
The Process of Making Change

IMPLEMENTING THE SEI across two institutions and many different departments involved putting in place many pieces and finding ways to adjust those pieces when unanticipated challenges arose over the course of six years. This chapter describes that full process of implementation, starting with the method for funding the work and then putting in place the planning, departmental and institutional structures, and oversight required to move the project forward. I then discuss the core of the SEI effort, how the faculty members in each department were supported in a deliberate process of transforming the courses they were teaching, and in that process, transforming their approaches to and methods of teaching. The final part of the implementation was collecting as much data as possible as to the results, including the differences across institutions and departments.

Implementation of the science education initiatives spanned more than six years, with many tasks having to be completed within the first year. (See Figure 3.1.)

Proposal Process

When departments first considered the SEI call for proposals, the concept was so novel that they had little idea of what to do; thus the proposal development process was fairly interactive. During the proposal development process, departments were provided with a framework for carrying out

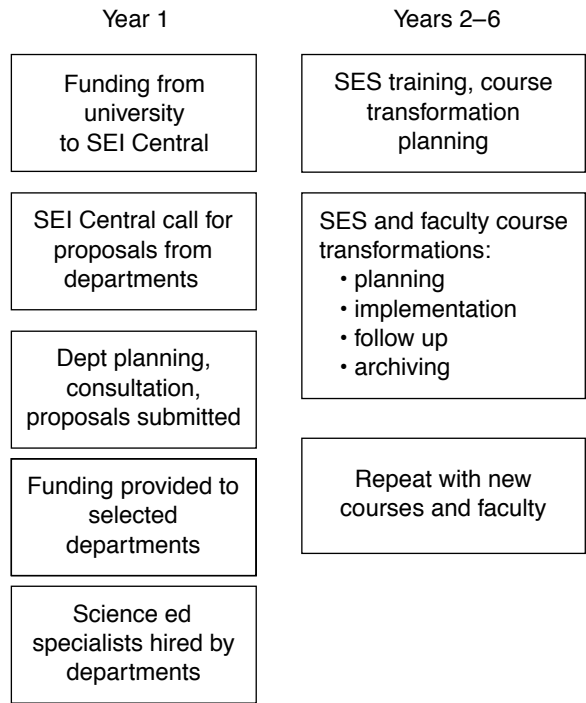


FIGURE 3.1. An implementation plan spanning six years

changes, including the vision of a transformed course and the possible use of SESs in this process. This framework guided departments in the types of activities that they could support with SEI funding. While the framework encouraged a general set of activities, the focus was on the outcomes, and departments had substantial discretion in how they expended the funds and how they structured their proposed work. The departments were explicitly told that funds could be carried over from one year to the next, to optimize how they were spent. Additionally, as a result of early experiences, it was important to make it explicit that funding could be discontinued in future years if sufficient progress was not made.¹

In all cases, shortly after the call for proposals was sent out, I would attend a departmental faculty meeting to discuss the research on science education, what they might do to improve undergraduate education, and how to go about it. The proposal process and decision-making criteria were also presented. In retrospect, the level of faculty participation, the issues raised,

and how the chair managed the discussion and dissent (primarily about the effectiveness of different teaching methods) during those early meetings turned out to be a fairly good predictor of the later outcomes of the department. During this process, either in those meetings or in materials provided to the department, the department would be introduced to the idea of SEEs who could be hired with these funds and trained by SEI Central. Because the departments had so little precedent for an effort like this, they had difficulty understanding all that would be involved, and hence had difficulty being very specific in their proposals.

Early experiences led to adding the requirement of an explicit list of courses to be changed, a roster of faculty who would be involved, and a timeline for the project.² When these requirements were not put in place, many commitments were largely ignored after funding was provided. Making the commitments more specific helped to ensure that the department carried out adequate planning and was ready to live up to the commitments it was making, and helped to add some sense of urgency through having milestones and timelines. Even if these timelines were not strictly adhered to, having such goals resulted in fewer problems within departments.

One very early success was that the SEI call for departmental proposals resulted in all of the departments at both institutions having serious department-wide discussions about how they might improve teaching in their undergraduate courses. Although departments have often had discussions about curriculum, in most (and quite possibly all) cases this was the first time department-wide discussions about pedagogy had ever taken place. When I spoke at the faculty meetings about research on how to improve science teaching, this was the first introduction of these ideas to most of the faculty. To encourage such department-wide discussions, one criterion was that the departmental proposal had to be submitted to a faculty vote.

Resistance to the SEI efforts also emerged early. One expected source was a set of faculty members known to attach little importance to undergraduate education. The underlying fear, which was sometimes stated but more often only implied, was that this would result in the department's weakening its commitment to high-quality research and/or would compel individuals to devote more time and attention to their teaching. An unexpected source of active resistance came from a number of senior faculty who were widely recognized for their teaching skill, based on student evalua-

tions, but whose reputations had been built upon being great performers in the classroom while giving traditional lectures. Presenting data on the ineffectiveness of traditional lectures and calling for the shift to more effective pedagogies and different measures of teaching effectiveness can be quite threatening to such individuals.

Finally, a significant source of resistance was the belief in some departments that they could not make any sort of commitment that a transformed course would continue to be taught in that manner, because “we cannot tell the faculty how they should teach.” The choice of what was taught and how it was taught in a given course was considered to belong entirely to the individual faculty member teaching the course. Three departments sent in proposals requesting money but made it clear there was no commitment to doing anything beyond asking the faculty if they would like to make changes in their teaching. This individual “ownership” of courses (sometimes even claimed to be a matter of academic freedom) is an aspect of departmental culture that was an ongoing challenge for both SEIs across all departments. It was second only to the formal incentive system as a barrier to change.

The size of the potential grants affected how resistance was handled. The leadership in the department, primarily the chair, had to make a decision about how much time and political capital they would invest in building a consensus—including, possibly, enlisting sufficient support to overwhelm the opposition. Although it varied by department, the chairs at CU seemed less willing to do this than the chairs at UBC, probably because of the smaller grant size. The greater and more visible support from the administration at UBC may also have been a factor.

Evaluation and Funding of Proposals

Once proposals were received, care had to be taken in evaluating them. Then key decisions had to be made regarding the timing and size of grants. It was important to allow for faculty incentives as part of the proposal. Each of these points is discussed below.

