeking disconfirming evidence from the interview transcripts and other data sources (Miles & Huberman, 1994). Once the most frequently cited factors had been identified, we assigned a valence in order to denote a positive (+) or negative (-) influence on SCALE activities, based on a respondent's indication of the nature of the factor or our own analysis of the factor and its relationship to SCALE goals. Each weighted factor was then linked to those SCALE activities with which respondents associated it. Again, we constantly referred back to the data when making these assignments and actively sought disconfirming evidence in the interviews and documents. We then used the following criteria to evaluate if a factor would be included in the final analysis: (a) document-based evidence of institutional phenomena, SCALE activities, or SCALE outcomes; and (b) at least three respondent accounts of institutional phenomena, SCALE activities, or SCALE outcomes. The resulting factors constitute the primary data for this case study.

Causal Network Analysis: Situating the Factors Within a Time-Ordered Display

Using the results from the coding, we organized the factors in a time-ordered display in order to identify relationships between factors at T1 and T2 and the ways SCALE mediated the implementation process between the two points. A causal network is "an abstracted, inferential picture organizing field study in a coherent way" (Miles & Huberman, 1994, p. 153). Factors identified in the data are located on the *y*-axis according to where they are categories within the ICF, and on the *x*-axis (which denotes time) according to whether they occurred at T1, T2, or as a SCALE activity.

Exploratory Cultural Schema Analysis

Working within the interpretive tradition of Strauss and Quinn (1998) that uses natural discourse to identify cultural models, we analyzed the cultural schemas for math instruction held by two key subgroups active in the SCALE project. *We strongly emphasize that this is an exploratory effort to identify cultural schemas, undertaken in order to understand the role of culture in STEM education.* First, we identified a specific SCALE activity that involved cross-disciplinary working groups, as this was a central focus of SCALE and an opportunity to observe cultural processes in action. The selected activity was the Math Preservice Committee, which included subgroups of math faculty and their graduate students from the Math Department and math education faculty and their graduate students from the Curriculum and Instruction Department. We then used the following procedures to identify cultural schemas.

First, we analyzed text coded for the ICF category *collective values and beliefs* for respondents from the two subgroups of interest: mathematicians (n = 8 unique mathematicians) and math educators (n = 6 unique math educators). When at least three respondents expressed a similar value or belief pertaining to math instruction, we classified it as a cultural schema. Using this process, we identified various cultural schemas, some shared among mathematicians and others shared among math educators.

Second, we analyzed if and how these schemas were engaged or illuminated during the activity based on a smaller subsample of respondents (n = 5 unique math educators; n = 5 unique mathematicians from both T1 and T2) who were directly involved with the Math Preservice Committee. This evidence is based on respondent accounts of their experiences and perceptions during the activity and the way in which their own—or their counterparts'—beliefs, values, and tacit assumptions were made visible.

Third, we analyzed changes in cultural schemas and/or personal mental models that could be attributed to the activity, either by the respondents themselves or by analytic inference. Our focus on personal mental models when analyzing project outcomes, as opposed to the subgroup's cultural model, was necessitated by the small sample size. Our assumption is that any changes due to the SCALE intervention pertain not to the cultural schemas of this group but only to those of the individual respondents.

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