SIX

The Post-Mortem: What Worked, What Didn't, and Why

THIS CHAPTER IS an overall analysis of the SEI as an experiment in institutional change. What aspects of the model and implementation were successful and why, and what aspects failed? I focus on aspects of the SEI model for change that seemed good initially, but turned out not to be effective until after adjustments were made. This chapter summarizes the elements that were found to be of greatest importance in improving how the departments taught science. In many cases this involved recognizing and dealing with entrenched barriers in the culture of the departments and the institutions.

The SEI was an experiment in change, designed to answer a vital question: Is it possible to scale up the use of research-based instructional practices and support changes in the teaching culture and practices at a department level? Looking across all the results summarized in Chapter 5, it is clear that it was successful in achieving large-scale change—the teaching of hundreds of courses by hundreds of science faculty was improved, enhancing the instruction of many thousands of student credit hours each year. However, it is also clear that the degree of success was quite variable across departments and institutions. The degree of success in improving teaching methods in any given department is determined by the complex interplay of three basic elements (see Table 6.1).

First are the factors that determine how individual faculty members make decisions about their work in general and teaching specifically. Second are the departmental cultures and how departments function as

Table 6.1. Factors determining SEI impact on department

Faculty decisions	Departmental culture and function	Effectiveness of SEI model at supporting change
External incentives Personal satisfaction Fears of unknown	Leadership and management Distribution of responsibility and authority Course ownership and oversight Curriculum problems Perverse incentives	Elements that clearly worked (competitive grant program and embedded science education specialists) Elements that worked after modification (specific commitments, funding contingent on progress, SES training, focus on willing faculty) Elements that failed (improved efficiency, data driven, sense of urgency)

organizations. Third is how well the SEI model supported change in that context of departments and faculty decisions. It is revealing to dig into the details of those three elements as they are likely to be important to any effort to change the teaching at colleges and universities. This is done below, starting with the SEI model.

Elements of the SEI Model That Clearly Worked

Competitive grant program. A competitive grant program for departments with substantial funds at stake produced widespread attention and discussion of undergraduate education and how they might improve it in every department. Such discussions were quite novel, and in many cases were the first exposure of the faculty in the department to science education research and its findings. In many cases it also mobilized those interested in improving teaching to act with sufficient energy to achieve broad support across the department.

Science education specialists emedded in departments. SESs within the departments proved to be a highly effective way to provide the necessary knowledge, expertise, and time-saving assistance in transforming courses and faculty teaching. It is hard to imagine how the results shown in Chapter 5

could have been achieved without them. I believe that the three critical elements to their success were: they were hired by and seen to work for the departments; they had extensive disciplinary knowledge; and they were well trained in research-based teaching and how to work effectively with faculty members.

Elements of the SEI Model That Worked after Modification

In the initial years at both institutions there were major problems in many areas, particularly in figuring how to establish and maintain good SES-faculty working relationships in departments. In later years the program functioned much more smoothly and effectively due to the recognition of the importance of the items listed below and addressing them suitably.

In terms of overall management and success of the SEI at the central level, the most important characteristics were persistence and flexibility in approaching departments, learning what they need to do to be successful, and providing them with encouragement and pressure to do what is needed. There were four major changes that were found to be necessary in the SEI general management.

Greater oversight of departments and more specific commitments and timelines. First was requiring the department proposals to contain specific commitments in terms of deliverables and timelines. That means giving lists of what courses were to be transformed on what schedule and which specific faculty members were to be involved. In many cases, the timelines turned out to not be realistic, and often things took longer for quite valid reasons. However, requiring this level of detail, including teaching assignments three years in advance, at least laid out specific targets that departments would have already discussed when the proposal was submitted. This avoids the problem that was often encountered in the early days of the SEI, where every faculty member is saying, "Yes, that is what the department was going to do, but I never promised to do anything. Get somebody else."

Making funding contingent on progress. Second, was making funding for a department contingent on progress, rather than on being fully committed upfront. This provided needed accountability and meaningful oversight to ensure that commitments were being met and money was being well spent.

More extensive and formalized initial and ongoing SES training. Third was establishing a formal and extensive training program for SESs, and making sure that both the departments and the SESs understood from the beginning that this would require a substantial investment of time, particularly during their first semester.

Focus on changing willing faculty members rather than particular courses. Although the original vision of the SEI was to systematically transform the curriculum, starting with the introductory courses and working upward, that was unrealistic. It did not properly recognize that the important change is in the faculty, and the courses themselves are secondary. The outcome was more successful when departments focused on finding receptive faculty and providing them with the support and incentives to make changes in whatever courses they were teaching. Of course, priority was given to courses that would affect more students over smaller specialty courses, but what was most important was to build up an ever-increasing number of enthusiastic faculty who would pursue, demonstrate, and champion the SEI teaching goals.

A particularly severe manifestation of the error in focusing on courses involved large introductory courses taught in multiple sections by multiple instructors. Such courses seemed to be the obvious place to start carrying out course transformations. They would greatly benefit from having a high-quality set of materials and assessment items that could be used by multiple instructors; it would save time and create a course that was more effective and consistent for student learning. However, as noted in Chapter 3, it was discovered that multiple-instructor, multiple-section courses where the instructors were used to having substantial autonomy were much more difficult to transform than single-instructor courses. The instructors were often quite resistant to transforming such courses; some were even resistant to agreeing on common topics and exams. In most cases, the fact that the departments and the leadership had now clearly endorsed such changes made little difference due to long established precedent of no supervision. In several cases, a large amount of SES effort was expended on these courses with little success. This held true in multiple courses across several departments. Progress was eventually made in some of these courses after changes were made in the instructional staff.