Evaluation of Proposals

Because it would take time for departments to figure out the specifics of such a novel effort, the initial funding decisions were made primarily on the basis of how much commitment and general buy-in was indicated. This

primarily involved getting a general sense of the department's overall level of commitment, as conveyed in the proposal, and the structures in place for overseeing undergraduate education and its improvement.

Early experience showed that the text of the early proposals per se was not a good indicator, particularly with regard to a department's general sentiments or the functioning of departmental structures. There was often a serious disconnect between the broad commitments expressed in the proposals and what was actually done to fulfill those commitments once funding was provided. As noted above, judgments based on the proposals were more accurate when there were more specifics, such as milestones and timelines and individual faculty names attached to the work to be carried out, and so the requirements for such details were added to the later calls for proposals.

As discussed later in this chapter and in Chapter 6, the organizational structures within a department and the abilities of the people filling the necessary management roles were very large factors in the degree of success of each department's SEI efforts. These turned out to be difficult to evaluate from a proposal alone. Requiring the proposal to explicitly state which individuals would be responsible for filling these roles, and then carrying out a separate evaluation of the commitment and competence of those individuals, proved to be the most accurate means of judging which departments were most likely to be successful.

Timing and Size of Grants

Departments were in very different places initially with regard to both their size and their ability to plan and carry through on a proposal, and so the starting time, duration, and size of the grants were adjusted accordingly. The original design goal was to fund five departments at UBC at a level of \$2 million each. The \$2 million figure was based on the scale of investment described in the organizational change literature as necessary to bring about major change within an organization, and it was also consistent with estimates of the costs needed to transform all the regular undergraduate courses offered by a large science department. The planned funding level per department at Colorado was \$1 million. That was an imprecise decision based on the amount of money available; the value of sending a clear message that while not all proposals would be funded, it was highly probable that a department would be funded if it made a serious effort; and the estimate that

there were roughly that number of departments capable of tackling major improvements in teaching.

At CU, four departments were funded in 2006 at about \$800,000 each. Although it would have been possible to fund an additional department, it was felt that the remaining proposals did not show a sufficient level of commitment. In the majority of cases, the most serious problem with the proposals was an explicit statement to the effect that “We will invest time and money in transforming these courses for the better, but if any faculty who are teaching them wish to ignore these changes and teach a different way, they will be allowed to do so.” These statements were put into the departments’ proposals in response to opposition from faculty members. Later, three other departments were funded at a lower level, and with lower expectations as to the extent of the transformation. The seven funded departments included the Department of Molecular, Cellular, and Developmental Biology (MCDB) (2006–2011, extension 2011–2013); Integrative Physiology (2006–2012); Geological Sciences (2006–2011); Chemistry (2006–2011); Physics (2007–2011, extension 2011–2013); Astrophysical and Planetary Sciences (2011–2013); and Ecology and Evolutionary Biology (2011–2015).

Although the CU call for proposals had offered the possibility of somewhat larger grants, upon reviewing the proposed budgets I realized that the departments were unable to find productive ways to spend more than \$800,000, often because of the limited number of faculty who were willing to be involved in course transformations.

At UBC, there was more variation in the starting point of the various departments, and so there was a decision to have multiple rounds of proposals and funding. The earth, ocean, and atmospheric sciences (EOAS) department and the UBC biology program, were funded in 2007 for large-scale change. In other departments, pilot projects were funded to sustain the momentum begun with the proposal development process and to encourage them to develop stronger proposals for the second round of funding. Most of these pilot grants targeted individual courses, with the hope that such efforts would lead to more specific and realistic proposals for larger-scale funding. Specific feedback was given as to what was needed to strengthen their proposals—usually this involved making more specific commitments about who would be responsible for doing what when, and developing plans for changes that would be more widespread than first proposed. In most cases, this structure led to more successful large-scale proposals in later years.

Table 3.1. SEI funding levels by UBC department

Department	Funding level (\$ M)
Earth, Ocean, and Atmospheric Sciences	1.6
Biology	1.8
Physics and Astronomy	1.7
Computer Science	1.3
Mathematics	1.5
Chemistry	0.7
Statistics	0.3

Similar to CU, departments at UBC seldom came up with credible budgets for spending the full amount that was possible. The departments and their total funding levels are listed in Table 3.1.

The original intent was for the SEI grants to have a five-year duration—sufficient time to transform the courses, but a clear signal that this was a limited-time intervention. As the program began, it became obvious that it would take nearly a year after the funding commitment for serious course transformations to begin. That time was needed to hire and provide at least preliminary training to SESs and to decide on courses to transform and plan what would be done with them. During this ramp-up year, little funding was needed. Based on this, it worked best to operate on a six- or seven-year budget plan: a planning year with little expenditure, five years of full funding and activity, and a final “cleanup” year with low funding, when materials and results are archived and there is a graceful transition to teaching the transformed courses without SEI funding.

In reality, the ramp-up and ramp-down times and levels of activity in a given year varied widely across departments, depending on availability of SESs, faculty teaching assignments and leaves, and other factors. It was best to insist on sustained progress, but to exercise flexibility with regard to detailed schedules.

Allowance for Faculty Incentives as Part of the Proposal

One of the reasons that departments had trouble initially finding ways to spend the full amounts of money that were potentially available was that we discouraged spending substantial funds on direct incentives to faculty to participate in SEI activities, such as reducing teaching loads or buy-outs.

In retrospect, it was a mistake to discourage such direct financial incentives to faculty, and that policy was later changed. As discussed in Chapter 6, the SEI experience demonstrated that the formal incentive system of the institution provides a very strong disincentive to spend time on teaching. Direct incentives to faculty are necessary to counter this inherent disincentive. We initially believed that the amount of flexible money provided by the SEI to departments would provide sufficient incentives to individual faculty members through perceived indirect benefits, but that was not the case. As noted in Chapters 5 and 6, direct incentives to faculty members, such as a reduced teaching course load for a limited time, or summer salary, worked well when handled properly, but to be effective they required specific agreements in terms of deliverables, timetable, and working arrangements with SESs.

Hiring and Use of Science Education Specialists

All departments began by hiring SESs and, with the exception of one department, all incorporated them as critical components of the course transformation effort. Although the number varied according to funding, at Colorado there were typically two or three SESs per department, while at UBC there were typically three or four per fully funded department. Smaller and correspondingly lower-funded departments had as few as one, although having at least two in a department worked better than having only one.

