TWO

The SEI Model for Achieving Change

THE GOAL OF the SEI was to improve undergraduate science teaching, but this required change in established traditions, practices, and cultures of research-intensive universities, which are inherently large, complex organizations. I recognized that this was a formidable task and put considerable thought into the design of the initiative, attempting to craft a model that would address all of the most critical factors. This required first identifying as many of the important factors as I could, which I did by talking to many people and looking into the research literature on both adoption of innovations and bringing about change in large organizations. Early on, it was clear that the academic department was the critical unit for changing teaching at such institutions, as departments control what and how the science courses are taught. So, I did my best to identify the values, beliefs, and practices (that is, the "culture") of each different science department and to see how the general principles for achieving innovation and change would apply in that context. These considerations led to the model for change represented by the SEI and discussed in this chapter. It was intended to apply leverage for change at the most essential points and address all the critical barriers to adoption of novel teaching methods, while recognizing that there were many unknowns.

In the current culture of university STEM education, the impetus for improvement relies primarily on individuals acting alone, rather than on organizational structures supporting that change. As a result, teaching innovations are inherently fragile and challenging to scale up throughout an institution. The focus on individual creation of instructional materials is also inherently inefficient, as faculty continually reinvent the wheel. Currently hundreds of instructors each year individually invent their courses anew, even though the equivalent course is and has been previously taught in many other institutions, including their own. However, the knowledge and materials produced by all those other examples, as well as the research on more effective ways to teach specific topics, are not being widely shared or used. A new institutional culture is needed that supports coherent, collective efforts to use the most effective teaching methods and optimized instructional materials. Organizational structures and incentives also need to support this culture.

The goal of the SEI was to transform undergraduate science education by creating a culture within academic science departments where research-based, effective teaching and course design were the new normal. The SEI focused on the department as the essential unit for educational change and on the large public research university as the most relevant institutional type. The core component of the SEI model was that departments competed for substantial one-time funding to support changes in teaching, with most funds being used to hire postdoctoral education specialists to work with faculty within the department, and the remainder going toward direct incentives to faculty. This structure provided expertise, skilled labor, and incentives for educational innovation, offered support for a limited time in order to create a sense of urgency, and helped forge shared visions for change through the development of proposals for the competition. The desired outcomes were improvements in course design and student learning, improved faculty teaching expertise, shared course resources, and an overall cultural shift in departmental norms for instruction.

I started with a plan for how courses might be designed to be more effective, based in part on my own experience in successfully transforming some physics courses. These transformations started with articulating a detailed set of learning goals, then creating instructional activities for class and homework that targeted these goals and were based on methods that research had shown to be most effective. I created multiple ways to measure how well students were achieving these goals, and used these measurements to optimize courses through multiple offerings. In these efforts, I was assisted by Katherine Perkins, a talented recent PhD in chemical physics who was interested in developing expertise in teaching. I saw how enormously valuable it was to have a collaborator such as Kathy helping with these course transformations. These courses were subsequently passed on to other instructors who continued to teach them using many of the same methods and materials. I was also inspired by work at the University of Illinois in which a departmentally owned large introductory physics course was established, with faculty members rotating in as part of a team to teach the course, using established materials and research-based teaching methods.

Achieving widespread change in educational practice, as described above, involves changing both the individuals involved in teaching and learning and the academic organization that represents the aggregate of these individuals, along with the procedures, cultures, and norms of that organization. This brings together aspects of both diffusion and adoption of innovations. In this case the innovation is more-effective teaching methods. In universities, the academic department is the dominant organizational unit with regard to education, with larger institutional structures exerting an important but distant and rather diffuse influence. The SEI model was guided by the literature on what factors facilitate and inhibit the spread of innovations and organizational change, particularly the work of Everett Rogers on the adoption of innovations and the work of John Kotter on organizational change. The principles presented in those works were, to the extent possible, implemented in the context of large research-intensive science departments at large research universities.

The Diffusion of Innovations in Education

Rogers has laid out five steps (see Figure 2.1) that individuals and organizations go through sequentially in the successful adoption of innovations: knowledge, persuasion, decision, implementation, and confirmation.[1] At each stage there can be failure and, consequently, uncertainty as to whether the next stage can be reached. These stages offer useful ways of thinking about how to bring about innovation in undergraduate education.