I did see a large multiple-instructor course that carried out a major transformation without problems. In this case, a single faculty member was

clearly seen as being in charge of the course, and provided centralized leadership. This structure would seem to be generally desirable for maintaining the quality and consistency of instruction in multiple-section courses while reducing instructor preparation time. Although this structure is the norm in some departments, in others, strangely, it is not.

I also recognized the need to modify the original SEI course transformation model of progressing sequentially through developing learning goals, improving assessments, and then designing good instructional activities. While this method of backward design does result in a high-quality transformed course, it was a process that only a fraction of the faculty were willing or able to follow, often because of the difficulty they had initially with formulating good learning goals. From the SESs I learned that it was more successful to take a flexible approach, starting with particular instructional issues of interest and concern to faculty members and help them achieve noticeable and rewarding progress. Only then could they progress to other steps in the process. This shifts the emphasis from a results-centered backward design approach to a people-centered incremental steps and "small wins" approach.

Elements of the SEI Model That Failed

Improved efficiency. Although the SEI was successful in changing the teaching practices of many faculty and in many courses, the SEIs made little progress in improving efficiency by achieving departmentally developed and owned courses with good consensus learning goals and shared instructional activities and assessments. The original hope was that by working together to create effective courses designed to be part of a coherent curriculum, faculty time would be minimized while maximizing student learning, as materials, assessments, and learning goals could be passed along, reused, and improved as faculty rotated through teaching different courses.

The benefits of improving efficiency and effectiveness for individual faculty, and departments as a whole, seemed to be too radical a change from the prevailing culture of individual ownership of courses. The idea of sustaining the course structure by passing on materials and assessments was not perceived as worthwhile by the individuals or departments who would need to do the necessary work. There was no structure within the departments that would assign to someone the job of ensuring that materials were

archived and passed along so as to allow faculty to use their time most efficiently, and there were no incentives in place for anyone to take responsibility for such activities at a departmental level.

One of the most obvious manifestations of this difficulty was the lack of transfer of transformed courses. After a course was transformed through the SEI, there was rarely a departmental expectation or plan that other faculty would use the course materials. While many course transformations were sustained, this was due largely to decisions made by individual faculty members rather than a result of departmental policy. The exception was that in a few cases departments arranged to have a transformed course cotaught by the transforming instructor and a new instructor who would be taking over the course.

Widespread collection and use of data. As discussed in Chapter 3, the regular collection and use of data on student learning and attitudes outcomes for ongoing improvement has not been embraced by any department. While we saw some individual faculty members collect and use this type of data, it never became departmental policy or had departmental resources supporting such efforts. It is hard to see this ever happening unless it is driven by the institutional accountability and incentive system.

A sense of urgency about educational improvement. A substantial unsolved problem was how to create a sense of urgency in the SEI work, so that it was seen as a priority both by the department and by individual faculty members. A sense of true urgency—that is, the activity needs to be given high priority because change is needed now, and if it does not occur, serious consequences will ensue—is known to be an important ingredient in creating change within organizations.[1] The original intent of the SEI was to create this sense of urgency by providing resources (money and SESs) for a finite period of time, and encouraging departments to take maximum advantage of these resources before they were gone. Faculty and departments almost never viewed the SEI in this way, resulting in slower change and less than optimum use of the SEI funds.

This was likely the result of the formal incentive system at the institutions and their misalignment with the improvement of teaching. Within the institutions the adoption of better teaching methods was unrecognized by the incentive system in promotion or tenure decisions, or in levels of support for departments. The involvement with an SEI course transformation was nearly

always seen by faculty to be a voluntary activity, from which they could withdraw without penalty. If the formal incentive system recognized and rewarded SEI-like improvements in instruction, it is likely that one could accomplish these changes faster and with far less money that was required for the SEI. The process would still be greatly enhanced by having SESs guide the faculty in making changes and acquiring teaching expertise.

Department leaders, most notably in UBC EOAS, were sometimes able to create a modest sense of urgency. The EOAS leadership laid out a detailed plan showing when SESs could work with which faculty on which courses over the course of the SEI, and hence what had to be accomplished by specific dates if the work was to be completed before the end of the SEI funding. This plan was regularly reviewed with the faculty. The formal agreements with deliverables and timelines connected with incentives and signed by faculty members embarking on course transformation efforts also served to elevate the priority of the work.

Factors Influencing Faculty Decisions about Teaching

The success of the SEI depended on many factors, but the most essential was how faculty members decided to make changes in their teaching methods. Through many discussions with SESs and some with faculty, I identified factors that entered into those decisions. Many of these factors have been previously noted by others, although I omit "time," which is usually listed in the literature, in favor of factors that determine prioritization. This is because no faculty member has unused time, rather their decisions are always based on how they prioritize the use of the limited time they have. I found that the concerns that discouraged faculty from adopting new teaching methods and working on course transformation were quite consistent across departments, and the extent to which departments dealt with these concerns was largely the determinant in their SEI outcomes.

The formal (dis)incentive system. The dominant barrier to the adoption of better teaching methods at these and other universities is the formal incentive system, which is actually seen as a disincentive to put time and effort into teaching. The universal concern for tenure-track faculty was how adopting new teaching methods would impact their research productivity. Whenever the issue of changing teaching was brought up, it invariably led to the question "How much time will this take?" A longer conversation

made it clear that this really meant "How much time will this take away from my research?" This concern was always raised, even at the proposal stage of the SEI, and in the extreme cases the decision of the department was to not submit a proposal, as it was felt that any benefits to improving teaching would be outweighed by the negative impacts on research.

