NEW DIRECTIONS FOR HIGHER EDUCATION

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Building Robust Learning Environments in Undergraduate Science, Technology, Engineering, and Mathematics

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PART FOUR

The Perspectives of Leadership

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Systemic reform of undergraduate science and mathematics education requires that faculty innovators and administrative leaders work together.

The Variables of Positive Change

Daniel F. Sullivan

Systemic change requires an institutionwide strategy. What distinguishes efforts at institutionwide reform from course and curriculum development, which is also important, is that this reform is about systemic change, and systemic change requires an institutional strategy. Systems are groups of variables linked together organically. The links are not simple linear, sequential, cause-and-effect relationships. There are positive and negative feedback loops, and the system is dynamic. (It is clear where the kaleidoscope metaphor within Project Kaleidoscope came.)

One must come to think of one's own institution as a system. A strategy for systemic change must involve all the relevant institutional variables, and all or most of them must be in play pretty much from the start. Sometimes it feels like pushing several large rocks up hill simultaneously, and it is.

In addition, local opportunities and barriers matter a great deal; the local details, in fact, are critical. Building on successful models from other institutions is helpful and necessary, but science education reform always involves local adaptations of more general strategies, not simply the dissemination of packets of success from one institution to another. Communication and sharing are critical, especially at the level of strategy and exemplification, but no institution can acquire a module from elsewhere and just install it. It has to adapt what it sees working elsewhere to its particular circumstances or invent solutions, in partnership with faculty and others on campus. Local resource constraints and historic commitments require different trade-offs from one institution to another, and the details of campuswide politics introduce other opportunities and constraints. However, it should be noted that most common problems are being addressed somewhere and that the most expeditious and cost-effective approaches over the long term are to identify, build on, and adapt reforms initiated in other settings.

Systemic change takes time. The institutions I know that are making the most progress have been at it for a long time. A significant increment of change can take five to ten years precisely because many variables must be in play simultaneously. The system itself is complex.

Institutional strategies should build on existing strengths and involve faculty and administrative partnership. Systemic change is most possible when there is a strategic science or mathematics education strength in the institution that can be built on. In all institutions I have visited, ranging from those with the highest reputations to those that are struggling, I met at least some faculty who understood how to do undergraduate science and mathematics education well and who seemed to have the capacity, with appropriate support, to get things going in the right direction. Finding a source of bottom-up leadership that can be joined with institutional leadership is a key to successful change.

For a great many years, the national approach to improving undergraduate science education was primarily, though not exclusively, to encourage and then respond to individual faculty initiatives. If there was a national systemic change strategy, I believe it was to create a critical mass of change agents at institutions by supporting strong, inventive, and entrepreneurial faculty one by one. If and when a critical mass was achieved, the thinking went, institutionwide reform would be under way, and it would also be sustainable. The premise was that this would work because faculty are around for a long time, while presidents and deans change with remarkable frequency. A better strategy is to focus on the faculty.

In many instances, this strategy paid off handsomely. Initiatives begun in some institutions as far back as the late 1960s and early 1970s are now the foundation stones of today's reformed and reforming programs, sustained at least partly by the now-mature faculty who received initial federal support many years ago.

Yet it is clear that the colleges and universities that have come the furthest in science and mathematics education were those where faculty innovators and leaders were joined by senior administrative partners to pursue together—institutionally—the ideas faculty had for doing science and mathematics education better. Presidential and top-level administrative leadership is a critical multiplier of faculty efforts. In fact, I do not believe that real institutionwide reform can happen without strong partnerships between administrative and faculty leadership.

Administrative leadership, critical when the quality of science and mathematics departments is strong, is also critical when programs are uneven or faculty leadership is unevenly distributed across departments. Long term, there is no substitute for shaping a faculty of the best quality one can manage, having a compelling institutional vision, and tuning the faculty reward system so that it encourages faculty to do the right things. In the shorter term, for systemic change to happen, presidents and deans must find in the faculty those who are ready to move and place strategic bets. Again, partnerships are key.