The SES was a new type of position within an academic department, conceived to specifically fill the needs discussed in Chapter 2 of expertise in teaching and learning in the specific science disciplines. As discussed in detail in Chapter 4, the SES worked collaboratively with the faculty member in this course transformation process, and often established collaborations between faculty members. This reduced the energy and initiative required on the part of the individual faculty member, and hence reduced the barrier to change. Having the faculty member and SES working together to transform a particular course according to the SEI model provided a focus for the work that touched on all aspects of the teaching enterprise. The expectation was that such thoughtfully developed courses could then also be readily reused, making teaching both more effective and more efficient.

There was some background for this particular design. A few years before launching the SEIs, I hired Kathy Perkins and together we carried out transformations of two quite different courses following the approach

discussed in the “Course Transformations” section of this chapter. This test confirmed that a new PhD in science with an interest in education could develop the necessary mastery of teaching and learning within a period of several intense months, and could then play a major role in creating and implementing courses close to the ideal described. The materials for these courses were then archived and were subsequently passed along and reused with little change over several years through multiple instructors as a matter of tradition (rather than as a result of formal departmental oversight). Both of these courses used large amounts of active learning.

All aspects of the SES work, including hiring, training, supervision, and the jobs they carry out, are discussed in Chapter 4.

Departmental Organization for Managing SEI Efforts

It was challenging for most departments to organize and operate the SEI efforts. No suitable organizational structure existed for such work, nor was there local expertise as to how to make such an enterprise successful. Existing structures, such as the undergraduate course committee (often called the curriculum committee), are inherently reactive and so were ill suited to the task. Thus, over time, I put more requirements in place for structures to be established before funding was provided, based on structures that had worked well in successful departments.

In well-functioning departments, there was a SEI department director appointed to oversee the SEI activities. This person had clear authority, including hiring and supervising the SESs. The SEI department director's duties included:

- Overseeing the hiring of the SESs
- Determining how the SEI money would be spent
- Supervising the SESs (that is, SESs reported to the department director)
- Establishing the job expectations and requirements, including deciding which courses and faculty members the SESs would work with
- Establishing the working arrangements between SESs and faculty members
- Intervening when problems arose (such as with faculty members not fulfilling commitments with regard to collaborating with the SES)

- Meeting regularly with the department chair to report on activities (the chair arranged for regular reports to the department about the SEI work and accomplishments in faculty meetings and other venues)
- Arranging any faculty incentives supported by SEI funds, usually in conjunction with the department chair
- Under ideal circumstances, having some input into teaching assignments (but in no case did the SEI department directors have as much influence in this area as they would have liked)

The structure by itself was not entirely sufficient; how well the department directors functioned and were supported within the department made a large difference in how successful the SEI efforts were. When a department was funded (or under serious consideration for funding), SEI Central would sit down with the department chair and work out exactly how this necessary organizational structure would be established within the department and who would be the director. In one department, funding did not go through when it became apparent that no one in the department was willing to serve as the SEI director. This was a sign that the department did not see this as a sufficient priority.

When the department did not establish the chain of command as described above, typically the SESs would view SEI Central as their supervisor, and would come to SEI Central when they experienced problems working with faculty. This was a bad situation, because it was difficult for SEI Central to deal with problems within departments, and trying to address such problems made the SEI appear as a program that was being pushed on the department, rather than something the department was responsible for and invested in.

Course Transformations

This section describes the implementation of an extensive course transformation involving an SES and faculty. The heart of the SEI was the process of course transformation, in which an SES worked with faculty members to transform courses, and simultaneously the teaching methods of the faculty, according to the SEI principles. Typically, one SES would work with a sequence of faculty members to transform a sequence of courses. The details of scheduling and sequence varied substantially with department and

courses, but a typical situation was an SES working simultaneously on three courses: the pre-transformation planning stage for one course, the full transformation of an ongoing course, and follow-up, refinement, data collection, and analysis of a second iteration of a transformed course. The bulk of their time would be spent on the full-transformation course. For large and complex courses, it was not unusual for the full transformation stage to require more than one iteration of the course, with new elements and activities phased in and/or modified over multiple offerings of the course. The SES collaborated heavily with the faculty member during each step of the course transformation, taking on many of the labor-intensive duties that teaching faculty did not have the available time or expertise to attend to. In Chapter 4 I go into more detail about how the specific and rather unique elements of the job of SES contributed to the course transformation.

In a few cases, a small working group of faculty would come together to oversee the transformation of a course. At times that model worked well, with useful contributions from and interactions between multiple faculty members, and the resulting course goals and design gaining elevated stature within the department. Frequently, it was less successful, with only one or two faculty feeling it was worth their time to be involved. In some other cases, working groups were organized but functioned badly because one or a few faculty members in the working group were serious impediments to accomplishing anything, either through active opposition or simply because of their failure to fulfill agreed-upon responsibilities. In most cases, the SES still worked quite productively with a single faculty member to carry out the desired course transformation.

Typical Course Development Cycle

Below I discuss the ideal process for developing a course. However, the degree to which this cycle was followed varied considerably, primarily affected by the desires of the faculty involved and to some extent the departmental management of SEI efforts. It was not unusual for the order of steps to be changed or some steps entirely left out. Also, in some cases the SES worked more as a consultant to many faculty members in the department in regard to making incremental changes, rather than focusing on transforming a specific course(s). In that role the SES would provide advice on instructional activities that a faculty member decided to add to a course they were teaching. The model of full course

transformation was preferable, as it seemed to generally result in a higher-quality product, but there was flexibility to pursue all possible opportunities for adoption of improved instructional practices. In most cases, over time the SES took on both roles, working with individual faculty to transform specific courses while serving as a consultant to much of the department.

Outlining the Project Scope

An essential first step was for the SES and faculty member(s) involved to agree on what the project was to accomplish, and the respective responsibilities and expectations. In practice, few course transformations proceeded by working through the eight steps in Table 3.2 in a smooth orderly manner, and various different weightings were given to the three elements of establishing goals, assessments, and teaching methods. Although there was a large amount of variation in the process, often the SES would start by discussing with the faculty member(s) any issues or problems involving the course in question. The SES would then investigate and propose possible directions and activities to address the most salient problems, and then, as the relationship developed, build from there to try to address all seven steps of the course transformation in whatever order the faculty member found preferable. In particular, starting with learning goals turned out to be a problem with many faculty members; it was just too difficult for them. They had an easier time starting with what student difficulties they wanted to address, what sorts of activities and assessments they wanted to use, and what material to cover and why. After becoming immersed in those issues and establishing greater interaction with students through the use of more interactive teaching methods, they then had an easier time articulating learning goals for the course.