This priority given to research productivity directly reflects the formal incentive system. At UBC and CU, as at all research-intensive institutions, research productivity is carefully measured and rewarded, but teaching effectiveness is not. There is nothing in the formal incentive system that encourages the adoption of better teaching methods by individuals, or in fact even recognizes that there are different teaching methods that might be used. Similarly, the reporting and incentive system is blind to any collective departmental practices that would make education more effective for the students and teaching more efficient for the faculty. It is entirely reasonable that the faculty and departments align their priorities and efforts with the institutional incentive system, which by default means there is a disincentive to spend time on improving teaching or other aspects of undergraduate education. Another clear manifestation of this prioritization was that some junior faculty explicitly chose to put off working with the SEI until after they had tenure. Much of the success of the SEI, both overall and at the departmental level, was dependent on how well the resources of the SEI were used to counter the pressures of the formal incentive system.

The formal incentive system also served as a disincentive to non-tenure-track instructors adopting effective research-based teaching methods, even though their job descriptions did not include research. This was the result of the fact that the only comparative data relevant to teaching collected by the formal system were student course evaluations. These evaluations do not reflect the quality of the teaching methods used nor the amount of learning achieved[2] and are widely perceived as favoring entertaining lectures and penalizing active learning techniques.

Direct individual incentives provided by departments. Over the course of the SEI, I came to realize the importance of direct SEI incentives to faculty members to make changes in their teaching. Initially I encouraged departments to put nearly all of their funding into supporting SESs, with little funding for explicit incentives to individual faculty. This was a mistake, as it failed to recognize the full importance of the formal incentive system as a barrier. More faculty participated in SEI transformation efforts and with

greater enthusiasm when departments provided explicit incentives to them. Such incentives took many forms, and were most effective when they were tailored to the specific needs of the faculty member, often in a way that could benefit their research or free up their time. For some this meant support for a graduate research assistant or partial support for a postdoc, while for others a reduction in teaching load for a term or an additional TA was more attractive.

Another value to direct incentives to faculty was that it meant that SEI Central had a meaningful response if a department failed to follow through on its commitments made in their proposal. Without such direct incentives, SEI Central could and did threaten to cut off funding, but this had little meaningful impact on the faculty, typically the ones failing to fulfill commitments, since the loss of funding would not involve any loss to them personally.

Formal agreements with explicit deliverables. For direct incentives to be effective, however, they had to be connected to formal agreements laying out the expectations as to what the faculty member was to complete. I was surprised at first to discover how often otherwise responsible faculty would fail to live up to informal agreements to carry out course transformation activities, but then I came to understand why this was the case. It was a natural extension of the priority that teaching is given in a faculty member's life. While they all recognize that they have to show up for class, any extra effort devoted to teaching activities is routinely relegated to a lower priority than things like completing research proposals or reports, or solving an immediate problem that arises in their research. These early SEI activities were automatically put into this low-priority classification associated with all teaching activities, and so were often supplanted by other activities.

Initially it was very common for faculty to agree ahead of time to work on a course transformation but then back out at the last minute when they started to seriously consider what time and effort would be required. In many cases an SES was told when hired that he or she would be working with a particular faculty member to redesign a particular course, and then find the faculty member was unwilling. Similarly, projects that faculty members were paid to complete during the summer months seldom were done, and in many cases had barely started by the end of the summer.

EOAS showed us the solution to this problem, as noted in their results section. They established a rather formal-looking agreement that laid out the incentives being provided and a detailed list of expectations and deliverables from the faculty member in return. The agreement was then signed by the department chair and the faculty member, usually after the faculty member reviewed it with the SEI departmental director. Although such an agreement had no formal legal status, it carried with it a powerful message. Such an agreement caused a faculty member to think about this SEI work in quite a different way compared to their usual teaching activities, and as a result it was given much higher priority and was usually successfully completed more-or-less on time. Course transformations under the SEI were no longer seen as part of the "business as usual" of teaching and course preparation, but rather were something more urgent and high-priority, with clear incentives attached and corresponding penalties for failure to complete. The agreement also clarified expectations in advance, so faculty members had a much more realistic view of what would be involved and how they would be working with the SES.

Persuasiveness of educational data. I initially, and erroneously, believed that most faculty members would be convinced to change their teaching methods when faced with research data on the effectiveness of different methods. In reality, data, in the form of discipline-based education research results, had a limited impact on their attitudes. In retrospect this is not surprising, since the psychology literature suggests that people will often discount information that creates cognitive dissonance.[3] Accordingly, I found that if the data about teaching effectiveness conflicted with their core beliefs about teaching and learning, the tenets of their discipline about teaching, or their self-image as a good teacher, faculty could always find ways to discount this data, particularly if the data had not been collected in their classroom with their students. This finding has been supported in other studies.[4]

Perhaps the most dramatic example of this came when I was first presenting the idea of the SEI to the UBC physics and astronomy department, as the first step in the proposal process. I gave my standard presentation, in which I discussed ideas of physics education research and offered data from many studies showing the benefits of research-based physics instruction compared to traditional lectures. At end of the talk, there was heated opposition to these findings and the idea it would apply to UBC physics courses, led primarily by several award-winning faculty members who

were known for their charismatic lecture performances. After this argument went on for some time, a young woman stood up. She explained very articulately how she had been an undergraduate at UBC in physics and now she was a graduate student—and that everything I said was exactly correct, in her experience. She said she had gone to all those lectures and had been able to do well on all the exams but had never understood the material. Only now that she was a graduate student and having to teach many of these courses was she beginning to actually understand the physics. (I later learned that she was considered one of the top graduate students in the department.) This statement carried far more weight than all the research studies I had presented. It resulted in a great buzz of discussion in the room, some acceptance that maybe there could be some truth to this, and an acknowledgment that the department needed to look into it further.

