Chapter 13
Then and Now: Summary and Implications

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How Have Rates of Persistence, Loss, and Relocation Changed Since the Publication of *Talking About Leaving*?

Analyses from two national data sources (NCES and CIRP) discussed in Chap. 2 converge on the conclusion that the loss rate from STEM majors caused by switching into non-STEM majors has substantially dropped. In 1997, our *Talking about Leaving (TAL)* study reported the then most recent (1991) CIRP switching estimate as 44%, averaged across all STEM disciplines. By contrast, the overall STEM rate of switching reported in analyses, both of CIRP data for 2017 (Eagan, Hurtado, Figueroa, & Hughes, 2014) and of NCES data for 2013, was 28%. This considerable improvement occurs, however, alongside a second source of loss that is highlighted in Chen's (2013) NCES study: in addition to the 28% of STEM majors who switch into non-STEM majors, a further 20% of STEM majors leave their college or university without a degree in any major. Thus, the total loss of STEM entrants is 48%. Expressed another way, only 52% of students who enter a major in a STEM field complete a STEM degree.

Information about STEM majors who leave college rather than switch majors was not available from any national data source at the time of the original study, so we have no way to determine whether these losses have changed over time. We also lack research evidence about which students are lost. However, in Chap. 7, our Gardner Institute collaborators, Koch and Drake, contribute to our understanding of these losses from their study of DFWI rates in STEM "severe" gateway courses. As

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we discuss in the context of weed-out course effects, students with socio-economic disadvantages are at risk of leaving their institution following just one DFWI grade in a severe STEM gateway course even when their grades in other courses place them in good academic standing. As discussed in Chap. 1, our colleagues, Lee and Ferrare, also add to our understanding of switching as a form of permanent wastage. They report that: STEM switchers are far less likely than STEM persisters to attain a degree within 6 years, take significantly longer than persisters to obtain a bachelor's degree, and are at higher risk of dropping out of college altogether (Lee & Ferrare, 2019).

As we discuss in Chap. 2, there is consistency between the CIRP and NCES analyses in the switching patterns that they report, and most of these patterns are reflected also in our representative sample of six institutions. Some (CIRP) patterns reported in 1997 have continued: switching rates are still higher for women than for men, although the gap has narrowed—from 52% for women in the 1991 data to 30% in 2011. Relative differences among STEM disciplines continue. However, persistence has improved much more in some disciplines than in others. There are notable increases in persistence in both mathematics and biology. Engineering retains its position as the STEM discipline with the highest persistence rate, but there was a decrease in persistence of 5% in computer science. Relocation within STEM majors has increased slightly, except in mathematics where fewer students moved to another STEM major than in 1997. Switching rates also varied substantially among institutions. Thus, which institutions and what STEM disciplines students enter have important consequences for their chances of graduation with a STEM degree.

In Chap. 2, and throughout the book, we comment on changes in STEM persistence by men of color and women of all races and ethnicities that were evident in our sample institutions. At all six institutions, and across the range of students' standardized math scores, disciplines, and GPAs, women switched at a 7% higher rate than men (viz., 18% compared with 11%). Thus, the factors contributing to higher switching rates for women were present at all institutions and in all STEM majors. However, as noted, women's overall switching rates have decreased since 1997, although with marked variations by discipline: the rate fell sharply in mathematics (from 72% to 30%) and in computer science (from 69% to 31%). There were also marked improvements in the physical sciences and biology. The switching rates for men also decreased (from 41% to 26% overall) but less so than for women, with the lowest rates in engineering, the physical sciences, and the biological sciences. However, the switching rate for men in computer science rose to 55% from 46% in 1997.

Switching rates for students of color were not reported in the original CIRP analysis but are reported in the most recent CIRP and NCES analyses as 42% for African American, 41% for Hispanic students, and 28% for white students. However, as we discovered, traditional designations by race/ethnicity—often expressed in terms of underrepresented minority (URM) status in institutional and other records—beg questions about what these designations actually mean. When students' math scores and URM status were assessed for their contribution to switching, math scores accounted for switching better than did URM status. Indeed, in our logistic regression model, URM status, by itself, did not predict switching at all. As our interview data findings also confirm, an important part of the greater switching risk experienced by students of color is created by poor high school preparation. When gender, URM status, and math scores are combined, underrepresented minority women who enter university with lower standardized math scores switch at much higher rates than any other student group: one-third of URM women switched from STEM majors compared with 14% of all students. In Chen's (2013) analysis of NCES data, academic performance also explained rates of switching better than race/ethnicity by itself. In this study, much higher proportions of lower performing than higher performing URM students switched out of STEM (19% vs. 6%).

The larger implications of these findings are, first, that focusing on race/ethnicity as if it were a significant independent variable appears to be inherently, if unintentionally, racist. Second, the characteristics that create what appear to be issues related to race/ethnicity, are more accurately, issues of socio-economic and educational disadvantage. Thus, raising the quality of math and science preparation in high schools that serve large numbers of students of color has the potential to significantly increase their STEM persistence rates. Indeed, all of our study sources triangulate on the conclusion that major improvement in persistence rates would be achieved by raising the level of science and math preparation in the K-12 system for all students.

Mapping student switching patterns for all students allowed us improved insights into who is most at risk for switching and when. All demographic and academic factors (student GPA, standardized math scores, incomplete grades, and the average difficulty of courses experienced by students) significantly predicted student switching. Of special note, "being a woman" remained a significant predictor of switching with all other variables held constant. Academic duress and incoming level of preparation both play a major role in these patterns. As we discussed in Chap. 7, students who received poor or incomplete grades in gateway courses in their first and second years were particularly prone to switching. Throughout this book we also highlight the loss of high-performing women from STEM majors. Women not only switch more than men but (as we also reported in the original study) are also over-represented among switchers with high academic performance levels. Much higher proportions of women in the higher versus the lower performing group (59% vs. 41%) switched from their STEM majors. As to when students switched, 50% did so by the end of the first year, and 80% by the end of the second year. Students with higher standardized math scores, URM students, and Pell grant recipients all switched later than their comparison groups.

We also found patterning in the destination majors of STEM switchers. Some pathways were based on affinity, similarity between subject matter, and pursuit of a career related to an original aspiration. Frequent pathways were: from biology to psychology and other social sciences, engineering to social sciences (mostly economics), and from all disciplines into undeclared majors. Pathways from engineering and computer science to undeclared majors were higher than expected for students with lower academic performances. A larger than expected number of lower-achieving than higher-achieving students (15% vs. 6%) left STEM for undecided majors and remained in these for more than one term.

In what follows, we draw on findings from the student interviews, SALG survey, and other sources to explain the patterns found in these statistical analyses and to weigh the contributions of a wider array of factors that contribute to switching, loss from college, and relocation within STEM.

What Contributes to Decisions to Switch and to Problems for Those Who Elect to Stay?

As detailed in Chap. 3, all of the contributory causes of switching decisions that students identified in the first study were also identified in the present study. While no new concerns emerged, there were, as we outline below, changes in their relative ranking. We also found increased complexity in the array of reported concerns that were being simultaneously handled by STEM undergraduates. These are reflected in increases in the sheer number of issues that prompted STEM switching decisions (from averages of 4.2 in TAL to 12 in TALR), in the numbers of concerns reported by all participants, and in students' accounts of their difficulties described throughout this volume.

Although, as discussed in Chap. 2, the extent of STEM switching has reduced since the original study, what has not changed are the contributory causes of switching. Important among these are the negative effects on persistence of students' learning experiences in STEM classrooms:

- *Problems with STEM instructor pedagogy* were found to be slightly greater than was reported in the TAL study: 48% of switchers mentioned poor teaching in their STEM courses as prompting their decisions to leave, and issues with instructor pedagogy were described by 96% of all switchers and 72% of persisting seniors.
- *Problems with STEM curricular design*, notably, content overload, over-fast delivery pace, and poor alignment between course elements, contributed to leaving decisions for a comparable proportion (31%) of switchers to those in TAL. However, in TALR, it affected far more (86%) of switchers overall, and 56% of STEM persisters.
- *Conceptual difficulties with one or more STEM subjects was found to* play only a small role in students' decisions to leave them STEM majors, then or now, but it was of concern to 80% of TALR switchers, overall. This finding (as we discussed in Chap. 5) is related to the high reported incidence of under-preparation in high school.
- As discussed in Chap. 7, *issues of under-preparation*, which create serious difficulties in surviving "severe" (i.e., weed-out) STEM foundation courses, were found in similar proportions in both studies. However, a higher number of TALR switchers overall cited under-preparation as an important aspect of their difficul-

ties (viz., 64% compared with 40% in TAL). Under-preparation also continued to create survival issues for about one-third of persisters.

- *Loss of interest*, which was often a consequence of poor learning experiences in foundation courses, still ranked highly (3rd) in its contribution to switching decisions, and (similar to TAL) was 61% of all switchers' concerns. As noted below, losing interest is commonly paired with finding alternative interests in other majors—in non-STEM disciplines for switchers and within STEM for relocators. Together, they reflect the push–pull nature of the decision-making process.
- *Finding and accessing timely appropriate help*—which was often critical to persistence—continues to be as serious a problem as it was 20 years ago: 80% of STEM switchers overall and 31% of TALR persisters struggled to find the academic resources and the support they need to survive.