Paradoxically, having significant facilities and technology needs can be a wonderful boon to systemic change. One thing we have learned is that getting facilities and technology right is critical to getting change to happen; conversely, if facilities and technology are barriers to effective teaching and learning, change is very hard. Bucking facilities that are improperly conceived to support learning communities eventually wears faculty down, and they give up, even when highly motivated to do the right things.

The old architectural maxim, "We shape our spaces and then they shape us," is nowhere truer than in science and mathematics education. When teaching spaces have been designed for the traditional lecture, recitation, and lab format, it is difficult, if not impossible, to do studio teaching or to teach intensive, combined lecture-lab courses where students spend more of their time doing science. It is also difficult to take advantage of the high leverage on student learning that the use of technology can provide, especially in courses with students organized in groups for collaboration in learning—the way much science research is conducted. Furthermore, for student-faculty research to thrive, there must be spaces thoughtfully planned and set aside for that purpose. Thus, any serious attempt at systemic change must include a local commitment to assess the state of facilities and technology and then to ensure that spaces and technology support the new approaches to student learning desired.

When an institution has facilities needs it must address, its leaders have an unusual amount of leverage on the other players who must be a part of systemic change. Because significant amounts of capital must be raised to address science space needs—among college and university facilities, they are the most expensive—the attention of everyone in the institution is drawn to the teaching and learning issues at stake. The process of facilities programming and design can be a wonderfully strategic vehicle for forcing the extensive conversations systemic change requires. I believe, therefore, that although other factors are important, institutions seeking systemic change in the sciences are lucky if they have major facilities problems to address.

The existence of real facilities and technology needs in an institution often looks like a barrier to most college and university leaders precisely because they know such investments will be costly, and because they see themselves as lacking the ability to raise capital easily. I do mean to say, however, that a strategy of systemic change that ignores the facilities dimension is inadequate. At whatever level the institution can afford, a facilities improvement plan must be a part of the strategy of systemic change.

Understanding the local institutional cost structure of science and mathematics education is important if cost is not to become a barrier to reform. This discussion of facilities leads naturally to the issue of the cost structure of undergraduate science and mathematics education. If systemic change is to happen, it is critical to make a careful study of the cost structure of the system devoted to science and mathematics education in each institution. The reconfigured science education system sought must be financially attainable and then financially sustainable. Study of the cost structure may show that changes initially thought to be too expensive may be quite affordable. Or it may turn out that change in science and mathematics education may be possible only if trade-offs are made against other possible institutional educational goals, something that is frequently tough to manage. One thing we know from experience is that absent clear evidence that a reformed system is both financially attainable and then sustainable, key institutional players will block reform.

In the vast majority of colleges and universities, systemic change in science and mathematics education will not be possible without comprehensive, multiyear, combined operating and capital budget financial planning. It is continually surprising to me that so few institutions engage in this kind of planning. In both the independent and public sectors, failure to achieve overall institutional financial equilibrium will create an institutional climate antithetical to the kind of boldness of imagination, risk taking, and new investment necessary for institutionwide systemic reform. This is not the place to rehearse this argument in detail.

What is important here is to reinforce how important overall institutional planning and financial equilibrium are to the accomplishment of systemic change in science and mathematics education. It can happen only in the context of a larger institutional plan, which is necessarily a part of each local strategy of systemic change.

An important benefit of the required change to new accounting standards is that we must look much more frequently now at total institutional financial health when we examine our numbers. It has been my experience that when one begins to look at one's institution in this new way (new to us, old to our trustees from for-profit corporations), degrees of financial flexibility (and sometimes financial weakness) emerge that are hidden when we examine ourselves only in a fund accounting mode.