However, when it was possible to work through the eight steps in an orderly manner, the results were usually best, so the implementation is discussed in that order.

Developing Learning Goals

Learning goals define what a student should be able to do as a result of learning the material. Both course-level learning goals and topic-level learning goals were typically developed. Approximately five to ten

Table 3.2. Central features of course transformation planning

Steps	Description	Tasks
Project scope	What do we want to accomplish?	Meetings—establish deliverables and timelines
Course- and topic-level learning goals	What do we want students to learn (for example, content, skills, habits of mind, attitudes)?	Meetings, create, review
Document student thinking	How do students think about the material of the course, and what do they know coming in?	<ul style="list-style-type: none"> • Do literature review • Observe course before and after transformation • Interview students
Teaching methods	How will we help them learn the material?	<ul style="list-style-type: none"> • Create course materials and activities that target learning goals, consistent with research • Select teaching practices and course structures best suited to material, constraints, and faculty desires
Assessment	How do we know if students achieved the learning goals?	<ul style="list-style-type: none"> • Exams, conceptual assessments, homework • Pre-/post-course surveys • Student interviews
Materials archived	How will others find/use what we've done?	Organize materials locally and online
Plan for sustainability	How to support adoption and/or adaptation of course materials and methods by others?	Interact with faculty and administrators prior to and following transformation; implement support and transition strategies, such as co-teaching

course-level learning goals were created, which were broad and not necessarily related to particular course content (for example, “students should be able to simplify real-world problems in terms of basic physics concepts”). For each topic, several learning goals were developed that were more specific and represented a concrete step toward achieving a course-level goal (such as “students should be able to construct a free-body diagram depicting the forces on an object”).

Learning goals are more specific than a listing of topics. All learning goals needed to be operationalized so that their accomplishment (or not) was *measurable*. It was very common for goals to be proposed that were too general or vague so that it was unclear how students would demonstrate that they had successfully achieved that goal. For instance, the initial attempt to produce learning goals commonly included “Students should understand . . . [various topics].” Such goals would then need to be rewritten, since two faculty members could have very different ideas of what “understand” means in the context of the course. These goals were rewritten in terms of what students would be able to do if they understood the topic or concept at the desired level.³

Assessing Student Thinking and Learning

The SEI process for assessing student learning typically began by soliciting input from faculty who had previously taught the course and faculty who had taught students in subsequent courses, in order to identify student weaknesses. Next came consultation of the discipline-based education research related to the course material and an examination of student performance on exams, both the standard course exams and, where available, validated third-party tests covering the material. Finally, there were student interviews, both formal and informal, on the course material. Frequently, the course exams were modified as a result of this process to better target the goals that were arrived at. A detailed description of investigation of student difficulties in the CU Physics Department that was part of an independently supported research project (and hence was more extensive than many other SEI efforts) is described in work by Chasteen et al.⁴

Creating Course Materials and Implementing the Instruction

There are many models of how to create course materials, but the most important thing is that the course be aligned with the established learning goals and that the materials provide practice and guiding feedback to the students, informed by known student learning difficulties. Specific strategies and teaching techniques of the sort that were used are discussed in Chapter 2 and the references given there. The SEs were trained in the use of these techniques, as well as with the education research literature, so that they would be able to provide insight and guidance on possible teaching

options. They would collaborate with the faculty member to apply this knowledge to the specific material and learning goals to be covered. Often there were a number of research-based teaching methods that could be used in a given context, and it usually wasn't obvious whether one specific method would be more effective than the others. The choice of which method to use was often determined by the faculty member's interest in or comfort with a specific method.

While each individual case was different, a common path for an instructor was to proceed incrementally, starting with modest changes and then building on those changes. The change to standard lecturing that was usually easiest to start with was introducing questions to students into the middle of lecture, followed by student-student discussion. Usually this was in the form of "clicker questions" and "peer instruction" or "think-pair-share."⁵ These were good initial steps in transforming instruction, as they involved relatively small changes by the instructor, but they provided opportunities for greater interaction between instructor and students, which would typically result in instructors making further changes as they better understood student thinking and saw improved student engagement. Other relatively readily adopted new teaching methods included in-class worksheets, placing TAs in large lectures to facilitate group discussions, two-stage exams, concept mapping, learning to circulate among students and listen to conversations about activities, and providing learning goals to students before and during class. SEI Central worked with the SESs to develop short (one- or two-page) guides for faculty on optimal implementation of these and other commonly adopted teaching methods. These were posted on the CWSEI website (www.cwsei.ubc.ca/resources/instructor_guidance.htm), and many are included in Appendix 1.

Sometimes these new teaching methods would first be demonstrated in the course by the SES while the faculty member observed. Somewhat more frequently, the SES would only provide coaching and guidance to the faculty member as he or she implemented the methods. The SES would typically observe most classes during the first implementation of a transformed course, providing assistance as needed and feedback to the instructor after each class. As there are countless ways to do most any teaching method incorrectly, a critical role of the SES was to know the principles of learning that lay behind specific techniques and the specific elements of implementation that could help and hinder the effectiveness of that technique, and then pass those along to the instructor.

This knowledge and its effective transmission were an important part of the SES training.

Assessing Course Outcomes

Another aspect of scholarly course transformation is the use of assessment data to allow for reflection and iterative improvement upon the transformed course. As discussed in Chapter 5, the type and extent of outcome assessments varied wildly and was generally less than desired. Among the choices were common or similar exam questions or other student work, such as clicker questions or homework, compared across years; instructor-independent measures, such as concept inventories, used to test students on content mastery; diagnostics and performance in subsequent courses; ability to answer more difficult exam questions than in previous years; student interviews; and classroom observations, usually using the Classroom Observation Protocol for Undergraduate STEM (COPUS).⁶ In too many cases little assessment of the course was carried out beyond the instructor's impressions. Although the data were limited and varied in type, in virtually all cases where data were available, they showed improved results in the transformed cases.