We found marked changes since the original study in other "iceberg" items:

- *Discovery of an aptitude for a non-STEM subject now* ranks first among all factors prompting switching. It was cited by three-quarters of switchers as directly influencing their decision to leave and as a consideration by all switchers, compared with 10% and 12%, respectively, in the original study. The large jump in citation of this concern may reflect the large percentage of our interview sample who were high performers. Their representation reflects our institutional records count of high performers as 26% of STEM switchers across the six participating institutions. As we discussed in Chap. 10, high-achieving students often pursued multiple majors and minors in both STEM and non-STEM disciplines and moved to non-STEM majors for reasons that reflect their cross-disciplinary interests and options.
- For 61% of TALR switchers (compared with 23% in TAL) *loss of confidence* was a factor in their decisions and was also a concern for 79% of switchers overall. Losing confidence was also a problem for 44% of persisters. The increased ranking of losses of confidence from ninth to second place may, again, reflect the high proportion of high-performing switchers, two-thirds of whom were women and half of whom were also women of color.
- There was a large upward shift in students' *negative reactions to the competitive climate experienced in STEM classes*: 52% of TALR switchers (compared with 14% in TAL) cited negative class climate as a reason for switching. This experience also created problems for 81% of all switchers and was an issue for 42% of persisting seniors. Competitive class climate issues not only continued but also appeared to be growing as major deterrents to persistence. Intense status competitions among peers, encouraged by steeply curved grading practices, created isolation and failure to develop a sense of belonging that we found to be greatest among women of all races and ethnicities, and men of color.
- *Problems in financing college* emerged as a far more widespread concern in the present than the original study: 30% of TAL switchers cited financial problems as a factor in their switching decision. This rose to 70% of TALR switchers overall, and 48% of persisting seniors also registered financial problems as a serious

concern. In Chap. 11, we discuss how students in this study were paying for college and note the increase (since TAL) in both student working hours and their worry about large loans, which affected the career-related decisions of both switchers and persisters.

- *Choosing STEM majors for reasons that prove inappropriate* was a concern mentioned as a contributor to switching decisions by 48% of the TALR switchers compared with 14% of students in the first study. It also continued to be a concern for switchers overall and for persisters.

Career-related concerns were also found to be a far more pressing influence on students' decisions in the current than in the original study:

- About half of switchers overall, both now and then, *rejected the future careers and lifestyles* to which they projected STEM majors would lead. However, in the current study, twice the number of switchers (58%) than in the first study (29%) identified this a reason for their decision to switch.
- Similarly, nearly twice the number of switchers in this study (54%) than the prior one (27%) explained that they changed to a non-STEM major partly because it *offered more appealing career opportunities*.
- Making *system-playing moves into other majors as a means to further career goals* was a far more prominent strategy among switchers in the current than the original study: 26% of all switchers either sought or had considered non-STEM majors in which they could both achieve their career goals and graduate with higher GPAs. Their motivation was to gain a competitive edge in professional, graduate school, or job applications. We discuss these strategies in Chap. 10 and the rise in system-playing as a persistence strategy in Chap. 12.

As noted above, women's overall switching rates have decreased since the original study although with marked variations by discipline. Interview study results that clarify which factors keep women's persistence rates lower than those of men are summarized in the balance of this chapter. They also offer clues about what has contributed to the upward shift in women's persistence rates. The iceberg tables, broken out by gender, reveal that differences between male and female students in many categories of concerns are less than in the original study. The relative importance that women and men assigned to concerns that prompted switching or relocation was then seen to reflect broad differences in the ways in which men and women approach their college and careers. An overall finding of the present study is that the gender gap in attitudes toward STEM-related education and career goals has narrowed. For example, 20 years ago, male STEM students (and their parents) took a more instrumental approach than women to their education and career choices. Thus, men were found to be more willing than women to place career goals above intrinsic interest and personal satisfaction. In the current study, roughly one-quarter of both men and women reported readiness to switch to non-STEM majors to improve their GPAs and thereby their career prospects. This instrumental, consumerist trend, which is also reflected in parents' attitudes toward their daughters' education, is reported in Chap. 11 and summarized later in this chapter.

In our overall findings about the difficulties of persistence for students of color, the issues were not significantly different from those reported in the original study. As discussed in several chapters (notably, 2, 6, 7, and 9), several of these problems arose from the same source. Inadequate preparation (often in under-resourced high schools) in academic readiness, study skills, and how to navigate the college system was reported by 73% of all switchers of color; it was a contributor to switching for 35% and continued as a problem for 41% of persisting seniors. As we discuss in Chap. 5, consequential difficulties arose in transition to college that contributed to switching decisions for 73% of students of color compared with 31% for white switchers. Discouragement and loss of confidence because of low grades in early courses was a common concern for all students and was reported by 74% of white switchers. However, among switchers of color the figure rose to 92%. Among persisting students of color 78% of seniors of color described how difficult they had found it to adjust to college and 59% reported loss of confidence related to course grades as part of their struggle to survive. Difficulties in seeking and getting appropriate timely help was a problem for almost all (92%) students of color, compared with 76% of all white students, and the competitive, unsupportive STEM culture which (as described in Chap. 9) made it difficult to belong contributed to 62% of switching decisions for students of color compared with 49% of white switchers. For all switchers and seniors of color, this rose to 88% and 60%, respectively.

Because, in the original study, we found no variation between the participating institutions in the top-ranked problems contributing to switching, we checked to see if this had changed. In Chap. 2, we reported variations in the extent of switching by institutions with two of the research universities registering the highest rates. Given the findings of the observation study (cf., Chaps. 6 and 8) of research-based instructional strategies in use in some foundational courses in some institutions, we speculated that the likely cause of institutional variations was the extent to which improvements in teaching methods were in place. Our institutional analysis in Chap. 3 indicates that problems with STEM learning experiences were the highest ranked concerns for all switchers and persisters regardless of the extent of switching in any institution or disciplines, and the appeal of alternative majors for switchers was grounded in these issues at all six institutions.

In the following sections, we expand on these overall findings, noting which issues continue to prompt the continuing gap by sex and race/ethnicity in persistence rates.

The Centrality of Curriculum Design, Teaching and Assessment Methods

In 1997, criticisms of faculty pedagogy contributed to one-third of all switching decisions. Complaints about what students referred to as "poor teaching" were cited as a near-universal concern by switchers overall and (at 74%) were the most commonly cited problems of persisting seniors. Concerns about curriculum structure, assessment practices, and pedagogical effectiveness pervaded all but 7 of the 23 factors driving switching decisions.

In this study, our examination of the consequences of students' learning experiences is wider in scope. In Chaps. 6, 7, 8, and 9, we examine both negative and positive student learning experiences in STEM courses, drawing on the interview study; our institutional data analyses across all four academic years; and the SALG surveys deployed in STEM foundation courses. We also draw on findings from a collaborative observational study led by Ferrare (2019) of teaching methods in the same courses as the SALG survey, and from a multi-methods study of "severe" foundation courses (often referred to as weed-out courses). This is augmented by a study of the consequences of DFWI rates in these courses conducted by our colleagues, A.K. Koch and B.M. Drake, at the Gardner Institute.

Our findings about the negative consequences of STEM pedagogy, course design, and assessment methods for both switchers and persisters are comparable to those of the original study. However, a higher proportion of switchers (48% compared with 36%) reported that problems with their learning experiences were key reasons for their decision to switch out of a STEM major, and 96% of all switchers (compared with 90% in TAL) registered problems with the quality of STEM teaching. Similar proportions of persisting seniors (72%, compared with 74% in TAL) expressed frustrations with STEM teaching methods, and 78% of all students (compared with 83% in TAL) described how particular aspects of STEM course design and educational practice had negatively affected them. In the original study, we reported little variation across the sample institutions in these findings. In this study, problems with poor quality teaching were ranked first by persisters in all schools (91%–96%) and by switchers overall in all but one school (91%–100%). However, the highest negative scores for teaching were given by students at three (of the four) large universities in the sample. Over half of the switchers at these three schools also cited poor teaching as a major contributor to their decision to leave STEM. As suggested by the foundation course observational study, these variations may reflect institutional differences in the extent of efforts to improve students' learning experiences in STEM majors as part of a nationwide effort that has been ongoing since publication of the original study.

We have far more information in this study about what kinds of teaching methods students encountered. There is a high degree of concurrence across our studies in their portrayals of the teaching methods used. In the interview study, all but one of the 95 switchers and 57% of the 143 persisters reported that non-interactive lectures were the dominant modes of STEM teaching, especially in introductory courses. The SALG survey results from foundation courses echo those of the interview study: the most frequently reported teaching methods and student class activities were the most conventional. In almost all classes, students report that they were taught by lecturing. Interaction was predominantly via problem sets, practice tests, in-class discussions and reviews. Ferrare and his team of class observers identified two different forms of the lecture method that, taken together, accounted for 75% of teaching styles in foundation courses. "Chalk talks" (lecturing while writing on a board) was observed in 41% of courses, and "slide shows" (lecturing aided by premade slides) in 34%.

From his analysis of semi-structured interviews with the instructors in these observed courses, Ferrare found that the teaching strategies deployed in these two types of lectures are informed by distinct, coherent, and tacitly understood beliefs about how students learn science. Chalk talk lecturers emphasized what students should do to facilitate their own learning. Thus, an underlying belief that informs their approach as teachers is that posing problems facilitates practice through individual "perseverance": students should "grind away" at conceptual problems until mastery is achieved. Chalk talk lecturers explained that their use of Q&A (whereby students pose and respond to questions through dialog with the instructor) reflects the importance that they give to intellectual risk-taking. Slide show lecturers believe it is important to introduce students to the theory and mathematics of new concepts, then model applications through repetition and variability until students can solve the same type of problem—a process enabled by clicker questions.

Unlike the original study which contained few reports of teaching methods other than "straight lecturing," in our current studies we find evidence of more active and interactive teaching and learning methods. SALG write-comments recorded some group work in 71% of the foundation courses surveyed and the use of clickers in 53% of classes. In an intensive inquiry into a sub-sample of 28 foundation classes, students described participation in group work in 20 classes, the use of clickers in 15 classes and group projects in 7 classes. SALG respondents' written descriptions included methods whose common characteristic was their incorporation of learning technologies. In interviews, small group work was reported by about one-third of all students, and interactive forms of lecturing by one-quarter of switchers and one-third of persisters. Other methods mentioned were clickers, demonstrations, some online instruction, and a scattering of other classroom activities. Ferrare's observation team also reports interactive forms of teaching in 26% of foundation courses. These were also reported in interviews by 26% of switchers and 33% of persisters. Small group work was the most common interactive method recorded in all three studies. In these classes, the boundary between instructors and students that is sharply preserved in lectures was replaced with more open interaction.