Another example of where a local example was found to be far more convincing than published research came from the statistics department. Early on, one faculty member who had been stimulated and encouraged by the SEI carried out cognitive interviews with about a dozen students who had received As in his course the previous year. He found to his shock that almost none of them could explain the most fundamental concept that underlay the entire course. After that, he and others in the department were convinced they needed to change their teaching.

While data are seldom convincing, I found it to be true that science faculty will generally pay some attention to research data and give it some thought, even if they were not convinced by it and of the need to change. However, faculty were strongly biased toward data from their particular discipline and were not influenced by data from other fields; frequently they expressed the belief that what works for teaching in one field, such as physics, may not apply to teaching in other fields, such as chemistry or biology. In contrast to the science faculty, the mathematics faculty largely ignored educational research data—perhaps not surprisingly, as their discipline is not an empirical science.

Rewarding personal experiences. The evidence that seemed to have a bigger impact on faculty changing their teaching methods was more personal. When teaching using interactive research-based methods, faculty consistently found teaching more personally rewarding, because their students were much more engaged in learning and showed both greater interest in the topic and more attention to the instructor than the instructor had

previously experienced. Also, the level of intellectual interaction with the students was much higher, and so the instructor felt they were contributing much more to students learning the rich complexities of the subject. I believe that making teaching a more personally rewarding experience is the primary reason that the SEI was successful in the face of the barrier provided by the formal incentive system, and it is the primary hope for the sustainability of these teaching methods. The SEI provided encouragement and support for faculty to try out and learn to use these new teaching methods in a reasonably successful way, but the reason they continue to teach this way, and proselytize about it to their colleagues, is because they found it personally more enjoyable.

Observing a session of a transformed course was a powerful influence on faculty decision-making. This seemed so influential that I tried to make it as easy as possible for faculty to observe such courses. As in most universities, at UBC visiting another faculty member's class was highly unusual and considered quite strange. To counter this barrier, I encouraged departments to make a list of model transformed courses and, after getting permission from the instructors to have visitors to their class (which instructors were always happy to grant), distribute the times and locations of such example courses to all the faculty. At UBC, the job of assembling and emailing to the faculty a list of such sample courses that would welcome visitors from across the college was initiated by SEI Central and later adopted as an activity of the dean's office. This implicitly recognized and endorsed the efforts of faculty who had carried out very successful course transformations, as well as making it easy for other faculty to see these methods being used in practice. Second to the impact of actually observing a well taught class in person was hearing an enthusiastic colleague describing the experience, often in informal settings, such as over coffee or lunch.

Fears of the unknown. Faculty had several specific fears when considering adopting new teaching methods. One was "Will this hurt my student evaluations?" I saw that it was helpful for the department chair to explicitly reassure faculty members that their student evaluations would be handled differently so they would not suffer from lowered evaluations. In reality, this fear was quite unfounded as discussed in the "Student Evaluation" section of Chapter 5, and this concern largely evaporated at UBC as the SEI became well established.

Another faculty concern was "How will I cover all the material?" This was best handled by laying out in detail how the various elements in a transformed course worked to make the learning more efficient and thereby maximize the material that could be covered and learned. We trained the SESs to show faculty how a significant amount of material, particularly simpler transfer of information and mathematical derivations, could be moved out of class via pre-class reading or homework, freeing up time. Thinking about using instructional time more efficiently was often a novel but convincing idea to many faculty. Having examples of actual courses that had been transformed without sacrificing substantial amounts of material, especially in combination with hearing from faculty involved in such efforts, was also usually quite convincing.

Another fear was "How will I keep control of the class?" The idea that instructors will lose all control once they let students start talking with each other in class is a fear held by a nontrivial minority of faculty. Having the faculty member observe a well-run active-learning class was the best way to address this concern. It also helped to show them tricks for running a very large interactive class, such as having a bell that is rung to signal to students that they should stop talking and pay attention to the instructor.

A less common concern was "Won't these methods be helping the weaker students at the expense of the top students?" This was most commonly raised with adopting new teaching methods in upper-division courses. As more students became familiar with these teaching methods, however, the views of the students, particularly many of the strongest students, provided the most powerful and articulate arguments in favor of the new methods. Data on learning for the students at the institution also likely helped. We had data from the upper-division physics courses showing how, once the students had experienced the use of clicker questions and peer discussion in such courses, the students were overwhelmingly (four to one) in favor of such methods. It was also helpful to show faculty that before the students had experienced teaching this way in upper-division courses, they had exactly the opposite opinions (four to one against).

Departmental Culture and Function

The basic requirement for success of a course/faculty transformation was the combination of a trained SES, a willing faculty member, and adequate

planning. However, the quality of the management of the department determined how likely it was that all three of these would happen at the same time, and how often there were problems in the implementation. Ultimately, once a department was funded, the primary determinant of departmental success was simply the overall quality of the organization and management of the department. None of the problems or solutions in this regard are unique to the SEI or academic departments; they largely reflect good management planning and practices in any organization, and the failures that result when good practices are not followed. However there are a number of elements in the department culture, such as how "ownership" of courses is perceived, oversight of the large introductory courses, and the status of non-tenure-track instructors that impacted the SEI results.