One place where such financial planning can produce important benefits is in the purchase and maintenance of capital equipment, an area that often produces great frustration among science and mathematics faculty. Major pieces of equipment are frequently too expensive to afford with funds available in one year's operating or capital budget. But if one approaches science equipment funding on a three-year basis, planning for lumpy expenditures and spreading them out over departments to smooth overall cash flow, departmental planning can be stabilized, and it may become possible to purchase items inconceivable in any other way and without outside grant support. This mode of budgeting for capital equipment purchases also maximizes the opportunity that faculty and the administration together have to seek outside support to supplement institutional funds. Savvy foundation officers look both for an understanding on the part of the institution of the need to include equipment costs, not just construction costs, in facilities plans and for institutional commitment to support science education intelligently over the long haul. An equipment acquisition plan is one important kind of institutional commitment.

A global look at the cost structure of science and mathematics education may also include the discovery of positive financial consequences from improved student retention. When introductory science and mathematics courses are pumps and not filters, good students not only stay in science and mathematics longer; they also tend to drop out less frequently. Some institutions capture this positive effect through improved admissions selectivity (when there are fewer students to replace, fewer applicants need to be admitted initially), leading to a stronger market position, with its impact on net tuition revenue. Others achieve it through lower annual student recruitment costs, though this is very hard. Still others capture it through higher enrollment spread over the same fixed cost base. Although such positive financial benefits are clearly possible, they are hard to predict and therefore hard to build into a multiyear financial plan. Nonetheless, there are many institutional examples of this kind of effect.

Getting the introductory courses right is absolutely critical. This is an old insight that continually bears repeating because things are still not right with the introductory courses: systemic, institutionwide reform in science and mathematics education cannot occur if the introductory courses are filters. At most institutions, the introductory courses still need the greater near-term attention. This is true regardless of whether the students go on to science and mathematics majors or whether they are destined to major in the arts, humanities, or social sciences and the goal is just science literacy. In my experience, the institutions that have come the furthest in undergraduate science and mathematics education reform have begun by improving their introductory courses with real passion.

My experience teaches that careful thought needs to be given to what happens if systemic reform is really successful. One must pay attention to the possibility of a whole range of unintended consequences. Student recruitment patterns may be dramatically altered, with consequences for both nonscience departments and science departments. On many campuses that have strengthened their programs, the percentage of incoming freshmen planning to major in natural science or mathematics increases significantly. As learning science becomes more attractive to prospective students, more and better ones apply for admission and are accepted, and more of those accepted enrolled. At the same time, current students were more satisfied and took even more science courses. How could anything be wrong with this picture?

If enrollments in nonscience courses decline as a consequence of a dramatic increase in the attractiveness of science courses, there will be serious institutional curricular planning issues, increased political opposition among nonscience faculty to further (or continue) investments in science education, and a decreased willingness among faculty in nonscience departments to collaborate with science faculty in interdisciplinary teaching. At the same time, even when an institution is able to increase the numbers of science faculty, such increases always lag enrollment growth and are never proportional to enrollment growth. The pressures on science faculty increase dramatically as a result of their success, and burnout among the best faculty becomes an issue. Thinking through these possibilities ahead of time is crucial.

Improving institutional capacities to assess learning outcomes, and therefore to evaluate the impact of attempted reforms, is essential, as is fine-tuning the faculty reward structure so that it is in line with the direction of planned reforms. Without changes in the reward structure, reform will not happen. A research-rich environment for students cannot be created unless even the faculty at undergraduate colleges and universities without a research mission are supported as they seek to do research appropriate to the setting. It is impossible, in my view, to expect students to learn how to ask good questions, analyze, and be lifelong learners with the intellectual curiosity of the educated person if faculty members are not also expected to model these qualities.

These are some of the things I have learned through experience in my time as a liberal arts college leader of undergraduate science and mathematics education reform. My recommendations are practical and applicable to a wide variety of institutional settings exemplifying a different mix of resources, strengths, constraints, and opportunities—the realities that institutional leaders face in their day-to-day efforts to move their institutions forward. The work of institutionwide systemic reform of undergraduate science and mathematics education is critical to institutional health and the future of our students and our nation.

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