As in the original study, students explained that what makes STEM learning "hard" is both the nature of the subject matter—intrinsic hardness—and hardness that is created or enhanced by prevailing instructional strategies. From experience, students found that the same material, taught better or worse, could be made more or less "hard." Paramount among instructional methods that made learning artificially hard for both switchers and persisters are: failure to present topics in a logical sequence, incoherence and inconsistent pacing in presentation of material, leaving out important information, poor management of class time, and reading Power Point slide content without inviting discussion, taking questions, or engaging in two-way exchanges. Conceptual understanding was further compromised where instructors fail to offer applications, examples, and sample problems or to provide context for theoretical material via conceptual connection to other bodies of knowledge and real-world phenomena. These omissions make it harder for students to apply what they are learning. Used in combination, these methods limit student comprehension and generated a sense of overwhelm. They are commonly reported in foundational courses but are still described in senior-level courses. The relationship between flaws in curriculum design and problems with conceptual grasp and application is similar to that reported in the original study. In sum, poor learning outcomes were achieved by delivering too much course material at a level that was inappropriate for the course designation at a pace that was too fast for digestion, and by misalignment between class content, labs, assessment, and homework. Content challenges can be motivating for students when thoughtfully devised *as part of* the curriculum. However, they can also create unnecessary struggle, confusion, and low levels of comprehension when they occur *because of flaws in* the curriculum structure.

Also frequently cited as deterrents to engagement and motivation were dull, spiritless presentations where instructors showed little engagement with either the course material or the learners. A commonly cited indicator of instructor indifference to student learning was failure to pause and check the degree to which students were following the instructor's line of thought and understanding the concepts being laid down. It is notable that we recorded substantially more descriptions of indifferent, lack-luster teaching than of engagement and passion from persisters than from switchers. As in TAL, students insisted that there is no inherently dull material—only dull teaching. They wanted to be intellectually stimulated by their teachers' passion for their discipline and encouraged by their enthusiasm to share it. Over one-quarter (29%) of switchers migrated to non-STEM majors, in part, because they offered more engaging and interactive learning experiences. The students' claim that disengaged lecturing induces "passive learning" and prevents them from building conceptual understanding, and engaging with subject material in depth is validated from multiple sources. As reviewed in Chaps. 8 and 9, many research studies and reports by public and private foundations, and by disciplinary and professional societies, support students' appraisals that interactive teaching, incorporation of active, hands-on activities, small group work, and use of authentic problems all outperform "straight lecturing" in enabling a solid understanding of, and ability to apply, core concepts and engage students in their own in-depth learning.

Students stressed that they valued teachers who demonstrate by their attitudes and behaviors that they want them to learn. Their descriptions of "how they learned best" included instructors who were approachable and available, encouraged questions, took an interest in students' progress, understood why some things were difficult and were willing to help students surmount them. The characteristics of "good" teaching most frequently identified by students included not only improvements in pedagogy that they enumerated but also improvements in the attitudes of instructors toward learners. Students clearly understood the connection between learning theories and learning practice, and the changes they wanted required shifts in both. As noted above for the lecturing formats that accounted for 75% of observed gateway course teaching, the beliefs of students and instructors about how these courses "should" be taught are entirely divergent. In the minority of multi-modal and group work-based courses observed, instructors' and students' ideas of the best ways to learn science were better aligned.

As discussing the learning process in class was uncommon, students could only guess at why their instructors taught as they did and thus they offered their own theories about their instructors' motivations and rationales. Students commonly explained the prevalence of lecturing, despite its dysfunctionalities for learners, in terms of the research priorities of STEM faculty and lack of departmental rewards for good teaching. They explained instructors distancing behavior and refusal to take an interest in them as individual learners as evidence of an assumption that students are lazy, stupid, unmotivated and, thus, unworthy of their instructors' attention. From modes of teaching that neither stimulated nor sustained their interest, they deduced that instructors took little responsibility for enabling learning and that they were expected to learn on their own. Where lectures were disorganized and incoherent, they assumed that instructors lacked the professional skills to deliver their content to best effect. Failure to provide and require education in teaching methods for instructors and graduate student teachers prompted two assumptions, notably among seniors, that departments and the university itself did not value effective teaching skills, or that they were aware of poor teaching quality but saw intervention as over-riding academic freedom. We imagine that it would have surprised many students to learn that instructors' rationales, particularly for their lecturing methods, were informed by a belief that this was how science had to be learned.

It is important to make clear that, as also found in TAL, most students' problems with their classroom learning experiences were not laid at the door of graduate teaching assistants. There were exceptions where graduate TAs, untrained in pedagogical methods, were assigned to teach introductory courses—as was the case of the whole calculus sequence in one sample institution. Students largely experienced TAs in recitations or labs, and over half of switchers described the value of clarifying their understanding in interactive sessions with a teaching or lab assistant. The other half registered negative experiences with TAs but only 3% of switchers included them as a factor in their switching decisions. Persisters rarely complained about their teaching assistants and one-third reported good experiences with them.

We believe that the modest moves into research-based instructional strategies (RBIS) evident in these studies will be encouraging to the STEM education improvement effort that has been ongoing between the original and present studies. Ferrare's findings, however, underscore conclusions from educational change research that wider uptake of RBIS has to begin with acknowledging how instructors conceptualize the student learning process, then persuading them to consider the research-based learning theories that underpin research-grounded teaching.

As discussed in Chap. 6, Ferrare's (2019) findings that instructors' teaching methods reflect their beliefs about learning align with research indicating a common belief among STEM instructors that the ability to "do science" is innate and fixed rather than something that grows with interest and effort. Through their modes of teaching, assessment, and contact with students, instructors who believe in "fixed intelligence" convey the message that only "innately gifted" students are likely to succeed—a message that many of our interviewees encountered and that some had internalized as "true." STEM instructors who believe that it is part of their job to identify students with natural ability and to encourage others to do something more suited to their presumed abilities were clearly doing just that. Instructors who believe that intelligence can be developed were more likely to show students how to become better learners and motivate them do their best. That such beliefs have important consequences is supported by Canning, Muenks, Green, and Murphy's (2019) finding that instructors' beliefs about the nature of intelligence (whether fixed or capable of growth) predict student motivation and achievement better than other aspects of their teaching. Ferrare and Miller (2019) further report that the patterned ways in which introductory STEM course instructors explain students' success can inhibit their taking steps to ameliorate factors that contribute to failure to persist even where the role of social inequalities is acknowledged. In contrast to our report in Chap. 12 that seniors augmented determination and ability with an array of survival strategies and resources to survive, 22% of instructors' "interpretive frames" explained persistence solely in terms of students' individual ability. A further 23% posited that anyone can succeed if they develop relationships in which students learn by struggling together. Poor preparation was acknowledged by 10% but was not seen as something that instructors could address, and 25% conceded that instructional factors were important but that, given the "great strides" made in instructional improvement, "STEM success is no longer predicated on these constraints." (Ferrare & Miller, 2019, p. 10).

Taken together, instructors' beliefs about the nature of students' intellectual capacity, how science must be learned, and what determines persistence are powerful influences on student outcomes of teaching and on student–instructor encounters grounded in these beliefs. As Ferrare makes clear, the dominant teaching methods used by instructors in foundation courses are entirely consistent with their beliefs about how students learn (or should learn) science and, as such, legitimate their use. However, it is also clear from student accounts of how they learn best that students' learning theories and those of their instructors sharply diverged.

The Significance of Weed-Out Courses

As in the original study, about one-third (35%) of switchers cited weed-out class experiences as major contributors to their decision to leave. It is in these (largely) foundation courses that we found problems with aspects of course design, pedagogy, and assessment methods to be the most extreme. Flaws in course design and delivery occur in other courses, but constructed forms of hardness were consistently reported as features of teaching methods in courses identified as "weed-out" by their nature and consequences. They form, in effect, the tip of the iceberg.

Switchers and persisters described, in the same rank order, the characteristics that distinguished weed-out classes from other foundation courses: assignments are misaligned with content and grading is steeply curved; overloaded content is pitched at too high a level for an introductory class and is delivered at too fast a pace for absorption; teacher behavior conveys indifference about whether or not students learn; curriculum organization is incoherent and its delivery misses steps and explanations; and a competitive class culture is created by curved grading that also has the effect of disconnecting grades from students' own sense of their content mastery. By this combination of methods that students describe as confusing, intimidating, and discouraging, instructors effectively convey the message that the major is "too hard for them." Our discussion of concordance between the distinctive ways in which foundation course instructors teach and behave toward students and what they believe about the nature of intelligence and how science is best learned is particularly relevant to our understanding of why weed-out courses are taught in these distinctive ways and with such consistency of form over time.

How Grades Contribute to Switching

From our logistic regression model of variables drawn from institutional records and transcript data, we found that receiving DFWIs in "severe" (SF) courses is a good predictor of switching even when other variables are held constant. Students also have a higher risk of leaving a STEM major if they: receive one or more poor grades in, or do not complete, an SF course during their first year; have a lower overall GPA (even with no DFWIs), enter college with a low SAT/ACT mathematics score; come from a family with lower socio-economic status (indicated by a PELL award); are a first-generation college student; or are a high-performing student whose leaving is associated with receiving one poor grade. Combinations of these characteristics substantially increase the switching risk. However, failure to complete, or receiving poor grades in an SF course, by itself, increased a student's chances of leaving a STEM major by 5%. Thus, it is SF courses that grades-related contributors to STEM switching are most evident.

An important contributor to these patterns of risk in SF courses is their distinctive use of curved grading systems. Although used in many other courses, in SF courses, steeply curved grading creates quotas of students with D and F grades to an extent that is large enough to depress STEM department grade averages (Rask, 2010). Although 12% of students who did not receive a DFWI switched after an SF course, the rate almost doubled (to 23%) for students who received one DFWI and jumped to 33% for those receiving two DFWIs. While students with higher standardized math scores switched less than those with lower scores, the difference in switching rates for both high-performing men and women almost doubled for those who received one DFWI in an SF course. As other researchers have also observed, if one aim of these courses is to reduce student numbers to a manageable size, they do so effectively.