Leadership and management. The primary leadership in departments is provided by the chair. I saw that the chair played a major role in the SEI success. There were a number of examples where the chair changed during the SEI program. In all of the cases where the new chair was not supportive, the SEI work slowed substantially, and in the cases where the new chair was more supportive, progress improved. There were examples, however, where the chair was quite supportive but there were other important elements missing, and in those cases progress was relatively slow. So it is clear that a supportive chair is necessary but not sufficient to ensure SEI success.

The large impact of the chair is somewhat surprising, as generally the chair has relatively little impact on the life of a science department faculty member. I believe that there are several reasons for this special importance in the context of the SEI. First, the chair plays a major part in the management of the SEI program, either directly or in terms of who is appointed as SEI department director. As discussed above, a productive SEI program requires considerable planning and management of multiple resources: funding, faculty, SESs, and teaching assignments. This is challenging for all departments, and how successfully it is carried out depends mostly on how well the chair understands the complex task and ensures that competent people attend to it. Second, the importance of the chair is amplified by the fundamental conflict between the SEI and the formal incentive system, which penalizes faculty for spending time on SEI activities. A chair who is highly supportive of the SEI work, however, can counter the negative message of the formal incentive system through numerous small rewards to faculty members: desirable teaching or committee assignments, space as-

signments, salary increments, and so forth. Good chairs also emphasize the importance of the SEI work by having it be on the regular agenda of faculty meetings, bringing to the attention of the department particularly notable accomplishments, and seeking other recognition for participants through teaching awards, thereby encouraging faculty to participate. They can also ameliorate the fears about lower student teaching evaluations. Of course, the chair's effectiveness at fulfilling all of these functions depends on how respected he or she is within the department and how good a leader he or she is. A supportive dean was also important, with the most obvious direct impact being in their selection of department chairs who were supportive of the SEI.

Departmental management of SEI efforts. Whenever a department left SEI oversight up to an existing committee, it did not go well, as such committees were fundamentally reactive. A successful SEI transformation effort required a new structure within the department, such as the formation of a new position and/or committee with the charge of bringing about change in undergraduate teaching.

In addition to having the appropriate structure in place, there must be an individual who has the responsibility to oversee all the SEI efforts. The SEI department director handles many of the general management tasks present in any substantial project, such as hiring and supervising the SESs (including making sure they know what they are supposed to be doing and how they should be prioritizing their time), leading the planning efforts, deciding on allocation of resources, reporting to the department and SEI Central on progress, and so forth.

The SEI department director needs to also carry out an essential management task that is unique to the SEI: putting in place the unfamiliar and somewhat delicate collaborative relationship between faculty member and SES. Four problems were encountered most commonly. First was the faculty member treating the SES as simply a TA, doing little besides carrying out routine instructional tasks on the instructor's behalf. Second, some faculty members failed to meet with the SES or provide materials or feedback in a sufficiently timely manner for the SES to do anything useful. Third, it was a problem when the SES tried to be too helpful and ended up creating most of the teaching materials without the involvement of the faculty member; as a consequence, the faculty member never learned how to do it. Finally, faculty members sometimes decided they were too busy or

otherwise not interested in being involved with course transformation, and just told the SES to go away.

With multiple SESs working in a department with multiple faculty members to transform courses and teaching, it required considerable planning by the department to make sure all the pieces of faculty member time, teaching assignment, and SES availability and area expertise were aligned. The necessary planning required people in authority with good organization and planning skills. One particular area that was a common source of problems was teaching assignments. Prior to the SEI, few if any departments had a multiyear plan for which faculty would be teaching which course, but I found that to be essential for good SEI progress.

The role and management of the long-term non-tenure-track instructors within the department was also important for the success of the SEI. Such instructors ended up being powerful supporters of SEI efforts in some circumstances and obstacles in others. Across the various departments, the status, roles, and management of non-tenure-track teaching faculty varied dramatically, as did their involvement in and contributions to the SEI efforts. Non-tenure-track instructors who were very involved in SEI activities tended to be instructors who were highly respected and well integrated into the department. They often rotated through teaching a variety of courses. Many of these teaching faculty became leaders and models of the SEI teaching methods and greatly facilitated adoption within the department as a whole.

There were also many examples where this was not the case. A particularly problematic situation was when there were introductory courses or labs always taught by the same long-term non-tenure-track instructors. These cases often (though not always) led to such instructors being quite disconnected from the departments as a whole and essentially unsupervised, and the courses and their goals often were at odds with the thinking of the regular faculty. Often, these instructors taught sections of large multisection introductory courses, which contributed to the difficulties in transforming these courses. These problems were usually not recognized until the SEI became involved, but then the department often felt incapable of addressing the situation because it would involve too much conflict.

Course ownership and oversight. A fundamental aspect of the culture of departments that was very relevant to the SEI work was their view about course ownership. At one extreme, the courses are owned and defined by

the department and the faculty teach the courses that they are assigned in line with expectations set by the department. At the other extreme, the departmental control stops at the course name and number and the faculty member is free to teach whatever and however they want in the course. I found that views about course ownership were variable but tended to be embedded within department cultures, and those views had a substantial impact on the willingness of the faculty to engage in SEI activities. This was most apparent when departments were first considering submitting proposals. In some departments, the sense of individual ownership of any course that a faculty member might teach was so strong that there was overwhelming opposition to the idea of following any sort of guidelines as to best practices, such as those laid out by the SEI. There was also strong opposition to the idea that a faculty member who might be called upon to teach a carefully transformed course would be expected to adopt the learning goals, materials, and methods that were developed.