Dealing with Faculty Teaching Rotation

There are very different policies about the rotation of faculty through courses, depending on both the department and the level of the course. It was difficult and inefficient to transform courses in which different faculty members rotated through too frequently, and also difficult when there was too little rotation. In the case of frequent rotations, a faculty member might teach a particular course intermittently a few times over a period of several years or teach the course for a couple of years and then move on to an entirely different course. In these cases, it was very difficult to work with an individual faculty member on transformation of that course, because (1) the faculty member who helped develop the transformed course materials might not teach the course again soon, and (2) an individual faculty member might not have a great deal of incentive to invest the kind of time required to transform a course because he or she would not benefit from the effort.

Too frequent faculty rotation remained a nagging problem for the SEI.⁷ However, a few approaches have been helpful in reducing the problem. I

pressed the departments to have a faculty member teach the transformed course multiple (typically 3 to 4) times, and/or for faculty who are experienced with active learning to teach the course subsequent to the transformation. I encouraged the departments to partner the SES with multiple faculty members in succession in the course, both to transform the course and support new faculty members in teaching it. Finally, I insisted on the departments setting expectations that the SESs would create well-organized, easy-to-use course archives and give faculty members new to the course an introduction to this archive. When there was little or no rotation of faculty through courses, each course was essentially seen to be “owned” by a faculty member, with the teaching and topics entirely a matter of that person’s individual choice. As discussed in the “Barriers to Change” section of Chapter 6, this made changing the teaching of such courses quite difficult.

Co-Teaching

An alternate approach to preserving the benefits of a transformed course and transforming the teaching of faculty members was to have another faculty member co-teach a transformed course with the instructor who had carried out the transformation. These arrangements worked best when the two instructors truly worked as a team (rather than trading off course duties), including planning the course together, coming to most classes, and jointly developing exams. A variation on this model was to partner an SES as a co-teacher with a faculty member who was new (or relatively new) to the course.

While only a select group of faculty participated in such co-teaching programs, they were almost all highly successful. New faculty members reported that they spent less time on teaching preparation than many of their junior colleagues, and they quickly became highly effective teachers—in some cases, among the best in the department. Established faculty members who took advantage of co-teaching reported that they greatly enjoyed the experience and learned a great deal from observing their colleagues teach—something that is usually rare in a department. As a result of such successes, and to support sustainability of better teaching methods, external funding has been obtained at UBC to establish a long-term program of such co-teaching in some departments for the purposes of faculty development.

SEI Central Oversight

SEI Central served three basic purposes. First, it was an engaged funding agent participating in the development of proposals and making funding decisions. Second, it provided oversight of the departmental activities and gave feedback, particularly on how to improve the results. Third, it served as a trainer of SEEs. That training also included providing substantial individual guidance to the SEEs on both pedagogical issues and on effectively working with faculty and dealing with difficulties in the department.

Administrative Role

SEI Central played an important administrative role, taking on responsibilities that would not have been supported by departmental structures. As such, SEI Central required some funding, employing a director and/or associate director and administrative staff. At UBC this consisted of two or three FTEs in the earlier years, and one FTE in the final years.

SEI Central responsibilities included:

- Soliciting and reviewing proposals
- Administration and oversight of funding and budgets
- Advising on hiring of SEEs
- Training of SEEs
- Assisting SEEs with design and analysis of interventions and assessment, and with writing up and publishing of education research papers
- Support of SEE community (planning of regular meetings, providing information, and participating in discussions on SEE forums)
- Monthly meetings with each departmental SEE team (the SEE department director and SEEs)
- Quarterly meetings with the group of SEE department directors and the associate dean
- Soliciting and providing feedback on annual reports from departments
- Running an annual SEE mini-conference with presentations and posters
- Website maintenance, including course materials archive
- Collaboration with other institutions

Training Science Education Specialists

As no new SES had the preparation needed to serve in the role effectively, and neither the departments nor the universities' centers for teaching and learning had the knowledge or capacity to train the SES, this training was one of the most important jobs of SEI Central. The details of the training are discussed in Chapter 4.

Annual SEI Mini-Conference Events

Annual half- to full-day gatherings served to celebrate and show off SEI accomplishments, as well as support a community engaged in educational work. These events featured talks by a mixture of faculty and SESs, poster sessions, lunch, and workshops on various aspects of science teaching. These were intended to serve as an important dissemination and recruitment tool, attracting many faculty from both participating and nonparticipating departments to learn about the SEI activities within their departments and elsewhere. Unfortunately, few faculty attended these events who were not already directly involved in SEI activities. However, it did serve as a good way for participating faculty, SESs, and graduate students from across the SEI departments to learn what others were doing and generate a sense of being part of a large and vibrant program. At UBC, the dean and associate deans were always prominent attendees, demonstrating their support for the SEI. These annual events also attracted a number of visitors from other institutions, coming to learn more about the SEI. The poster sessions proved to be particularly lively and well attended. Sample materials and an agenda from such a conference are available at www.cwsei.ubc.ca/EOYevent2014.html.

Central Resources and Website

At UBC, SEI Central took responsibility for developing an extensive website providing resources for faculty, SESs, and the outside world (www.cwsei.ubc.ca). This includes detailed information on how to carry out course transformations, specific topics in teaching and learning, SEI publications and presentations, instructional videos, videos showing instructors and students in transformed courses, and other material. A small SEI library is also maintained, with about twenty particularly valuable reference books available to SESs and faculty working with them.

To facilitate the transfer of courses, a fairly elaborate online system was constructed that allowed materials to be easily archived and accessed. This was more difficult and expensive than anticipated for a variety of reasons. While an extensive survey of user needs was administered when designing the system, later on when it came time to use it, users wanted different capabilities, and different departments and individuals had strong opinions about specific details. Materials for some transformed courses were posted on the website, but it was disappointing that full sets of materials were posted for only a small fraction of the transformed courses. One of the reasons that many departments have been exploring the hiring of someone to an SES position on a permanent basis is to facilitate archiving and dissemination of materials, as they have found it very difficult to get faculty members to do this.

Program Oversight by SEI Central

As noted above, closer oversight of departments was needed than initially expected. Progress was monitored through a combination of inputs. First, written summaries from the SESs were required (every two weeks in the early years, monthly in later years) on what they had accomplished. Frequent individual meetings were also instituted with SESs, particularly when they were encountering problems.