First, one must have some mechanism to increase knowledge: the level of faculty awareness of alternative types of pedagogy and of research on learning. Next is persuasion: convincing them to learn more about the innovation. The third stage, decision, involves establishing an environment in which faculty perceive a benefit-to-cost ratio that is sufficiently favorable that

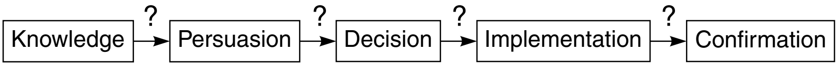

FIGURE 2.1. Steps in the adoption of innovations
Source: Everett Rogers, *Diffusion of Innovations,* 5th ed. (New York: Free Press, 2003).

they will decide to adopt, or at least tentatively try, the innovation (new ways to teach). That is followed by implementation, a critical stage in which they try teaching differently and decide if it is successful or not. That finally leads to the confirmation stage, in which their experiences with these new approaches lead them to decide whether they will continue to use the innovation. In this case, that experience includes their personal feelings and the feedback they receive from students and the department.

In many work practice innovations, it has been shown that the success of a change process often depends heavily on how it is related to culturally based practices of the organization and how it impacts core members' self-identities.[2] As Rogers discussed, what seems to matter most in individuals' attitudes and responses to proposed innovation is the way in which they perceive the relative value of any change—that is, whether and how they can link what is proposed to what they already value.[3] There are two rather distinct aspects of the culture of a science department at a research university: the culture of teaching and the culture of scientific research. The goal of the SEI was to change the teaching culture, but to carry out that change in a way that relies heavily on the values and practices of the research culture. This shift, I hoped, would bring the teaching and research aspects of the culture much closer together, which should facilitate the change process.

Faculty members who do scientific research understand and value quantitative results. Also, faculty understand and value conceptual and higher-order thinking skills and expert attitudes about science. Thus, the SEI aimed to provide faculty members with meaningful ways to assess student learning, particularly higher-order thinking skills; to show that these assessments quantitatively demonstrate the superiority of new research-based teaching methods over traditional approaches in terms of getting students to think more like scientists; and to show that there are underlying empirically determined principles of learning that can be used to design instructional activities and provide predictable results.

Essentially, this model would have the self-identity of faculty members as scientists expand to include their identities as teachers of science. However, this requires that their teaching practices and measures of success be based on research, empirically grounded principles, and objective data. Although this was the original design concept for the SEI, I learned that it gave too much emphasis to faculty as scientists and the belief that their "scientific thinking" would transfer over to how they thought about teaching. In reality, while there was a complex mixture of reactions, teaching was generally viewed more as a personal, emotion-based activity than as a scientific, evidence-based activity. During the vital persuasion and decision stages, it turned out that the dominant factors for most faculty were the personal satisfaction and emotional responses they received from teaching and from interacting with students in a particular manner. This was balanced against the feedback they felt was provided by the formal incentive system in terms of their research productivity and how they were evaluated by students. That formal incentive system was entirely negative to innovative teaching, but what mattered was how negative it was perceived to be.

There are many other factors that can influence faculty and departments in their decisions to try or reject educational innovations. As discussed in the next section, the SEI attempts to address most of these, starting with providing large amounts of flexible money to departments.

Once faculty members and their departments are committed to trying to transform and improve the undergraduate education they provide, there are still three significant hurdles that are evident when one maps Rogers's stages model onto a faculty member's adoption of innovative teaching methods. First, typical science faculty members have little knowledge of research on learning, of meaningful assessment techniques, and of effective research-based teaching practices. Second, they do not have time to go out and learn these things on their own, let alone put them into practice effectively in actual courses while maintaining their current level of other responsibilities for research and service. Third, most do not have knowledgeable, interested colleagues with whom they can discuss and develop these novel teaching ideas.

Unlike science research, science teaching is typically a solitary effort. Many teaching improvement efforts have involved the formation of "learning communities" devoted to development and implementation of improved, innovative practices, and I too wanted to establish teaching as much more of a collaborative process among faculty. Such collaboration is also an essential part of the scientific research enterprise, and so by building this into the SEI model, I again aimed to incorporate cultural values from faculty members' scientific research identities.