We found, as we did in TAL, that grades are a complex, multi-faceted variable that have predictive value because of the significance that students assign to their grades. Low grades put students at high risk of switching even where they are sufficient for them to continue in a STEM program because students respond to grades as significant for their self-assessment and identity. It was common for switchers to describe STEM grade shock as part of their transition from high school to higher education. Typically, this affected students with high incoming math SAT/ACT scores who described themselves as "top students" in high school where they had seldom, if ever, received grades below a B. C or even B grades were defined as "failure" and undermined their prior identities as good students. Disquieting projections of an imagined unsuccessful future prompted thoughts of switching both among those who switched and those who did not. Students who were unable to recover their sense of identity as competent students were at risk of switching into programs where they could regain a sense of successful selfhood. In the original study, 23% of switchers cited discouragement and loss of confidence created by low grades in early classes as factors in their switching decisions. By contrast, in this study, the rate rose to 61% of switchers. Men of color and women of all races and ethnicities were even more likely to report that issues with low grades contributed to their switching decisions (69% and 67%, respectively).

The importance of the distinction between the objective and subjective meanings of grades and their consequences for switching is particularly clear in the reactions of many women to low grades. As discussed in Chap. 7, our collaborators, Koch and Drake, also found that women did better on average than men in SF courses and had lower DFWI rates than course averages. Despite this, women had higher rates of switching than men overall and switched at higher rates than men across the math score distribution. Women of color with low math scores switched at significantly higher rates than other students. Curve grading systems in SF courses played a major role in these departures. Among switchers, half of the women, but less than a third of men, were prompted to switch because of low weed-out course grades. Women had less tolerance than men, whether for receiving low grades or for failing classes. Regardless of actual performance scores, women accustomed to getting good grades who received a single C grade, an incomplete or a withdrawal in a weed-out course were at high switching risk. The gendered effect of low grades was also evident beyond SF classes among persisters: although senior men were over twice as likely as their female counterparts to fail and/or retake courses, persisting women expressed less tolerance for low grades and failing classes than did men and were over twice as likely to report their demoralizing and psychologically traumatic effects.

The apparent indifference of SF course instructors toward novice learners seeking academic help and encouragement reinforced self-doubt that is independent of actual performance. The search for validation from significant others that we encountered among women in the original study had not disappeared. Many young women were still less able than their male peers to diminish the significance of reversals, take them in stride, and refuse to allow low grades or distancing behavior by instructors to throw them off track. By projecting a poor overall future performance from poor grades earned in one class or even on one exam, some students switched pre-emptively. What seems to have increased since the TAL study are parental and societal expectations for young women (see below) which they internalize into self-demands to such a high degree that many senior women reported that they still had difficulties in letting them go. Some such women left to find a major where they could once more feel good about themselves and graduate with a high GPA. As some seniors described the choice, it may be "better to bail than fail." Fragility of self-confidence was particularly marked among women of color. The risk of switching due to weed-out course experiences is particularly high for those women of color who enter with below-average ACT/SAT math scores.

Failure to adjust to low grades, particularly in weed-out courses, distinguished switchers from persisters. Similar proportions of switchers and persisters failed, or had to repeat, classes, including some students with high incoming math scores. However, fewer persisters considered failing a course to be a psychological crisis or described it as threatening their continuance in the major. As a matter of survival, most persisters had found ways to adapt to what they described as the STEM tradition of lower grades. Coming to understand the nature of curve grading was also important in the grade adjustment process. Being assessed by the logic of norm referencing was novel and alarming to most incoming students. Some continued to assume that their instructors used criterion-referenced grading to indicate the extent to which they understood course content regardless of how many others did also. Students who continued to view grades in this light had trouble accepting a C grade as other than as evidence of low conceptual competence even when they performed well relative to the curve. As seniors explained, survival requires normalizing single poor grades as a setback, not a deal-breaker.

The advice of peers, advisors, and instructors helped many STEM majors to make this adjustment so that their academic struggles did not come to signify lack of ability or discount future success. As in the original study, we heard many "fork in the road" stories in which a decision to stay or leave turned on a serendipitous intervention by an instructor or advisor who persuaded a capable student that they should stay. More experienced students often play an important role in explaining to younger students how to put low grades in weed-out courses into perspective. We observed how valuable such "translation work" is to survival, especially for women with high self-demands whose confidence is undermined by the consequences of curve grading.

We also note that this is clearly a place where timely interpretation and encouragement can be brought into play to divert talented but self-doubting students from ill-founded departure. Designated and faculty advisors might make use of this finding by organizing a unified, intentional practice of enabling students to make better appraisals of their own competence and thus avoid precipitate decisions. However, STEM departments might also review whether and when the use of curved grading is appropriate and effective. Is there good correspondence between what is taught and tested and what students are able to demonstrate about their learning? Does it enable the loss of students whom it would be worth retaining?

Which Students Are Lost from Weed-Out Courses?

Our combined findings clearly demonstrate that a student's chances of passing "severe" STEM gateway courses and of remaining in college to successfully graduate are greatly diminished by belonging to low-income and first-generation families who may also be of color. In Chaps. 2 and 7, we reported several apparent differences between students of color and white students in math and science preparation and STEM course performance. However, in the logistic models, these differences disappeared because other variables explain switching rates better than race/ethnicity per se. We therefore explored what variables intersect with race/ethnicity to explain the switching risks of students of color in weed-out classes. As we further describe in a following section, we found a strong relationship between race/ethnicity, first-generation college status, and the enhanced risk of arriving in college under-prepared for introductory STEM courses. From student accounts, we also learned that working-class parents of all races and ethnicities were also less likely to know how higher education works, what career pathways exist, and how to get the most out of college. They were also less likely to be able to provide funds for college, so their children more often had to work to pay for their education and support themselves while in school. Thus, students of color, along with other working-class, first-generation, and immigrant students face a set of structured socio-economic and educational disadvantages in STEM majors that derive primarily from the limitations of their circumstances with additional problems experienced by women and students of color from disadvantages groups.

The non-random, nature of losses from STEM majors arising from weed-out foundation course experiences is further corroborated by Koch and Drake who also identify high weed-out courses as responsible for losses among students who are first-generation and Pell grant-eligible. This group includes many students of color who consistently had DFWI rates that exceeded both the averages for their course overall and those of their white peers. Students whose families had less financial and social capital have clear disadvantages in STEM SF courses. Koch and Drake's findings also help to explain what contributes to the 20% national rate of college drop-outs from STEM majors: for first-generation and Pell grant-eligible students, an unsuccessful outcome in just one weed-out course is related to the decision to leave the institution altogether, even when the student is otherwise in good academic standing. Thus, not only does earning a DFWI grade serve as a predictor for attrition, it is also a predictor of who ultimately graduates.

Thus, across all our studies, switching as a result of weed-out courses was found to disproportionately occur among students who enter with a constellation of socio-economic disadvantages. These risks are evident when examined singly, but, they greatly increase when they occur in combination.

STEM courses that appear to be designed and taught so as to discourage students presumed to be the least capable of continuing paradoxically produce consequences that are dysfunctional to such aims. Students who leave STEM majors because of weed-out course experiences include high-performing students—some in the highest math scores quartile—whose interest is dissipated by insufficient intellectual challenge, engagement with authentic science, and exploration of theory in the limited "school science" presented to them. Among these are multi-talented students with viable interests both in the arts and humanities and in the sciences some of whom are undertaking multiple majors and minors in a wide variety of fields.

Weed-out experiences can force such students to choose whether to drop or keep a STEM major.

We observe that substantial numbers of STEM persisters are now combining their STEM degree studies with pursuit of non-STEM credentials—a trend that was barely discernable in the original study. As a matter for further research, it is largely unknown to what extent which non-STEM pursuits make a positive contribution to STEM degree persistence. Often, students' pursuit of a non-STEM credential along with their STEM major has the effect of creating a liberal arts education with application and relevance for many careers and lifetime interests beyond the narrower confines of particular disciplines. Addressing this trend might be an important focus for collaborative planning discussions across departments. STEM degree programs might recruit more students into STEM programs and ensure their retention were they to offer degree programs that accommodate students' interests in other (including non-STEM) disciplines.

Another sub-set of high performers make pragmatic moves from STEM disciplines into majors that enable them to improve their GPAs and, thus, increase their chances of acceptance into competitive graduate and professional programs. Even though students with high ACT/SAT scores are less likely to switch, we found them to be surprisingly vulnerable to the effects of DFWI scores. Losses from this talented group following weed-out courses are high, even among both women and men with the highest math scores on entry. As we have clarified throughout this book, the processes of switching are also far more haphazard than the rational choice model would predict. This is especially evident in the decisions of perfectionist students for whom experience of one setback (often a moderate grade misinterpreted as failure) was often the basis for a move intended to restore self-esteem.

In light of these findings we propose that low tolerance for less than perfect performances is a more accurate explanation for switching by many high-performing women than is loss of confidence—which is an explanation of long-standing in the research literature. There is still strong evidence in both our current and former studies, and in ongoing research by others, that lost confidence is a major contributor to many women's switching decision. However, this explanation may more accurately apply to that larger proportion of women entrants to STEM majors who are not the highest performers.

The longevity of the weed-out "tradition" appears to reflect its perceived functionality. However, our evidence from this combination of sources contradicts any presumption that weed-out courses are necessary in STEM majors because they select for those who are best fitted to continue and discard only those who are not. It may be sustained as a system by good intentions such as, being cruel to be kind in diverting poorly equipped or ill-suited students elsewhere—a rationale that may also be seen as ensuring the future high quality of STEM disciplines. However, STEM departments that sustain weed-out courses appear to be mistaken about which students they are discarding. Because the class, race, and gender biases in these losses as well as the loss of very talented students appear to be unknown, whether to instructors or their departments, we may presume that they are unintentional. The weeding out of majors from other disciplines, provided as a kind of "service," by math and the physical sciences, is more overt. But, as attested by some angry switchers from engineering and health-bound professions, it is blind to the interest and potential of students with applied science career trajectories.

Of all of our findings, the patterned dysfunctional outcomes of the STEM weed-out system prompt, perhaps, the greatest need for departmental disciplinary and institutional review and reconstruction of traditional teaching and student assessment practices.