Typical problems encountered by SESs included difficulties working with a faculty member, figuring out how to juggle multiple priorities, and carrying out research (for example, trying to define research questions or produce publications). Problems of the first type were the most common and most serious. In the early years, it was quite routine for a department to assign the SES to work on a course, but the faculty member teaching that course had no interest in being involved, and no one in the department could or would intervene. Alternatively, the faculty member with whom the SES was to work was nominally agreeable to the collaboration, but then in practice would not cooperate. For example, the faculty member might always be too busy to meet with the SES or provide them with the course materials, or would only send lectures or activities to the SES for review and feedback just before class. Occasionally SESs would be working on a course in which multiple instructors were involved who had fundamentally different goals for the course, which meant that the SES was caught between opposing views and unable to make progress. SEI Central played an

important role in helping to advise SESs on such challenges, and over time, we learned how to manage and avoid problems like these. The main improvements were to get departments, primarily through the SEI department director, to be more proactive in avoiding such problems and providing support and guidance to the SES early as problems started to arise. (See Chapter 5.)

When things were working well, each report from the SES would provide a new list of changes made in courses or new assessments of student learning and difficulties. Thus it was very easy to see progress, and correspondingly easy to see when there were problems. Although poor progress was most commonly due to SESs being assigned to work with faculty who were uncooperative or did not understand the expectations, there were times when the problem lay with the SES. When we became aware of a potential problem, we would meet with the SEI department director to better understand the source of the problem and figure out steps to deal with it. Such issues were much easier to deal with in departments where there was a department director who clearly understood that this was part of the job and had the authority to address the problem, whatever the source.

Monthly meetings with departmental SEI teams (the SEI department director, all SESs, and others, including graduate students and undergraduates hired temporarily) were very useful to review progress and plans. These were the primary opportunities for SEI Central to provide feedback to the department on its progress and to provide input on proposed directions.

There were also quarterly meetings with the SEI department directors and, at UBC only, the associate dean and occasionally other members of the university administration. These meetings allowed departments to share various practices and approaches, such as the most successful ways of incentivizing faculty and ensuring good working relationships between SES and faculty.

When there were serious concerns about lack of progress in a department or special problems, we would meet with the chair. Usually, but not always, this was at our request.

The most extreme element of oversight was terminating funding for a department. In the two cases where it was first proposed and then carried out, this served more to avoid wasting money than to bring about changed behavior in response to the threat of termination. This was an indication of a flaw in the initial SEI implementation design. More funding should have been allocated to direct incentives to the faculty, so that the threat of losing that funding would have been more of a concern. Instead, where termination

became a possibility, essentially all of the department's SEI funds were going into SESs rather than any other departmental support. Because the lack of progress stemmed from the unwillingness of the faculty to work on changing teaching, with or without the assistance of an SES, the loss of funds, and hence the loss of the SESs, was unimportant to them. This lack of priority placed on maintaining the SES was clear when I talked with the respective department chairs about the possibility of termination.

When termination of funding became necessary, we worked out with the SESs the timing and conditions for their graceful exit, and simply did not provide funding to the departments for their replacement. In one of the cases where funding was terminated (the UBC biology program), there was a subsequent change in department chairs and a major restructuring of the way the undergraduate program was run and overseen. With the new organizational structure and good people in positions of authority in that structure, the funding was then restarted, and there was good subsequent progress.

Challenges with Data Collection

As described in Chapter 1, my vision of the SEI was that it would be a step toward a data-driven education system, where educational data was routinely collected and used to improve outcomes. I had expected data to be regularly collected on student outcomes from courses (learning, attitudes about learning, and interest in subject) and instructional practices. I had also hoped to obtain data during the SEI on shifts in the departmental cultures, particularly the attitudes about teaching represented in those cultures.

The implementation of the SEI revealed a number of intrinsic challenges with collecting data on each of these outcomes. A substantial amount of data is presented in Chapter 5, but there was a large variation in the quality and quantity of data across the different outcome measures and institutions. Most of these difficulties were unexpected but in retrospect are understandable, as they are inherent in the structure and incentive systems of the institutions.

Challenges with Collecting Data on Student Learning and Attitudes

Originally, I thought this would be the most important outcome and straightforward to measure. In practice, it turned out to be quite difficult to track.

We were able to systematically collect these data in only a small fraction of the transformed courses in any department. The basic problem is the disincentive for individual faculty members and departments to collect data on student learning and other outcomes, particularly baseline data for courses and programs before they are transformed. This was not standard practice in any department, it takes work to collect these data, there is no benefit to the faculty member for doing it, and the results may reflect poorly on the faculty member and possibly the department as a whole. However, there are also a number of more specific issues encountered when trying to get such data, as discussed below.

First, one needs to get baseline data before a course is changed in order to determine the impact of any instructional changes, and there are numerous challenges in getting such baseline data. Generally, nothing exists except instructor-dependent measures, such as student performance on test questions created by the instructor. These tests tend to be highly idiosyncratic and usually of questionable validity, as instructors have no training in creating good tests and seldom get any feedback on the quality of their questions. So the instructor exam data are often unsuitable to serve as a baseline.

In a small number of cases where the course topics have been the subject of discipline-based education research, there are independent tests that have been developed to target the mastery of particular topics covered in a course. When such tests exist, they are very useful to use on a pre- and post-course basis to measure learning, but typically there is considerable instructor opposition to the use of such tests in untransformed courses, making it hard to get baseline data. Those instructors were usually quite resistant to allow such outside measures of their students' learning to be carried out, either because they felt threatened by the process or because they believed it to be a poor use of class time.

Even if the instructor in a course was supporting the future transformation, it could be difficult or impossible to get meaningful baseline data. Usually a good assessment, such as what would be produced by an SES in consultation with course instructors and SEI Central, is developed only while the course is being transformed, so there is no longer a traditionally taught course available to use as a comparison. Instructors who are interested in changing a course do not want to continue teaching the course without change for a year just to get baseline data. Finally, as instructors learn new and better ways to teach, they usually end up modifying (and improving) their

learning objectives and test questions. As a result, data they may have on student performance prior to the transformation, such as answers to exam questions, often no longer apply, because instructors no longer feel that such questions are appropriate to use after the transformation. In spite of these challenges, for roughly 10 percent of the transformed courses at the two institutions there have been common (or quite similar) good exam problems or instructor independent measures that are given year after year and can be used for comparison.