A second classic aspect of Rogers's work is the classification of the members of an organization considering an innovation into five groups: innovators, early adopters, early majority, late majority, and laggards. While some aspects of this classification scheme are convenient, I found it was not very useful for characterizing the adoption of innovative pedagogy by faculty, because, as discussed in "Faculty Attitudes about Teaching" (Chapter 5), individuals often do not fit well into such a simple categorization of attitudes, particularly when examined over multiyear time scales. There certainly are a few who are much more willing than others to try out new teaching methods, and a few who are quite resistant, but beyond that, things get more complicated. Some individuals are early adopters of a particular aspect of pedagogy but then are quite resistant to more extensive changes, while others may come to embrace novel pedagogies slowly but do so in a much more deliberate and extensive way. Also, predictions about the later behavior of individual faculty members based on their early reaction to innovative pedagogy (or their age or other factors) often turned out to be wrong.

Lessons from Recent History

In considering the goals and model for the SEI, it is useful to examine one recent example of a large and rapid change within universities: the enormous growth in the university research enterprise after World War II. As a result of this change, research is now an essential component of every large university and provides a major service to society. Most public U.S. universities shifted from being predominantly institutions focused on teaching students of their respective states to being modern research universities that looked to the nation and the world as their stakeholders.

There were three key factors in this change: (1) the shift was largely faculty driven, (2) there were clear measures of success, and (3) there were clear incentives for change at both the level of the individual faculty member and the department level. Individual faculty members saw that external research funding had become available, and they recognized that this would allow them to do more science, which in turn would increase their status both locally and among the wider community of scientists in their discipline and allow them to contribute to society in new and important ways. Transformation happened at the department level because departments primarily determine faculty hiring, review, and salaries, and the values of the department fuel or inhibit change in how faculty spend their time. There were clear incentives to departments to encourage faculty research activities (increased funding, larger and better facilities, increased prestige, better students), and there were clear measures of outcomes (research dollars brought in, papers published, work cited, scientific awards, departmental rankings) that became collectively accepted. These outcome measures became embedded in departmental and institutional evaluations, reward systems, and hiring criteria. This in turn drove the job market to give higher priority to potential faculty members who were more successful according to these measures. The resulting market forces impacted all colleges and universities. To hire good faculty, it was necessary for an institution to encourage and support research activities. The outcome was a major transformation of universities, largely driven by entrepreneurial faculty who saw clear incentives for their efforts in the large amounts of federal research dollars that had become available. While support and encouragement from the higher administration was important, the change was carried out at the levels of departments and individual faculty members.

This example suggests elements that are important for pursuing any widespread change in the university context, in this case the change being how the science courses are taught. Incentives to individual faculty members and departments must be clearly tied to educational outcomes under their control. Relevant outcomes must be readily measurable and show what is needed to achieve improvement. In addition to allowing comparisons between individuals, the outcome measures must also allow comparisons between departments and between institutions. The evaluation, reward, and hiring policies of the department and the institution must reflect the desired outcomes. And faculty who are successful by such measures need to be able to achieve greater recognition within their discipline, such as through publications, conference talks, and awards.

Putting all of these elements in place to improve STEM education will be a difficult and long-term challenge. However, it is much easier for an institution to implement the smaller set of elements necessary to drive department-wide improvements in teaching and to facilitate the efficient adoption of those improvements within the institution. The SEI was an experiment in trying to attain that goal.

Components of the SEI Model and Guiding Principles

The SEI was composed of the core components shown in Figure 2.2.

The adoption of innovation discussed above needs to take place in the context of an organization—individual academic departments and, to a lesser extent, the broader university. Few of the relevant decisions are being made by individuals in isolation; rather, they are shaped by the organization in which those individuals work. One must consider what is necessary to change the organization so that it encourages and supports the use of innovative teaching. The initial design of the SEI was based on many of the elements Kotter identified as necessary for organizational change to succeed, as applied to the context of research-intensive university science departments.[4] It should be said here that while experience supported the validity of all the important factors listed by Kotter, I was unable to successfully address all of them in this context; this is discussed further in Chapters 5 and 6.