The stronger the culture of individual ownership of courses in a department, the more difficult it was to get faculty to embrace the SEI transformation model. In some cases, such individual course ownership was felt to be a matter of "academic freedom," although it is difficult to see how one can claim the concept of academic freedom would apply to allowing a faculty member to teach in an ineffective manner or fail to cover the material listed in the official course description.

Even in departments where there was a sense of departmental ownership of some courses, there existed upper-division specialty courses that were always taught, and hence "owned" by a single faculty member. The fraction of courses transformed across the departments is quite dependent on the fraction of the courses offered by a department that are these specialized upper-division courses. A detailed examination of all the courses that have been transformed shows that relatively few upper-division (especially fourth-year) courses are transformed for any SEI department. Nearly all such courses have relatively small enrollments, are often offered only once every few years, and are typically taught by a single faculty member who is an expert in the subject. Very seldom—if ever—does any other faculty member teach the course or have any involvement with it. All these factors tend to make it harder to carry out the transformation of such courses, and for many of the same reasons such courses are a lower priority for transformation within a department when decisions are being made about how best to use SEI resources. If a faculty member teaches only such

courses, this also means that it is difficult to impact that person's teaching following the SEI model.

The existence of many upper-division specialty courses can make the fraction of courses changed an unreliable measure of overall impact within a department. Some departments offer, or at least show on their list of courses, a very large number of such upper-level courses—in some cases they account for more than half the courses listed—while other departments have far fewer. I discovered that when there are a very large number of such courses listed, most are seldom taught.

Curriculum problems. The SEI was focused almost entirely on improving how material was taught and learning was assessed. It did not address what material should be taught, other than expecting that learning goals for transformed courses be specific and well articulated. I felt it was the place of the department to decide what should be taught in its courses and curriculum, and that it would not be productive for us to be involved in those decisions. We adhered to that policy, but our deep involvement with the courses and curriculum through working with the SESs did make us aware of the wide variation across departments in terms of how much attention they paid to the quality of their curriculum. In far too many cases, it was apparent that there had been little attention, resulting in problems that negatively impacted student learning. The most serious curriculum problems were tyranny of content, entrenched dysfunctional course design, and poor curriculum alignment.

Tyranny of content. It was not uncommon to have instructors who would agree that these new teaching methods were better but who felt they had to stick with standard lecturing in order to cover all the material traditionally covered in the course. There was often a general consensus that too much material was being covered in such courses for students to learn, but the instructors nevertheless felt compelled to rush through it all, apparently motivated largely by historical precedent and departmental expectations.

Entrenched dysfunctional course design. There were a few other examples of courses in which the selection and organization of topics were firmly entrenched by tradition but made little educational sense. Typically, these courses consisted of a large number of assorted topics established decades ago that were covered rapidly, and which now had little connection to the

students' preparation or their future needs. These courses were the only cases where improvements in pedagogy produced no measurable improvements in student learning. Often faculty recognized these courses as problematic, but the department did not have a functional process for fixing them.

Poor curriculum alignment—redundancy and gaps. A less serious but more common problem was poor alignment between courses in a sequence. Our interactions with the SESs, with their deep immersion into many courses within a department and their understanding of student learning, provided insights as to how well the various courses in a sequence supported each other. Due to a lack of clear learning goals, a lack of knowledge by the instructors of the students' prior knowledge coming into their courses, and a lack of oversight by departments as to what the faculty actually taught in their courses and at what level, there were frequently substantial gaps or redundancy in the curriculum as taught. Essential topics of the discipline were omitted, as all the instructors assumed someone else would cover them, and other topics were covered in almost the same form in multiple courses. Also, prerequisite courses, particularly those taught in other departments, did not actually cover the material that the students were assumed to have learned, or covered it in such a manner that it was very difficult for students to see the connections. The presence of multiple-section, multiple-instructor courses (when the instructors taught independently) also contributed to curriculum misalignment, as the different sections of the same course often covered different material. In many cases, each instructor would select the topics he or she liked to cover, in whatever manner he or she chose. All of these factors contributed to poor alignment of the courses, resulting in considerable inefficiency in the use of both student and faculty time.

Fortunately, severe cases of dysfunctional curriculum were relatively rare. Also, in many cases, as faculty adopted SEI methods, they came to better understand student thinking and then recognize problems in the curriculum. Where the department had a suitable process they then took steps to fix the problems. Thus, the SEI has resulted in a number of beneficial changes to the content of courses and curriculum throughout the SEI departments.

Perverse incentives. Although they are not the primary driver of faculty and departmental actions, I encountered some perverse incentives within

the system that reward faculty and departments for teaching that drives away students from the major. Science departments generally spend more per credit hour on upper-level courses and labs, and support does not directly track enrollment so there is a financial disincentive to introducing more effective teaching if that results in more students being successful in introductory courses and choosing to enroll in upper-level courses in the field. The increased financial burden on departments of having more upper-division students was raised by several department chairs in the early days of the SEI. As a result, the UBC dean went on record as promising to shift funding to compensate for any increased upper-division enrollments for departments participating in the SEI.

Likely connected with the financial issues, some departments had established grading policies that limited the number of students that receive high and/or passing grades, independent of the amount the students learned. As noted in Chapter 3, this led to some conflicts within departments when improved teaching methods led to notable improvements in student learning and exam performance relative to previous years. In one extreme case, math had an unspoken rule that a large fixed fraction of students in their gateway course for the major should be failed each year. In this case, we made changing that policy a condition for SEI funding.