Another issue that arises in interpreting data provided by graded exams in courses involves departmental expectations around grading and failure rates. In several cases in which students' performance on similar exam questions improved as the result of changes in teaching methods, the instructors (often in response to pressure from their department) increased the difficulty of the exams, to have the grade distribution match departmental norms (for example, a B average). Thus, measures such as student grades and failure rates may be kept constant or may vary idiosyncratically with the instructor, independent of the student performance in any objective sense. Thus, I learned that student course grades seldom provided a meaningful comparison of the amount of student learning achieved with different teaching methods.

I was also interested in the impact of the transformed courses on students' attitudes as another measure of success. Did the course increase or decrease students' interest in the subject and/or their desire to pursue a career in the discipline? How did it impact their views about learning the subject and the best ways for them to learn? There are validated survey instruments suitable for measuring some of these attitudes,⁸ and in other cases non-validated questions (such as "Did this course increase your interest in taking another course in the discipline?") seem adequate. However, collecting such data from courses still proved difficult. If students are given such a survey during class and asked to fill it out, they usually will comply. Yet, few instructors were willing to use class time for this purpose. Most students are unwilling to take the time to complete such surveys outside of class, unless they are given a small amount of course credit for doing so, but the majority of instructors are not willing to allow course credit for this. As a result, although there are some encouraging hints that course transformations improve student attitudes toward the subject and learning, there were few courses in which the survey completion rates were high enough to provide confident results.

Confusion over Human Subjects Research Rules

A unique barrier to collecting data on educational outcomes came from some administrators, faculty, and lawyers at these two institutions who misunderstood the rules regarding human subjects research at universities. (The rules in Canada and the United States were basically the same.) I discuss this as the same issue may well be a problem for readers who wish to collect similar data at their own institutions. I encountered this at both institutions, but with some considerable investment of time and effort eventually overcame this particular problem at UBC.

The idea that rigorous assessment of the learning in courses, and hence the effectiveness of teaching, could be carried out and disseminated without being treated as human subjects research was not an accepted concept on either campus. Although there is a specific exemption within the federal human subjects research rules to cover evaluation of institutional quality for organizations such as educational institutions, few people at universities are aware of this exemption because such evaluations are so seldom done. Thus their first reaction was to treat any effort to collect data on student performance as falling within the category of individual curiosity-driven human subjects research. When treated as curiosity-driven research, such assessment of learning was thought to be subject to extensive paperwork, institutional review board (IRB) approval, and collection of signed student consent forms. This led to the bizarre initial stance of the respective IRBs saying it was completely up to the faculty what teaching methods they inflicted on students in classes, but if the SEI program wanted to measure what effect these practices had on students, that data collection would require a lengthy review and would be subject to written preapproval by students in order to avoid harming the students. The signed consent forms are a major burden, since they take a lot of time to collect and process, and students often fail to turn in the necessary forms and/or are understandably concerned and suspicious when consent forms filled with all the required legalese are presented to them.

Dealing with this issue of misinterpretation of the rules regarding human subjects and institutional research for quality improvement required a large investment of time on my part, including becoming the campus expert on the wording of the legal statutes and regulatory language on both human subjects research and student privacy statutes. The common standard set by many IRBs, which was initially invoked by IRBs at both CU and UBC,

was that any study producing data that might result in any form of publication is curiosity-driven human subjects research and requires IRB review and approval. Because it was important for both internal credibility and long-term career success that the SEEs be able to publish their work on documented instructional improvements, this standard posed a particular burden. There was a lengthy negotiation at UBC to deal with these issues, resulting in a clear delineation of institutional research versus traditional academic (“curiosity-driven”) research, and the establishment by the University Counsel of institutional policies governing the conduct of the SEEs and the faculty in SEI departments. Among other things, this led to a change in the UBC rule that anything involving publication required IRB approval.

I found that it was still important to have clear guidelines for SEEs and faculty working on SEI-supported projects as to which studies and data collection did and did not need to go through IRB review. It was fairly easy for SEEs or faculty to get so interested in an education research question that they would forget the special responsibility that goes with carrying out research in a real class that students are taking for their education. SEI Central or a suitable administrative person in the departments needed to briefly review all proposed studies to decide which might need IRB review and approval and which would not, and if the study would be raising any ethical issues.

The most common ethical concern that arose involved the establishment of a control group that was to receive traditional lecture instruction. I set the policy that it was unethical, and hence not allowed, for SEI involved personnel to establish such a control group on the grounds that they (or any reasonably informed person) had good reason to believe that students in the control group would be disadvantaged. This was true even if the control group was to receive instruction that is consistent with common teaching practice and many research studies. On several occasions, SEI Central pointed out that proposed studies by SEEs and/or faculty working on SEI activities that would have set up such a control group were not appropriate. On the other hand, when there was a faculty member who was going to teach using traditional lectures as part of his or her regular course instruction over which the SEI had no control, irregardless if a study was to be carried out, then it was ethical for SEI personnel to use that class as a control group, as students would not be disadvantaged due to the actions of the SEI-supported people.

Table 3.3. A set of guidelines regarding human research subjects' questions

Type of research	Definition	Data collection and publication guidelines
Studies of effectiveness of normal instructional practices using existing or routinely gathered data	Practices that are commonly being used in university classrooms at the present time	Data collection (including subsequent publication where warranted) needs only minimal review by any person at the university in a relevant administrative role (SEI director or associate director, department chair, or SEI department director)
Studies of large-scale changes in courses using research-based practices and assessments in use elsewhere	Significant changes are being made in the teaching of a course, particularly using methods that are not in such common use, and so the potential impacts are larger	Studies of these sorts of changes are subject to the same type of approval as above, but there is closer examination of the potential benefits and risks to students in both intervention and control groups, and steps to reduce harm. For example, arrangements might be put in place to readjust student grades in one group if it turns out that the other approach is superior, resulting in significantly higher performance for some fraction of the student population on a common exam.
Non-course-specific educational research	Involves a selected subset of students in activities such as individual interviews about educational experiences transcending a particular course	For the sake of expediency, we went through the standard IRB review process to get a broad approval for such activities. These were still considered "exempt" by IRB standards (not requiring full-scale review), as they involved minimal risk but do require consent forms. Much of this work could have been categorized as institutional research, according to the definition provided by the UBC University Counsel.