My first guiding principle was that the SEI was to be a one-time, limited-duration infusion of resources to change practices and culture that would

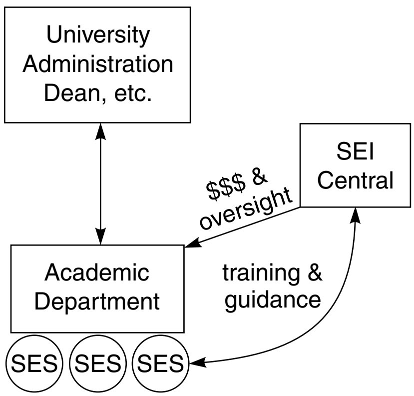

FIGURE 2.2. Core components of the SEI

A competitive grant program invited departments, not individual faculty members, to compete for substantial one-time funds. Several departments were funded. SEI Central made the decisions on funding and provided oversight to the departments that received grants. It also provided training and guidance to the science education specialists. Science education specialists were hired by the department with SEI funds. These provided expertise in teaching in the discipline, and also worked with faculty members to transform courses and teaching and to assess the results according to the SEI model.

then become self-sustaining. It costs money to bring about change, but the expectation was that the long-term ongoing costs of instruction would be the same as or less than what they had been prior to the SEI. The spirit was much the same as investing in the cost of retooling a factory with better equipment so that it can produce a better product at the same cost as before.

The scale of funding needs to be commensurate with the scale of change expected. The organizational change literature (largely based on studies of industry) indicates that major changes involve investments of 5 to 10 percent of the annual budget of the organization for time scales of around five years. I estimated that 5 percent of the annual budget of a large science department was about $400,000, and if that level of support was provided for five years it would come to a total of $2 million. A period shorter than five years would not be realistic for the scale of change that I was attempting, but a longer period would make it easy to put things off. This amount would cover the estimated costs of the labor involved in transforming the twenty-five to thirty undergraduate courses regularly offered by a large department. This meant that about $10 million was required for five large departments, to be spent over a period of about five years. This was a factor of ten to a hundred times larger than typical federal or institutional grants provided to improve teaching in the early 2000s, when plans for the SEI were being formulated, as grants typically targeted single courses or single individuals.

If there was to be any hope of making change sustainable, it had to involve a substantial number of the science departments at an institution. I chose five (of about eight) as the optimal number. If that many departments carried out major change, it would likely establish new norms for teaching science at the institution. And because the only model that science faculty and departments are familiar with for coming together and formulating consensus plans and commitments involves the pursuit of large competitive grants, I decided that funding for the SEI should be through a competitive grant program to which departments (not individuals or collections of faculty) could apply, and the chances of receiving funding needed to be high enough to warrant serious collective effort but low enough to give the sense it was a real competition that required their best effort. I also stressed the importance of experimentation and collection of data.

Because departments need to feel ownership of the effort and the changes that result, it is the departments themselves that must initiate participation, deciding as a unit whether to submit a proposal. This structure is designed to create a scenario in which departmental faculty collectively discuss SEI participation and the majority have expressed a desire and commitment to engage in improving science learning.

There needs to be a meaningful incentive for people to put in the effort and time required. This is true both for individual faculty members with regard to changing their teaching and for the department administrators with regard to the oversight of these changes.

The transformation of courses and the development of a sense of collective ownership of courses will occur only if the faculty's teaching methods and level of knowledge about teaching are transformed as well, so the processes of course change and change in individual faculty members' teaching should be integrated. There should be a specific structure to the course transformation process and specific outcomes for a transformed course, to ensure appropriate guidance and deliverables. As the process develops, highlighting early successes and small wins will build interest and enthusiasm.

Departments seldom have the necessary expertise in teaching and learning, but for long-term success such expertise must reside in the department. So the program needed to find a way to introduce it and embed it into the departments. Use of science education specialists (SESs), who are well grounded in the discipline and knowledgeable about teaching and learning, working with the faculty was the proposed mechanism for achieving that growth of departmental expertise. Having them be junior to the faculty has benefits, as the specialists will be more inclined to work with faculty in a partnership, rather than telling them what to do and being annoyed if their recommendations are not followed, and they are more willing than senior people to provide labor.