In summary, the success of any effort to carry out widespread improvement in the quality of teaching will depend on the complex interaction of many factors. I found that, with suitable flexibility and adaptation, the SEI approach was able to address many of the important factors. However, there are many others that are deeply embedded in the culture and functioning of the departments that play an important role.

Coda

THE SCIENCE EDUCATION INITIATIVE SHOWED that it is possible for large research-intensive science departments to make major changes in their teaching. Most faculty adopted innovative research-based methods, and as a result experienced teaching as a far more rewarding activity than they had found it to be using traditional lectures. Their students attend class more and are far more interested in learning the subjects and benefiting from instructors' expertise. Advancing the craft of teaching has become much more of a shared goal and focus of collaborative intellectual activity in these departments, with faculty sharing methods and results and seeking out ideas from others for novel ways to solve instructional challenges. These faculty did find that it takes time to learn to teach in this new way, because there is substantial expertise to be acquired, but that given suitable support, the time investment is not much greater than that required to create a new course. The results are perceived to be well worth the effort.

However, this majority experience did not come about easily or automatically, and was far from universal in all departments. As arguably the largest experiment of its kind, the SEI revealed a great deal about what it takes to bring about widespread educational change in the context of a large research-intensive university.

Here I attempt to distill from all the preceding chapters the most important lessons I have learned from this experiment. This Coda is intended to serve as advice to any deans, department chairs, or faculty members who

desire to improve how their institutions teach science (or for that matter, most any subject). If you count yourself among those ranks, know that your ultimate goal must be to convince faculty and departments that teaching well is not merely a function of knowing one's subject and having a suitable personality. It requires expertise based on established principles of learning and the knowledge of research-based practices that apply those principles to teaching in a specific discipline. To bring about such a change in beliefs and associated teaching practices, your three top priorities should be to provide incentives, to support departmental change, and to maximize faculty buy-in.

Provide incentives. First, you need to appreciate how powerfully the formal incentive system undermines the goal of improved teaching. The evaluation and incentive systems used in universities do not recognize that there is research on learning and that there are fundamental differences in the effectiveness of different teaching methods. Faculty universally perceive official incentive systems as penalizing any time taken away from research to innovate or adopt innovations in teaching. Automatically this causes faculty to place a low priority on efforts to improve how they teach. If you are like me and lack the power to change your institution's well-established incentive system, your first priority must be to find ways to counter it with informal incentives. Such incentives need to exist at both the department and the individual faculty member levels. What I have found is that, once a group of faculty has been somehow induced to spend time learning to use these new methods reasonably effectively, the greater personal satisfaction they receive from teaching in this manner proves more than sufficient to keep them teaching in the new way.

The incentives should start with getting deans (and ideally other administrators) to convey the importance of teaching-improvement efforts in both their public communications and private discussions with faculty. Deans can also ensure that department chairs recognize that improving teaching in their departments is an important part of their jobs, and urge chairs to pass along that message to faculty. Being in the good graces of your dean and department chair is not everything, but it is a significant incentive for most faculty.

Most other incentives require money in one form or another. The SEI showed that it does not cost more to teach using these more effective methods, but it does cost money to bring about change. Money can reduce

barriers by providing staff support (in the SEI's case, in the form of science education specialists) to minimize the time it takes faculty members to learn new teaching methods and develop new course materials. Money can also, in smaller but still significant amounts, be used to reward faculty for spending that extra time. Some might cherish release time from teaching or some summer salary, while others might want additional budget for a research assistant or piece of lab equipment. Finally, there are simple social incentives. You should continually look for ways to encourage faculty to communicate to their colleagues about teaching, and about how much more rewarding it can be to teach in these new ways.

How much money is required depends on how strongly the existing incentive system and the departmental culture discourages spending time on improving teaching, as well as the scale of the change desired. At most large research-intensive universities, assuming little change in the institutional incentive system, the cost is likely to be in the range of $50,000 to $100,000 per faculty member, spent over a period of five to ten years.

Support departmental change. Your second priority should be to create change at the departmental level. The departments decide what and how to teach, and so they must be the unit of educational change. I found that an effective starting point was a competitive grant program by which departments vie for substantial amounts of money, based on proposals to improve their teaching. The virtue of such a program is that it gets the department as a whole to discuss its overall teaching needs and opportunities in a way that seldom happens otherwise. I also saw that competing for substantial sums of money can produce a level of planning and commitment in departments that would otherwise not be considered worth the effort. It is important to require that proposals have a substantial amount of detail, specifying which courses and which faculty members are to be involved, and including milestones and timelines for what will be accomplished. You may need to work with departments to help them develop such plans, as they may start with little idea as to what such an effort might look like. You will also need to monitor progress after a department is funded to ensure that commitments are met; the long-standing habit of educational improvement's being treated, if left up to individuals, as a low priority is hard to break. While it is important to commit to several (typically five) years of funding to encourage long-term planning and action, the release of subsequent-year funds should be contingent on adequate annual progress.

I found that, once a department had agreed to pursue educational improvement, the success of its effort was largely determined by the quality of its leadership and administration, and that this quality varied greatly across departments. You will need the explicit support of the chair, but it is also necessary to have new structures and responsible people put in place for managing the program within the department. It never worked to have an existing committee—such as a curriculum committee—handle this job of managing SEI change activities. Such committees are designed to operate in a purely reactive mode, not lead change. We had to pay particular attention to how the department handled the three essential administrative tasks: planning and oversight of the collaborations between faculty and SESs; the associated long-term planning of teaching assignments; and the supervision of the SESs.