For illustrative purposes, Table 3.3 lists the basic guidelines that I worked out with the UBC university counsel. (These are in my wording, which removes the legalese but makes them easier to understand.)

Challenges with Collecting Data on Shifts in Departmental Cultures

Data on the broader impacts of departmental attitudes and culture are quite limited. The primary difficulty with collecting good data on this topic is simply the expense. Done optimally, it requires an objective independent evaluator to carry out extensive interviews, surveys, and observations of faculty and departmental staff as they conduct their instructional work and departmental business. While it seemed ethical to use institutional funds—which were in very short supply—to support the SEI improvements in teaching that would benefit students and faculty at those two institutions, it did not seem appropriate to use those funds for collecting data on shifts in attitudes and cultures of the departments. That data would primarily benefit those in the outside world who might want to use the results of the SEI to launch and guide their own similar efforts, but the results would come too late to make an impact at UBC or CU. Repeated attempts to secure external funding to support such studies of institutional change were unsuccessful.

Nevertheless, to the extent that it was possible to do so with minimal cost to the SEI, some data were collected on departmental attitudes. SEI Central sampled those attitudes as well as it could through the review of SES reports and departmental discussions, interviews with SESs, faculty, and department administrators, and some surveys. On a limited basis, we also had external researchers come in and sample faculty and/or SES views. The extent of the data is better from UBC, because we put greater emphasis on regular meetings and written reports from the SESs and on more frequent and formal meetings with departments. In essentially all cases, the different sources of input were quite consistent, but for some CU departments there was less consistency and hence greater uncertainty as to the general attitudes and response within a department.

Challenges with Collecting Data on Teaching Practices

The collection of data on the teaching practices used in courses was not done on any scale at either institution before the SEI, and getting such data also

encountered challenges. However, these challenges were less of a problem than those discussed above. First, there was little need for collection of baseline data to determine changes, because it was so unusual for a faculty member to use anything besides traditional lecture and recitation practices. Typically, if anyone was incorporating research-based methods, it was a well-known anomaly in the department. Second, the adoption of new teaching practices was so central to the SEI activities that by monitoring the activities of the SESs, the courses they were transforming, and the faculty they were working with, we could get reasonable data on the teaching methods used in various courses and the changes that had been made. As noted earlier, the more regular and detailed reporting by the SESs and departments at UBC compared to CU provided us with more complete and reliable UBC data. The annual departmental SEI reports required at UBC as to courses transformed, changes made in those courses, and faculty involved in those changes, were particularly useful.

Substantial effort was also put into developing tools that could be used by departments for routinely monitoring teaching practices. The COPUS (Classroom Observation Protocol for Undergraduate STEM)⁹ was an easily used observation guide for characterizing how the students and the instructors were spending their time during class. Various SEI departments are using the COPUS in characterizing and offering guidance to their instructors, and it is now also being used widely outside UBC and CU. Sarah Gilbert and I, in collaboration with numerous SESs, also developed the Teaching Practices Inventory (TPI).¹⁰ The TPI is a survey usually filled out by instructors that takes about ten minutes and provides a detailed characterization of all aspects of how a course is taught. It provides extensive and complete data on the teaching practices used in a course, so in any course for which it was used, we have detailed data on the teaching practices.

However, there were institutional challenges in getting faculty to fill out the TPI. Although we hoped that many departments would make this part of their regular annual reports by faculty because it provided so much more information about teaching than they had been collecting, this did not happen. At UBC there was sufficient financial leverage to get most departments to put in a reasonable effort to get their faculty to complete the survey on a one-time basis, and one department (EOAS) had most of its faculty complete it at both the beginning and near the end of their SEI funding. At CU, after negotiation, the dean urged the science department chairs to ask their faculty to fill out the survey. Only a few chairs did so, and in those

departments only a few faculty completed it, so no useful information was provided. Data on teaching practices at CU came primarily from SES reports and surveys and interviews SEI Central did with the faculty. These were less detailed and complete than the data from UBC.

These difficulties with the collection of data reveal how large a shift will be required in institutional and departmental cultures before routine data-driven educational improvement becomes the norm. The data that was collected on student outcomes, departmental culture, and teaching practices, and how these varied across the SEI departments, is presented in Chapter 5.

Common Obstacles and Desirable Elements for Successful Implementation

There was a complex range of factors acting at various levels to both enhance and inhibit the success of the departmental SEI efforts. Although every department had its own unique characteristics, there are many things that were consistent across departments, both in what worked and what caused things to fail. These are discussed in Chapter 6. Here I briefly list the most prominent obstacles and elements of successful departments encountered during SEI implementation efforts.

The first common obstacle was a lack of faculty commitment to the proposed work. When it came time for individual faculty to do the work called for in the departmental proposal, some of them refused. The willingness of new chairs to live up to the commitments of previous chairs was also a problem at CU.

Second, individual faculty “ownership” of courses was a common issue. The belief that no one else in a department could or should tell an instructor what or how to teach in a course assigned to that person was an ongoing challenge to SEI efforts. The strength of this belief varied across departments for no apparent reason other than tradition. On many occasions, department chairs and SEI department directors appealed to me to get faculty members to change how they were teaching, indicating that the department recognized that what a faculty member was doing was relatively ineffective but did not see itself as having the authority to tell the offending individual to change.

Another common obstacle can be put under the heading of “thoughtless teaching assignments.” Some departments had a tradition of making last-

minute, haphazard teaching assignments. This was a major problem for the SEI course transformations, which required consistent planning and implementation over several semesters. Temporary sessional instructors who were hired at the last minute to teach a course for a single semester were a particularly serious problem.

As already discussed, an obstacle consistently encountered was the lack of departmental structures to oversee educational innovation, such as the SEI.

A final unanticipated obstacle was the existence of courses taught in multiple sections by multiple instructors. As discussed in Chapter 6, this is a complex issue that has many local variations. Surprisingly, most such courses were historically operated in such a way that the individual instructors, many of which were long-term non-tenure-track instructional faculty, were largely free to do what they wanted with very little oversight or coordination. In these cases, transforming the courses proved to be quite difficult. As many departments recognized there were problems with these courses, they assigned SESs to work on improving the courses, but without the agreement of the instructors. As a result, considerable SEI funding was spent on these courses with modest results.