It is neither possible nor desirable to try to change everyone at once. The design was to systematically support the change of teaching by a fraction of the faculty each year, starting with the early adopters. The original concept of the SEI was that a department would systematically work to transform its undergraduate courses, starting with the introductory courses and then progressing up through the undergraduate program. For a variety of reasons discussed in Chapter 6, this approach did not work. As a result, I abandoned the idea of having departments change courses in a logical order and instead focused on ensuring departments had good planning and incentives in place to maximize the number of faculty fully engaged in transformation efforts, and to maximize the number of courses transformed.

The greatest barrier to faculty's changing their teaching is the time it requires. In order to make changes, faculty must use time that would normally be spent on research. As Kotter says, a sense of urgency—the feeling that this needs to get done now, and so it must take priority over the countless other demands on faculty members' and department chairs' time—is very important. As I will discuss in more detail in Chapters 3 and 5, generating such a sense of urgency always proved challenging, and over time I came to realize there were some unique features of education in the university setting that were responsible for this. As a result, I added some requirements for funding that modestly helped to encourage a sense of urgency about the SEI-supported activities.

Finally, because I was sailing in uncharted waters, I knew that considerable flexibility was needed. I had to be ready to make changes and adjustments based on what was working and what was not.

These components and principles were intended to address Rogers's first four stages in the adoption of an innovation, as well as the factors identified by Kotter as important for organizational change. I recognized that they did not address the longer-term question: assuming the changes were successfully implemented over the study period, would they become part of the culture and be sustained after the project's conclusion? I hypothesized that they would in fact be sustained, because the individual faculty would find that teaching this way was far more personally rewarding, the departments and higher administration would see compelling improvements in student learning, and the faculty and departments would value the gains in efficiency provided by collectively owned and systematically optimized and shared courses. Although more time is needed to determine if the changes produced by the SEI will be sustained, the results have been mixed so far. Only the first factor, greater personal satisfaction from teaching, has been realized, but it is proving to be more powerful than I had previously thought.

Different Institutional Contexts

The science education initiatives were separate programs with similar designs at two fairly comparable universities. Both were large public research-intensive universities that were the most prominent institutions in their respective geographical regions. The University of Colorado (CU) is the most prominent research university in the sciences in the Rocky Mountain and western Great Plains region; the University of British Columbia (UBC) is the most prominent university in western Canada. There is a great deal of similarity between these two universities at the level of individual faculty members and departments, and most UBC science faculty members have spent time in U.S. universities. I also found the general structure of the curriculum and the cultural beliefs of particular disciplines about learning and teaching to be very similar—for example, the math departments, physics departments, and chemistry departments showed far more similarities with their counterparts in the other institution than they did with other science departments within their own institution. Demographically, the UBC student population is somewhat more diverse than at CU and is majority Asian.

The original plan for the SEI was to achieve economies through the sharing of materials, data, and infrastructure between the two institutions. As noted in Chapters 5 and 6, very little of this happened. There turned out to be relatively little overlap between departments supported at the two universities, and there was also not much overlap between specific activities within similar departments. Also, as noted later, a failure of the SEI was that few of the efficiencies achievable through the sharing and exchange of materials and efforts were ever embraced by faculty at either institution. However, there was considerable sharing of experience and wisdom with regard to the best ways to structure SEI funding and management and training programs, and there was some sharing of ideas and methods between SESs at the two institutions.

There were various institutional differences that had to be considered. One was the stability of the administrations. At UBC, the administration at every level had been very stable, with administrators serving out their full five-year terms (and sometimes going on to serve a second term). At CU, for decades the turnover at all levels had been much higher and usually turbulent, making it much more difficult to imagine any large-scale institutional change driven by the administration.

A difference that turned out to have little impact was nomenclature: CU has department chairs, while UBC has heads. In all cases at both institutions, the authority and effectiveness of the head or chair seemed to be determined by the person's skills and stature in the department rather than by any formal authority. For simplicity, in the rest of this book I will just use the label "chair."