Developing a Sense of Belonging and Other Climate Issues

Problems with aspects of the cultural climate experienced in STEM majors continued (as they had in the original study) to undermine students' sense that they belonged in STEM majors. They contributed to half (52%) of all switching decisions, were an issue for 81% of all switchers, and 42% of persisters continued to struggle with them. Feeling that they did not belong was most often expressed by white women and students of color of both sexes, especially those from low-income families and "first-generation" families who entered STEM programs with poorer high school math preparation. Such students were more likely to have problems with belonging that were grounded in low assessment of their own competence. Their concerns were exacerbated in competitive classroom climates, and by difficulties in connecting to other students. This, most importantly, undermined their access to peer academic support.

For women, difficulty in developing a feeling that they belonged was rooted in the numeric dominance of men in particular STEM majors where male peers, and sometimes instructors, acted out their presumptions that women did not belong in their major. In contrast to the TAL study, we did not hear widespread accounts of male instructors who behaved badly toward women in class or allowed male students to be rude, hostile, or make sexually inappropriate remarks. Such behaviors were rarely reported in this study. However, we still documented instances where male faculty operationalized their beliefs that women did not belong by ignoring women's questions and contributions in class, tolerating male peer behavior that excluded women from participation, and, in office hour encounters, contesting their content knowledge and competence. Another remnant of our earlier findings was difficulty in relating to some of the women faculty in the physical sciences, especially older professors who had struggled to survive among hostile male colleagues and were disinclined to provide individual support to female students. This continued but was much rarer than hitherto.

Presumption of greater male competence, however, continued to be expressed and was a significant contributor to women's sense of isolation and exclusion. We continued to hear stories of male peers who assigned stereotypically gendered roles to women in group projects. Women's opportunities to learn new skills were, thus, preempted by male assertions of greater competence. Women often assumed that men had greater familiarity with course content gained through their informal interests. In engineering and computer science especially, disparities in informal STEM experiences translated into classroom status advantages. Some senior women described how they protected their self-confidence in competitive class cultures by avoiding male peers. However, this strategy also cut them off from sources of mutual peer help and support.

Women with high competence in math were not immune to the negative effects of competitive classroom climates or of being excluded from study groups. Their sense of belonging was confounded by limited connection to instructors and peers in the learning process, and less access to opportunities such as undergraduate research and internships. Challenges to women's competence and the risks of stigmatization were rarer in programs with near gender parity. In computer science and some engineering programs where the gender ratio could be as low as nine men to one woman, women reported particular difficulties in developing a sense of belonging.

The programs in which both women and men most often experienced unwelcoming, even hostile, class climates were engineering and computer science, and majors in which a high proportion of students aimed to enter medical or veterinary schools. In these contexts, climate issues often manifested as status competitions whereby some students who asserted a superior right to belong stigmatized and excluded others. Such artificial competitions were heightened by sharply curved grading.

Partly as an artifact of men's greater numerical representation in some majors, the processes that women describe limit their access to peer support, perpetuate gender segregation, and give male students control over the informal terms of performance and productivity in their classes. Left unchecked, negative peer dynamics systematically and unfairly disadvantage some students over others and promote outcomes that might not be what STEM faculty and their departments intend. Recognition that peer dynamics are a critical aspect of program climates and lie within their purview, a shared readiness among instructors to intercede in competitive peer dynamics and to rethink course design, assessment methods, group work, and academic support systems could all increase students' development of a sense of belonging and, thus, their commitment to persist.

External Influences

Patterns of STEM switching and relocation are shaped not only by aspects of students' within-college experiences but also by how these experiences intersect with variables in the outside world. Important among these are: why students chose particular STEM majors; how well-prepared they are to undertake them; how they finance their education; the appraisals they make of prevailing economic conditions and job opportunities; and the influence of parents and family circumstances in all of these.

Under-Preparation

In our discussion of weed-out effects, we pointed to the role that adequate high school preparation plays in the degree to which students can engage successfully with STEM foundation courses. Nearly one-third of students discovered on entry that they were under-prepared for these courses, of which General Chemistry and Calculus I and II were the most troublesome. The difficulty of trying to remedy missing understandings while simultaneously tackling new concepts directly contributed to 20% of switching decisions—a slightly larger proportion than the 15% reported in the original study. Under-preparation also prompted some relocation to other STEM majors where catching up could be managed. Students with preparation problems in multiple disciplinary areas were those more likely to cite poor preparation as a major influence in their decision to switch.

As in the original study, under-prepared students from families in working-class communities commonly described their schools as under-resourced. Teachers, though supportive of their talented students, were often under-qualified for the subjects they taught, calculus, advanced science coursework was not offered, and science laboratories were poorly housed and stocked. Our most significant finding is that students of color were over-represented among under-prepared students who switched. Students of color were more likely to come from working-class families, attend under-resourced schools, and to report poor preparation: 36% of under-prepared students were African American, 22% were Hispanic, and 16% were white. Women of color were the most likely students to attribute their switching decisions to insufficient preparation in under-resourced schools. This finding helps to explain the apparent connection between race/ethnicity and STEM switching.

Some under-prepared students both white and of color were aware of these deficiencies while they were in high school; others discovered, in retrospect, that the quality of teaching and intellectual challenge in their high schools (particularly in rural or low-income urban areas) was lower than that experienced by peers from better schools. They also described their families as having limited experience of higher education and financial resources to contribute to it. Early tracking also contributed to inadequate preparation. Women of color and first-generation students were most likely to report that they had been placed into low-ability math tracks in middle or elementary schools where they experienced little encouragement in math and science and found restricted access to more advanced, college preparatory curricula. Thus, the intersection of class, race, and gender is clearly significant in explaining patterns of under-preparation for early STEM courses.

Interview analysis revealed other ways in which students arrive ill-prepared for STEM foundational work. Although 61% of switchers had taken at least one AP or IB science course and over two-thirds of switchers had taken high school calculus, these advanced courses had not necessarily provided adequate preparation. Students described poor teaching, lack of challenge, superficial coverage of important concepts, and a focus on memorization without conceptual understanding. In addition to inadequate disciplinary knowledge and skills, many under-prepared students had experienced learning largely via worksheets and rote memorization and had little experience of abstract or conceptual thinking. Some students were unprepared for the workload, organization, and time management skills that undergraduate STEM courses required. These aspects of under-preparation were more common in poorer high schools but were by no means limited to them. Many students from affluent families and well-resourced schools who were adequately prepared in math or science had entered college with little idea of how to manage their work or study effectively for tests. Students who had earned As in high school with minimal effort often did not understand that they must now prepare for classes. Those who adjusted their study practices recovered relatively quickly, but slowness to adjust learning habits created persistence risks for otherwise prepared and able students. However, it was the constellation of inadequate disciplinary and learning skills preparation together with limited knowledge about how to navigate the college environment that most often demoralized able students from disadvantaged backgrounds. Under-preparation in all its dimensions created difficult transitions to college that often prompted an early decision to leave.

In sum, preparation issues and subsequent difficulties in college transition continue to play an important role in prompting able students to switch from STEM to non-STEM majors. As we have illustrated, problems of preparation and transition both reflect and exacerbate inequities of income, race/ethnicity, and gender that underlie so many of the contributors to loss from STEM majors that we encountered in this research.

Motivation and Influence in Initial and Subsequent Choices

How questions were posed to students about their choice of particular STEM majors was important. When asked in the SALG survey to rate a set of (research-grounded) reasons for choosing their STEM major, the highest rated reason, “I wanted a career in this field,” was one of four answers that focused on ultimate careers. Three other career-related ratings expressed gaining a particular STEM education as a means to a good income, job security, or as a stepping stone to a higher degree. However, as was emphasized in students’ written comments, apparently instrumental choices often reflected interest in, and the appeal of particular careers. Indeed, the second-highest rated reason was that, “A career in this major allows me to help others.” Choices prompted by altruism, including the desire to make a difference, were common, particularly among women and students of color. Lifestyle goals were also well-represented and often shaped particular career aspirations.

When invited to offer a primary, open-ended reason for their choice, the dominant themes in all students’ answers were affective rather than instrumental. Paramount were interest in and enjoyment of the field and a sense of a good fit between their ability and temperament and the kinds of careers to which it might lead. These responses were similar to those given by students in the original study. However, as the interviews revealed, the considerations weighed by students are now more complex, and both switchers and persisters chose between multiple, often competing, interests. While switchers generally had broader disciplinary interests than persisters, including both STEM and non-STEM fields, there were no great differences between switchers and persisters in terms of the primary reasons offered for their choices.

Switchers and persisters alike often changed majors as a result of exploring and honing their career interests during their undergraduate studies. Those who were more career-focused in their initial selection of major explored and refined career options as their understanding and awareness of careers matured. Fifty-eight percent of switchers who made career-related choices switched because they became dissatisfied with their initial choice and found more appealing career paths in non-STEM fields. As we also found in the original study, students who were very likely to switch were those who entered with a narrow career focus based on a long-held but under-informed aspiration or an altruistic but unrealistic career goal. Persisters were more apt to enter STEM majors with a general desire to “do” or “be” in a certain field, and then gradually refine their interests as their studies progressed and their field knowledge grew. Switching because of recognition of a mis-fit between their own interests, temperament and goals, and their experiences and career expectations in their STEM major perhaps comes closer to traditional explanations for switching than many of our other findings about switcher–persister differences.

Where the two groups differed most was in their incoming level of knowledge about their major or their chosen field. It was this variable that most influenced whether they stayed in their original STEM major. Under-informed students were more likely to switch, and lack of incoming knowledge was also a leading contributor to relocation into a different STEM field. More than half of switchers (56%) moved to a non-STEM major, in part, because they were under-informed upon entry about the nature of the STEM degree program and its related career options. This factor affected more than four times the proportion of students than in the original study especially engineering and computer science students.

As the most prominent switching factor related to students’ choice of major, this has clear implications for remedial action: policymakers and state departments of education could increase efforts to integrate engineering and computer science more robustly into the K-12 STEM curriculum; educators and STEM-based industries could collaborate to create mentoring and internship programs for K-12 students that provide a more realistic and nuanced understanding of the work of STEM professionals; K-12 school counselors, educators, STEM industries, and disciplinary societies could all do more to inform students about the vast array of STEM career options and help them to reflect on which career may best match their interests, aptitudes, and temperament; colleges and universities could also offer greater access to pre-entry advising to help students select an appropriate major and to inform them about pathways within STEM and other disciplines; STEM departments could create mandatory one-credit courses for incoming majors to educate them about the sub-fields within the discipline and the nature of career options with those fields. Were policymakers, K-12 and university educators, and STEM industries to collaborate to inform, mentor, and provide professional opportunities for students at all educational stages, students will be better prepared to succeed in their STEM disciplines and enabled to make more informed choices for their future careers.