In my experience, when a department exhibits conspicuous weaknesses in its administration, that problem is deeply rooted in the history and culture of the department. If you encounter a department that has serious and deeply ingrained dysfunction, my advice would be to simply avoid it. Fortunately, it is more likely that you will encounter departments where there are limited administrative weaknesses which can be managed with a little oversight and pushing—particularly if some of that comes from the dean. Finally, make it your mission to learn from your well-run departments what they are doing to make their change efforts successful, and share those practices.

There are many things that departments can do to counter the low priority accorded to teaching improvement. Consider what is signaled, for example when the chair makes it a regular agenda item at faculty meetings to discuss (and celebrate) the progress of efforts to improve teaching. More formally, explicit written agreements can be drawn up with all faculty members who will be involved in transforming courses. Such agreements might spell out the deliverables and timelines expected, and the rewards the faculty member is to receive for the work.

A key component in every successful SEI department were SESs who combined deep expertise in their particular discipline with expertise in teaching and learning in that discipline. SEI's model specifies that such SESs should be hired and supervised by the department and work collaboratively with the faculty to improve teaching. The SESs act as nonthreatening coaches, providing guidance and support to faculty members as they try new things in their courses. With SES guidance, a faculty member is likely to

implement research-based teaching methods in an effective manner from the beginning, and have a positive teaching experience in doing so. The SESs also provide expert and time-saving assistance in developing new course materials and assessments.

Finding SES candidates with the necessary disciplinary knowledge was a straightforward task. Often, they were new PhDs. It was not difficult, either, to find candidates with an interest in education, but it was largely impossible to find ones who also possessed the needed expertise in teaching and learning. I found it was necessary to set up a training program for the new SESs in the relevant research and best research-based teaching methods as applied in their discipline. The training also included guidance on how to work effectively with faculty. We had to make it clear to the SESs and their departmental supervisors that, in addition to the time needed for initial training, SESs need to reserve a few hours per week in perpetuity to spend on professional development, keeping up with the relevant research literature, and learning from each other.

Maximize faculty buy-in. In any SEI-type program, the primary goal has to be convincing faculty to adopt new and better methods in their teaching. This means first convincing them that there is expertise in teaching that is worth acquiring. There are many ways to convince faculty to buy in to the program; incentives, of course, play a large part, as does the use of resources (like SESs) to work collaboratively with faculty members to reduce the barriers to change.

I recommend you start by recruiting any willing faculty member to work on making changes in their teaching, and then accommodate them by adopting whatever process of change works best for them. I started out mistakenly thinking it would be best to transform the courses systematically through the curriculum, starting with the lowest level and working up, and in the process, transforming the teaching of the faculty assigned to teach those courses. What I found works best in the real world is to have far greater flexibility, and to focus on transforming the faculty rather than transforming particular courses. Which courses are easiest and most appropriate to transform will likely vary greatly with the local circumstances, and your top priority should be maximizing the number of faculty members in the department solidly on board with new teaching methods.

You should also stay flexible about how courses are transformed. Some faculty will be happy to carry out a complete overhaul of the course by

starting with creating a completely new set of learning goals. But, for many others, an incremental approach works better, for both psychological and logistical reasons. Faculty members often have trouble articulating good learning goals. In the SEI, we found they were more comfortable starting by incrementally adding new teaching methods, aided by an SES, to address specific difficulties that they had noted in their classes. Over time, they then became more comfortable with new ways of teaching, they developed a better understanding of student thinking in their courses, and their teaching and learning goals further evolved.

I still believe that it is important to urge faculty members to start a course transformation by deciding on the learning goals for the course, because having complete and detailed learning goals is so helpful for guiding and sustaining the improvement in instruction. You should appreciate, however, how difficult it is for most faculty to produce such a set of goals when they are first asked to do it, and temper your expectations accordingly. A typical initial response is: "I want the students to understand this set of topics [or these chapters in the textbook] . . ." Faculty often find it hard to express what they mean by "understanding" in the operational terms of what students should be able to do. However, if pushed, over time they usually can develop something suitable, particularly if they are regularly thinking about new teaching methods in the course and what benefits these may provide. Similarly, it was challenging to find ways to effectively measure learning in the pre-transformed courses that could then be compared with post-transformation results. I eventually accepted that this was unrealistic in most cases. It simply conflicted too much with existing institutional norms and expectations. We were able to get good assessments of learning in the transformed courses, with the SESs taking the lead.

Like just about anyone faced with trying something new and unfamiliar, faculty members have a number of fears about using new teaching methods. These can interfere with buy-in, if not addressed. Among most common fears: "It will take too much time away from my research." "The students will not like it, and my student course evaluations will go down." "I will lose control of the classroom, and it will be chaos." "I will never be able to cover all the course material I need to get through." Addressing the first fear largely depends on incentives. The best way to address the others is by arranging for faculty members to observe transformed courses being taught, and having them talk with other faculty members who are teaching transformed courses. I found these direct observations and conversations

to be more effective at calming such fears than any data. We also developed short handouts for faculty with specific guidance on how to avoid the other concerns raised.

Finally, when implementing a large-scale effort to improve teaching, you need to have flexibility and patience. You are attempting to change traditions that are centuries old. For many faculty members, one or two years of hearing about these ideas and discussing them with their colleagues may be required before they decide to put a toe in the water and try something different. During this gestation period, you need to provide faculty members with repeated educational exposure and potential incentives. Also, remind them that they do not have to do everything at once or be perfect the first time. Even modest changes will result in improved student learning. By their nature, these teaching methods are somewhat self-correcting. The methods allow the faculty member to better understand in real time how their students are thinking, and hence how to make changes to optimize learning and satisfaction.