A more important difference was administration involvement with the SEI. At UBC, the SEI was a highly publicized activity, with both the president and the provost participating in a number of events where it was highlighted; it was also the subject of a number of high-level university meetings, and there were regular reports on it to the Board of Trustees. The dean and relevant associate dean were involved on a regular basis, typically meeting monthly to discuss progress and on multiple occasions intervening with department heads when problems arose. The dean often spoke about it in public events as a point of institutional pride. Raising money for the extension of SEI-type activities after the original funding ran out was made a priority by the dean, and the dean was a prominent presence at the annual SEI mini-conference. Perhaps most important, the dean ensured that when new department heads were appointed, they were supportive of the SEI.

At CU, there was no significant involvement by the administration beyond the initial funding. Annual reports on the progress of the SEI were provided to all levels of the administration each year, but there were never any responses or follow-up discussions of these reports. In the selection of new department chairs, there was little if any consideration given to their attitude toward the SEI.

Although the authority of the dean was more limited at UBC than at CU because of how the institutions handled budgeting and faculty salaries, over time the difference in the deans' support of the SEI could be seen to have substantial impact, largely through the choices of appointments of department chairs and the messages implied by those selections (discussed further in Chapter 5).

A fourth institutional difference was that there was considerably less accountability at UBC on the level of individual faculty members. CU faculty have to complete a lengthy annual performance report documenting their research, teaching, and service activities, and departments and the dean then rate the research, teaching, and service performance of each faculty member, which determines a substantial fraction of the annual salary increment. At UBC, the faculty is unionized, and salaries and annual raises are almost entirely determined through a collective bargaining agreement. Faculty only submit an optional and informal report on their performance if they want to be considered for the very small fraction of the salary increment that is based on merit. At both institutions, the evaluation of teaching at the institutional level is predominantly based on student course evaluations and was perceived to have little weight.

Yet another institutional difference was that UBC is the institution of choice for students in British Columbia, a province that by international comparisons has a very good K-12 education system, and most Canadian students do not move around the country to go to a university. As a result, the students at UBC, particularly in the sciences, are better than at CU on average, but there is a large overlap of the two distributions. Curiously, when the SEI started, there was a pervasive and frequently expressed sentiment among the faculty at UBC that the students were weak, either in their academic preparation or in their work ethic, and that many of them did not deserve to be at UBC. Such sentiments were expressed far less frequently at CU, and the origin of such opinions at UBC was difficult to understand. However, there are hints that as teaching methods have improved and become interactive, such faculty sentiments may also be changing.[5]

There had already been a number of improvements in the teaching of science at CU before the start of the SEI, and there was generally a greater awareness and use of research-based teaching methods there than at UBC. There also was a relatively strong effort at CU in discipline-based education research (DBER) in physics and biology, with smaller efforts in other departments. These activities had been largely spearheaded by myself and other prominent science faculty members. The impact of the DBER program on the SEI work is unclear. At one level it provided a greater knowledge base and enhanced capabilities for assessment. However, I also got the impression that it created a sense among faculty members that "improving teaching is the job of the DBER faculty, and so it is not my responsibility" and thereby diluted efforts. There were also times when it appeared that the condescending attitudes of some DBER faculty may have made some regular faculty less inclined to be involved with innovative teaching methods. Over the course of the SEI, there was substantial growth of DBER at UBC.

A sixth institutional difference was that the overall funding models for the two universities are different, and while both are complex and have somewhat different priorities and constraints, it appeared to us that UBC was somewhat better funded.

A related difference was that just before the start of the SEI there had been a series of budget cuts at CU due to reduced state support, and so providing the $10 million needed for the SEI at CU would have required conspicuous cutting for other programs. This would have hurt other aspects of education and would likely cause substantial resentment among faculty and departments. That financial reality led to negotiations that resulted in a $5 million SEI at CU with a substantial fraction of that not coming from general funds, while the UBC program had a commitment of $10 million.[6]

That led to one last difference in the two institutions: because of the amount and nature of the funding, there was significantly less SEI Central support at CU. The CU director had a 20 percent appointment, the associate director position was a half-time appointment, and there was a 50 percent administrative assistant. At UBC the SEI was staffed at about twice this level. While it was intentional to have a very lean central staff and invest as much as possible in the departments, the staffing at CU was too lean (see Chapters 5 and 6), particularly after I left the director's job to take a position in the White House, leaving the associate director to take over those duties as well.