Parental Influences

When asked who or what had influenced their choice of majors, both switchers and persisters described the influence of parents as paramount in encouraging their entry to STEM majors, followed to a lesser extent than in TAL by high school teachers. Fathers exerted more influence than mothers in the choice of STEM majors and fathers clearly favored STEM-based careers for both their daughters and sons—a considerable shift from 20 years ago. A sub-set of both switchers and persisters chose to follow a parent's career in a scientific or technical field. However, what distinguished switchers from persisters was the *type* of influence exerted by parents. Persisters more often described their parents as encouraging an inclination toward the sciences and helping them identify fields of study that suited their talents, temperament, or interests. Switchers more often experienced parental pressure to choose STEM-based careers perceived to be secure, prestigious, or well-paid. They were also more likely to have family financial support for college contingent on following parental preferences. Selecting a STEM major in response to parental pressure rather than intrinsic interest resulted in choices that were highly unstable and prone to early switching.

Parents had influence in decisions to leave a STEM major as well as to enter it. The dominant concern of parents who disapproved of a student's intention to switch from a STEM major was for their child's future employability and financial security. They worried equally for daughters and sons about the long-term consequences of moves into non-STEM fields. Although more fathers than mothers opposed STEM switching for these reasons, parents of both sexes saw non-STEM degrees as inferior to STEM degrees in an uncertain job market. The tougher line that fathers now take with their daughters reflects their recognition that, in a world where marriage no longer ensures financial security, young women must achieve this for themselves. For fathers especially, viewing STEM degrees as good ways for their daughters to prosper in the world marks a huge change from the original study where young women often had to fight their parents, both to enter and stay in STEM majors. Some students questioned how much their parents knew about the career paths that they promoted, and about post-graduate requirements and the costs needed to achieve them. They clashed over parental estimations of how much money they could earn in parent-approved career paths and questioned the factual basis of expectations of high financial returns from a STEM undergraduate degree. Some parents who were disappointed at moves away from prestigious career fields—notably, medicine and engineering—sought to leverage compliance by withdrawal of financial support.

As in the original study, mothers and fathers differed somewhat in the criteria by which they judged a proposed switch of majors and careers. Mothers, who were often the student's primary confident and sounding board in their education and career and rethinking process, took into account the student's enjoyment, interest, and investment in the new discipline and projected career when assessing whether a revised choice would reduce stress, increase engagement, and secure future career satisfaction. Some parents, particularly fathers, qualified their support of a switch out of concern whether the proposed alternative would ensure not only greater enjoyment of the discipline but also viable future employment—a distinction between happiness now and happiness later. The hardest line was taken by those fathers who viewed higher education (and especially choice of a STEM degree) as an investment made in expectation of high future financial returns.

Where parents differed, and fathers took a tough stance against a move out of STEM, we noted a distinctive change from the original study findings. In the 1990s, fathers were less enthusiastic about their daughters' choice of a STEM major—preferring something more "gender-suitable"—and also took a more indulgent attitude toward a switch into a non-STEM degree by their daughters than by their sons. In the present study, daughters described their fathers as strongly favoring STEM degrees as a sound way for young women to secure financial security. We also learned that fathers were equally unsympathetic to moves out of STEM pathways for both daughters and sons. Other parents who disapproved the proposed switch were worried that, in an uncertain job market, all or most non-STEM degrees would lead to poorly paid, insecure work. Concern for loss of an entrée to a prestigious profession was most strongly expressed by parents in Asian American and immigrant communities.

Sixty percent of switchers described their parents as supportive of their decision to move to a non-STEM major and career path. The dominant concern of these parents was that their children would find a good fit for their talents and interests. This was widely regarded as a better criterion for a sustainable future than instrumental choices focused on career prestige or likely earnings. However, the rationales behind parental support for switching decisions were broadly of two kinds. Although their child's happiness was a central concern, some parents (particularly father and mothers based on their own work experience) urged consideration of happiness now versus future happiness via economic independence and security. Other parents supported switching and relocation moves because they saw passion for a discipline and its career options as the best routes to both present and future happiness. Rethinking their initial academic and career preferences as students discovered who they are and what they want out of life was seen as a normal and desirable outcome of higher education and worthy of their support.

Paying for College

An important persistence variable is the degree to which the difficulties of balancing academic work with employment places a student at risk of switching or of not completing any degree. In the original study, we reported student difficulties created by decreasing public funding for student tuition and fees, and that competition for shrinking financial aid had become racially divisive. Approximately two-thirds of interviewees had taken out loans and half were meeting some proportion of their educational and personal expenses by working, the average being 18 h per week.

Since the original study, average student working hours have increased and many students now work in the 20- to 25-h per week range. At this level of employment, college work starts to suffer.

Working 20 or more hours a week also distinguished switchers from persisters: it was cited as a problem by 70% of switchers and 48% of persisters and was a direct contributor to decisions to leave for 10% of switchers. While it prompted moves into majors where completing a degree while working is more possible, it sometimes led to failure to complete a degree. More switchers than persisters worked and switchers worked longer hours than persisters; and three times as many switchers as persisters reported work overload and stress. Persisters who worked longer hours reported difficulties in balancing work and school and saw a drop in their grades. We also noted demographic patterns in persistence risks created by the need to work: more students of color, and more women of all races and ethnicities worked than did white men. The groups with the highest proportion of working students were both switchers, namely white women and men of color (60% of each group). Students who worked less than 10 h per week worked mostly by choice and did not experience significant disruption in their school work.

The most common reason for students to work was that their families could contribute little or nothing to their college costs. Some students reported performance-based scholarships, and 27% of switchers and 25% of persisters received Pell awards. As in the original study, approximately 60% of STEM majors did not get financial aid. However, they expected it far less than hitherto. Those with limited or no family support simply expected to work and take out loans.

Repayment of student loans, a universal source of worry for both switchers and persisters, could strongly influence career choices. Concern about loan repayments caused some students to reject or delay graduate school and question whether their preferred career was financially viable. We noted a clear move away from careers that were once considered secure and lucrative. Given substantial loan obligations, the time and additional funds required to enter medical and veterinary fields were seen as greater than could reliably be recovered in a realistic timeframe. Such calculations prompted both relocation and switching into majors leading to careers in health and therapeutic fields that have shorter, less expensive trainings.

Overall, we estimate that the work-school stress that significant hours of work creates for both switchers and persisters has doubled since the 1997 study. In Chap. 10, we cited the work of scholars who have documented the reasons for this change—growth in the average net price of a STEM degree and a correspondingly large increase in student debt that is greatest among students whose family income lies just beyond the qualification limits for Pell awards. They also document an alarming rise in food and housing insecurity that is now greater among college students than in the general population, and lower rates of degree completion among students with the greatest financial need. In the original study, some of our student commentators on the weed-out system described it as a means test that is biased against those who have to work their way through college.

Student Appraisals of Economic Conditions and Job Opportunities

We found far greater concern than was evident in the original study about what prevailing economic conditions implied for job availability and their financial prospects. One-third of switchers and one-fifth of persisters described how their decisions to switch or relocate were influenced by the employment prospects and limitations that they saw in particular fields. Repayment of student loans was the predominant financial concern of both switchers and persisters. Consideration of the costs of undergraduate and graduate education that would have to be funded by student loans prompted rethinking of majors and career pathways away from those with a "high debt-to-salary ratio." Thus, initial choices based on interest or altruism were often replaced by instrumental career choices. Most students were doubtful about their chances of securing job with a high salary and focused on career pathways that seemed most likely to offer recession-resistant job security. More than the potential pay level of particular careers, both persisters and switchers saw a career's flexibility and versatility as their best chance of a secure future. Persisters looked for emerging fields with many applications, and relocators moved in order to position themselves in expanding and flourishing sectors. More than in the original study, students were wary about entering government service which (except the defense sector) was perceived as insecure. An indicator of a highly competitive job market that was widely resented was the new norm of unpaid internships that do not necessarily lead to employment.

Thus, students' concerns for their future increasingly reflected those of their parents. The single, most notable, outcome of these concerns was re-assessment of medical and veterinary careers, formerly considered secure and well-paid, but now judged as taking too long and costing too much. Favored instead for their shorter post-graduate programs and greater certainty of employment were other healthcare, therapeutic, and caring professions. Popular career choices that met these criteria were physicians' assistant, anesthetist, nurse practitioner, physiotherapist, and other growing health-related specialties. As discussed in Chap. 11, pragmatic re-appraisals were a contributory cause of switching in and of themselves. Perceptions of poor pay and low status trumped job security, however, in the marked decline of interest in teaching science and mathematics in K-12 settings. Only a handful of students expressed an interest in K-12 teaching, whereas, in the original study, 8% of both switchers and persisters intended to teach, and 20% were considering it.

Optimism was discipline-based with some STEM fields seen as more competitive than others. Across the entire student sample, persisters majoring in engineering or computer science were the most confident that current economic conditions would secure them well-paid employment. Chemists were also more optimistic because their discipline has fewer graduates. With fewer direct applications, physics was seen as less lucrative or secure. For first-generation students, including many students of color and students from immigrant families, career decisions were grounded in a primary obligation to "give back" to family. Largely absent in working-class families were socio-economic networks through which knowledge of, and access, to jobs might be secured. Students with access to family-based networks were very aware of their advantages; those who lacked them were actively developing academic and professional networks.

Overall, students' critical appraisals of the job market in the current economy and their concerns about long-term loan debt prompted widespread rethinking of original career choices. To better position themselves to enter a changing and uncertain job market, some students switched or relocated to other STEM majors. This marks a profound shift from the original study where, notwithstanding growing dependence on loans and working while in school, students expressed more optimism about their job prospects, and were more disposed to follow their interests and to choose careers that they saw as "making a difference."

The Personal Costs of a STEM Education

The processes that result in persistence (including relocation) for 52% of STEM entrants and in loss by switching or leaving college by 48% include struggles with negative personal consequences that affect both switchers and persisters (though in smaller proportions). As discussed in Chap. 10, the most common group of negative consequences (reported by 79% of switchers and 44% of persisters) was loss of confidence in face of low grades that contributed to 61% of switching decisions. Loss of confidence was greatest among women, half of whom were women of color, and most often occurred as a consequence of weed-out course experiences. Our finding echoes that of Ellis, Fosdick, and Rasmussen (2016) about what they describe as the effectiveness of Calculus 1 courses in destroying incoming confidence. Even with final grades of As and Bs, twice as many women as men with the same grades abandoned the idea of continuing to Calculus 2.

Also in Chap. 10, we discussed the role of "perfectionism" in the switching decisions of high-performing students that included men, but more often women, and in the ongoing struggles of persisting seniors. Conditioned to high-performance expectations for themselves, high-achieving STEM majors who are unwilling or unable to dissociate their grades from their identity are at high risk of switching. The mental and emotional distress they describe arises from low tolerance for less than perfect performances. Moderate grades interpreted as failure pose an intolerable threat to identities that are extrinsically derived from high grades and the status that they confer. Rather than making adjustments to stay in their major, switching enables high performers to regain self-esteem and a valued sense of self without having to change the reputational criteria upon which these are built.

Thirty-four percent of switchers and 8% of persisters reported depression, high levels of stress, chronic anxiety, feeling lost and overwhelmed, or living with intolerable fear. These included: the fear of admitting that one cannot cope with the work; the fear that this will only get worse, and dread of going to class. Another group of students described states of emotional and mental distress that not only precede decisions to switch or relocate but often linger beyond them. Reported by 23% of switchers and 3% of persisters, they include: feelings of guilt, failure, or regret; shame, self-blame for their difficulties, and feeling stigmatized as someone who failed or "couldn't make it"; being tired of feeling miserable, bad about one's self, or being too paralyzed to act.

Finally, chronic levels of stress, depression, fear, anxieties and/or guilt, shame, stigma, and self-blame took their toll on 15% of switchers and 7% of persisters in the form of mental or physical health problems, including exacerbation of existing health conditions and clinical diagnoses of depression or anxiety. Nationwide, campus mental health services and offices of student affairs have recently reported rapidly increasing rates of anxiety and depression among college students, and, as we were made aware during our site visits, a number of STEM majors commit suicide each year. As we review in Chap. 10, perfectionism in college students has been extensively studied (though not specifically for STEM majors) in relation to its maladaptive manifestations, such as procrastination, burn-out, anxiety, depression, eating disorders, and suicidal ideation. Curran and Hill's (2019) meta-analysis of studies on perfectionism among college students report a significantly rise in perfectionism over the past 25–30 years. They argue its origins in the increased competitiveness, individualism, and meritocracy that have shaped the neoliberal character of American and other world economies. As we document in Chap. 9, the struggle to belong in the negative, at times-hyper competitive, atmosphere pervading some STEM programs puts students at risk both of ill-health and of switching. As Travers, Randall, Bryant, Conley, and Bohnert (2015) describe, the risks are intensified where students conceal the effort put into achieving high grades, such that their success appears natural and easy, while other students lose face over their more overt struggles. We first noticed this behavior in the original study where young women were demoralized by the apparently effortless success of some young men. Two recent articles describe the rise of "effortless perfectionism" among women on competitive college campuses and the personal and emotional toll of sustaining such standards (Ruane, 2012; Yee, 2003). As we have also reported, for high-performing students with perfectionist tendencies the consequent assumption can be that there is no space between perfection and failure, and that only one very narrow and extremely high standard of achievement leads to success. The personal costs of a STEM educational experience may be disattended as somehow inappropriate to an academic life. However, they are a reminder that the benefits and costs of education are never purely cerebral but involve the whole person.

What Enables Persistence?

Almost half of the persisters in our sample had, at some point, doubted that they had chosen the right path, and 28% had actively considered switching to a non-STEM major. Women were more likely to consider switching than men, as were, African

Americans, and students who entered with low math readiness, but there were no disciplinary differences among persisters who had considered leaving STEM.

Persisters faced the same difficulties in course design, pedagogy, and assessment methods as switchers, and, like switchers, most persisters who had considered switching were responding to grades that they found irrational and disorienting. However, unlike switchers, they were prompted by these experiences to make adjustments, notably in their study habits. As they came to realize that curved grades do not reflect actual learning, high-achieving persisters also began to detach their sense of self-worth from their grades and GPAs. They described this as a long, difficult, but essential transition if they were to stay in their major. It involved accepting that, whether an apparently failing grade represented actual failure depended on how the rest of the class performed. In such crises, persisters differed from switchers in finding ways to adapt their expectations and academic identities, find resources, figure out how to navigate around their difficulties and keep going.

As we found in the first study, for switchers, crises over grades often deepened feelings of isolation and doubts about belonging. When decisions hung in the balance, the scales could be tipped in favor of persistence by the serendipitous intervention of a friend, advisor, or faculty member who normalized the struggle for them. Thus, persistence may depend on the randomness of supportive encounters. Talking to STEM seniors, it was clear that not all their difficulties were resolved. Some still struggled with perfectionist self-demands that they knew kept them at risk.

In describing how they had made it thus far, seniors rarely cited one single approach. Rather, they described an interacting array of individual, social, cultural, and institutional resources that they drew on to survive. These were, broadly, of four kinds. First, they cited personal traits that included maintaining determination and the will to succeed, sustaining intrinsic interest in their discipline and career goals, and a strong belief in oneself. While sheer determination and sustained interest often enabled students to overcome early struggles with low grades and other difficulties, men of color and women of all races and ethnicities also encountered social, cultural, and structural barriers to surmount which required even greater strength, stamina, and determination. Whether students held a privileged or marginalized position within their discipline also determined when the will to persist came into play: students of color and women drew on "grit" to overcome isolation or hostile climates, while more advantaged students used it to combat difficulties with grades or coursework. Altruism was cited by students of color, especially women, in sustaining their interest and motivating them through periods when they felt they did not belong their major.

A second group of adjustments were shifts in behaviors and identities that stressed, accommodating lower grades, developing effective work habits, and maintaining a balanced life style. There were no differences by gender or race/ethnicity in developing effective study and learning habits. Among students who entered under-prepared, whether conceptually or in time management and study skills, persisters managed to develop these capacities more quickly than switchers. As they advanced in their coursework, they learned how to adjust to the workload, expectations, and work habits required, and to adjust their study strategies to the course, the professor, and the material. Contrary to the belief that non-STEM interests are distracting, some seniors (women more often than men) advocated avoidance of total absorption in their major. They had discovered that nurturing wider interests for pleasure and counterbalance improved their STEM disciplinary focus. They engaged in sports, music, art, literature, and languages, or added another major or minor in a non-STEM field.

A third set of strategies focused on seeking out and using social and institutional sources of help and support, both formal and informal, and taking advantage of intellectual and professional out-of-class experiences. An important, common strategy (also reported in the original study) was working with informal peer study groups. These performed several important functions—enhancing students' conceptual understanding, giving social and emotional support, building a sense of belonging and community, and providing guidance and advice about STEM pathways. While some students benefitted from study sessions and supplemental peer instruction organized by departments, the majority of students also found informal peer study groups essential to their survival. Academically oriented peer support (including that found in STEM-related clubs) also supported the retention of underrepresented minority students. Despite their vital role of peer support systems in persistence, most students had to instigate and navigate these relationships for themselves. Students who had difficulty in connecting with a peer study group were at risk. These included students who are marginalized or underrepresented in STEM majors, students with health or emotional disabilities, under-prepared students, and students with outside responsibilities, such as children or full-time jobs. Despite institutional efforts to create a structured system of study groups, we also found (as in the original study) that not all students took advantage of them. An implication arising from these findings is that, discovering why some students do not use formal and informal resources, and experimenting with ways to encourage their greater use, would make a significant contribution to STEM retention, particularly for more vulnerable student groups.

The fourth group of strategies involved figuring out how to play a STEM major as a system in order to increase the likelihood of success. System-playing was noted in *Talking about Leaving* but was far more widespread in this study with persisters proving to be very savvy "consumers" who navigate their pathways through STEM majors in creative and improvisational ways. Seniors described how they carefully researched courses, sections, and faculty members in order to make selections that gave them the best chance of passing courses with good grades. They reviewed online resources and crowd-sourced comments to identify instructors, course sections, or even institutions and departments that would provide the best chances of success. Seniors described these moves as a form of game-playing to maximize their chances of securing a STEM degree. Some students undertook this research because they saw the quality of instruction as vital to their learning and retention, but, more often, students played the game purely to improve their grades. In weed-out courses, beating the class average was sometimes seen as more important to retention or advancement than actual learning or interest, and some seniors had reservations that "gaming their major" was not optimal for learning or long-term success. The circuitous course-taking patterns taken by many STEM students in order to persist and their relocations between majors and sometimes institutions to secure a better fit with interests or career preferences indicate that linear degree paths undertaken at single institutions are no longer seen by many students as the optimal way to secure a STEM degree. We note that the growth and widespread use of game-playing persistence strategies and the highly consumerist approach indicated by our findings also have profound implications for coherence and consistency in STEM degrees.

We deliberately included a sub-set of STEM seniors who had entered with lower math scores than the rest of our interview sample in order to learn how they had managed to persist despite the odds. Students who entered with low math readiness were more likely to consider switching out of STEM during their undergraduate careers. However, compared with high math students, low math students made much greater efforts to enable their own persistence and made use of a wider array of strategies and resources than their high math peers. They were also much more likely to actively manage their schedules in a way that best facilitated their success, including taking "risky" classes at community colleges. They were also more likely to cite their own determination, bolstered by strong parental expectations, as essential to their persistence. This was especially marked among students from first-generation and immigrant families. They also stressed the importance of finding a support system and figuring out how to navigate college STEM courses and coursework in the most advantageous ways. Higher percentages of low math than high math seniors cited the importance of these traits, adjustments, and strategies in all four categories of persistence enablers that we have identified.

We have highlighted the role of legitimating beliefs in explaining the perpetuation of STEM teaching practices with dysfunctional outcomes, and the ways in which such practices and their validations are absorbed by undergraduate and graduate students who carry them forward to another generation. Belief in a meritocratic narrative, which is widespread in STEM disciplines, belies the ways in which courses and institutions are structured in ways that facilitate or impede student success. In keeping with this dominant narrative, we also found that many persisting seniors ascribed their success to talent, intelligence, or self-efficacy while, in the same interviews, also describing their reliance on behavioral adjustments, their use of social and institutional resources, and their ways of navigating STEM majors as systems in calculated ways to secure success. Indeed, most persisters viewed their STEM major as a "game" to play and a challenge to overcome by judicious use of available resources while crediting their success to their personal strengths. However, it was clear from our evidence that personal characteristics alone were never sufficient to secure success. We propose that the danger of the meritocratic narrative that explains persistence in terms of individual interest, effort, and intelligence is that it absolves STEM faculty, departments, and colleges of responsibility for student learning and success. Yet, almost all persisters relied on the kinds of external supports that we have identified in order to succeed. As we concluded in the original study, determination, passion, and a strong will to persist were important, but not sufficient, components of persistence by themselves; we find this still to be true in the current study. This finding alone has implications for the design and teaching of STEM courses because it illustrates the role of institutional systems in students' success.

Envisioning the Future: What Institutions Can Do

As we have reported there is strong collaborative evidence from three of our studies that active and interactive teaching and learning strategies have, to varying degrees, been introduced in all six sample institutions where none were evident 20 years before. Although we cannot generalize from these findings alone, when added to evaluation reports from STEM education reform initiatives (reviewed in Seymour & Fry, 2016), they suggest that credit for the 16% drop in the national switching rate is likely due to the substantial efforts of the STEM education reform community and its funders, to the research that validates their work, and to the disciplinary and professional organizations that promote both of these. Over the last two decades, STEM instructors have collectively created a body of thematic, contextual, research-grounded curriculum and learning materials, an array of classroom-tested, active, interactive, and inquiry-based pedagogies, and learning assessment methods that explore students' depth of understanding, and ability to apply, extend, and transfer their knowledge. This expanding body of tested and discipline-relevant methods and materials has been disseminated to widening circles of instructors through online resources and communities, journal articles, conference presentations, and workshops that offer hands-on exposure to learning theories, research findings, and their classroom applications. With such a body of resources already available, the key question is how best can successful STEM education improvement strategies be taken to scale and sustained? Thus, the emphasis has shifted from the individual and collaborative efforts of STEM instructors to what institutions and departments can do to encourage and sustain all that the STEM education reform community have created.

To address the challenge of transformative change requires consideration of how institutes of higher education (IHEs) work. Their structure has evolved to preserve customary ways of carrying out formal tasks that are evident, for example, in the design of lecture halls, the criteria for departmental funding, and for faculty rewards, tenure, and promotion. Institutional structures privilege traditional teaching methods and do not easily accommodate new ones. This makes the resulting inertia hard to break, involving, as this does, both structural and cultural shifts. Indeed, resistance to change in its educational functioning may be seen as normal in higher education institutions. Thus, those engaged in the process of experimentation with educational improvement have learned that some strategies work better than others. Important among these is that successful teaching reform requires a combined top-down and bottom-up approach. From the top, it requires institutional commitment to the value of research-based instructional strategies (RBISs), shifts in the distribution of funding and rewards, and changes in organizational and physical structures.

Without sufficient top-down buy-in and material support, grass-roots efforts to institutionalize RBIS invariably founder (Seymour, 2001).

In light of this history, it is essential to convince chairs, deans, provosts, and college presidents that high-quality teaching and the scholarship of teaching and learning (SoTL) are important to their mission. That this idea is gaining ground is evident in the spread of institution-sponsored teaching and learning centers, undergraduate research programs, high-school-to-college bridge programs, and women-in-science programs. As it is departmental rather than institutional leaders that have most power to determine matters of curriculum and pedagogy, institutional leverage in these matters may appear to be indirect and marginal (Seymour, 2001; Seymour & DeWelde, 2016). What, then, do institutions have the power to do that contributes to sustained educational improvement that supports greater retention of STEM majors?

The existing institutional rewards system is the main structural deterrent to change for faculty who are otherwise disposed to rethink their teaching. The strategies that would improve their pedagogy are not yet widely embedded in faculty positions and rewards. In accord with Boyer's (1990) proposition that achievements in research and teaching should be judged by parallel criteria, some institutions have extended their criteria for hiring, promotion, and tenure to include evidence of teaching effectiveness and the scholarship of teaching and learning (SoTL) and discipline-based educational research (DBER). The institutional climate for classroom reformers seems to be improving: directors of STEM education initiatives cite tenure successes among their project participants and also a growing trend for new faculty to negotiate career paths that include their innovative teaching and SoTL (Seymour & Fry, 2016).

Institutions also have considerable power to encourage faculty uptake of new curriculum or pedagogy by changing their faculty time allocation policies. Providing release time to allow faculty innovators to do their work is critical to their chances of success. This is especially important for the principal investigators (PIs) of reform efforts who are teaching faculty. Any multi-institution project's administrative efficiency is undermined from the outset unless its faculty PI receives sufficient time from the host institution to organize STEM education reform efforts, particularly those that are multi-institutional in scope.

Strategic use of central resources plays a role both in encouraging and sustaining educational improvements. An effective form of institutional leverage is to offer annual awards to those departments that document educational improvements resulting in desired student outcomes over the previous year. These might include departmental self-study, defining learning objectives for degree programs, aligning course objectives across curricula, the introduction of research-based instructional strategies and assessment of their efficacy, and using data to understand the characteristics of students entering and leaving their majors. The purposive deployment of money, jobs, and resources is also critical in sustaining successful innovations after external funding ends. It entails providing administrative support and funding faculty lines or staff positions that service and support research-based instructional strategies. Administrative and physical structures may also need to be changed to accommodate new ways of teaching, for example, classroom redesign, the addition of technical teaching aids, and provision of service staff. We encountered evidence of such changes at all six of our sample sites.

In support of the institutional changes noted above, we have identified four more specific strategies that have been shown to be critical to the sustained uptake of RBIS pedagogy: (1) providing professional education in teaching methods and learning research for new instructors and graduate TAs; (2) financing and promoting workshops that support existing instructors in hands-on learning of new teaching and student assessment methods; and (3) adopting course assessment tools that provide instructors, departments, and the institution with data on the efficacy of course teaching. (4) Departmental self-study.

1. Durable, nationwide STEM education reform requires development of institution-wide professional education programs that ground the pedagogical knowledge and skills of current and future faculty in learning research. The professional education of graduate students as the new STEM teaching force is essential in enabling departmental transition to research-based teaching methods. Where instructors are developing new forms of pedagogy, it is critical to their success to ensure that their graduate teaching assistants understand both how the new methods work and their basis in learning research (Seymour, Melton, Pedersen-Gallegos, & Wiese, 2005). Institutions can provide funding and resources for teaching and learning centers, and institute professional development programs for the future professoriate—new instructors, post-docs, and graduate teaching assistants. They can also actively leverage departmental understanding and use of these programs.
2. Disciplinary-based workshops have, for two decades, been the main conduits of teaching knowledge and know-how. There is strong evidence that workshops foster the uptake and spread of within- and cross-institution educational reform by drawing in, educating, and enabling new faculty and incorporating them into the change effort. Workshops are effective because participants learn from each other by trying out alternative methods in a relaxed, private, and congenial context that encourages collaboration and builds connections. To work optimally, workshops must be of sufficient duration, offer repeated exposure in a progressive sequence, provide support for new reformers in their departments, use "old hands" as facilitators, and build facilitator capacity among newer recruits (Andrews, 1997; Connolly & Millar, 2006; Hilsen & Wadsworth, 2002). Workshops give participants motivation and skills. They also offer portals to like-minded people whom they might not ordinarily meet—colleagues in different disciplines, administrators, senior faculty, and graduate students. Many professional and disciplinary societies have stepped into this role by mounting workshops as part of annual meetings. Institutions that offer workshops can draw on this expertise, reap these benefits, and build disciplinary and cross-disciplinary communities where colleagues learn from each other how to deploy best practices in their classrooms.
3. Adoption and continued use of RBISs to improve pedagogy depend on faculty being able to get valid, reliable data about their efficacy for student learning

(Dancy & Henderson, 2010). As explained in Chap. 1, in order to learn what students in foundational classes were (or were not) gaining, we used a customized version of the Student Assessment of their Learning Gains (SALG) one-line survey (cf., Appendix C). Originally designed for STEM instructors with NSF support, but widely used by faculty in other disciplines, the SALG is available, free-of-charge, to all instructors. It is also used by departments and institutions as their course evaluation instrument. For example, the Gateways to Completion (G2C) initiative (whose collaborative research was cited in Chap. 7) systematically deploys SALG instruments, and the resulting data help participating institutions to improve student success in courses with historically high DFWI rates.

We encourage consideration of the SALG survey (https://salgsite.net/) by institutions and departments because systematic assessment of what students are gaining from their courses is essential if course improvements are to be sustained. SALG survey templates can be edited to reflect the learning objectives, contents, and methods of any course. Thus, they provide detailed information about what progress students are making toward course learning goals and which pedagogical strategies do, and do not, enable this. Such data can help instructors to make rational, targeted improvements to their course design and pedagogy, demonstrate the value of their RBISs to others, reduce RBIS discontinuation, and document their teaching achievements for tenure and promotion purposes. As a replacement for traditional course evaluation instruments (in which students are asked to assess their instructor), SALG surveys enable departments and colleges to make evidence-based improvements to programs and curricula and gather data for departmental accreditation purposes.

In addition to the 10,000 instructors who regularly been using the SALG for over a decade, the NSF has recommended SALG surveys to evaluate STEM education projects and they are widely used in the STEM education reform community for project evaluation and to gather data for SoTL publications. (The results of SALG surveys have been cited in over 450 scholarly publications.) The SALG-based Undergraduate Research Student Self-Assessment (URSSA) is used by UR directors (including the NSF's REU programs) to track student learning gains in UR experiences. A growing number of departments and institutions have adopted the SALG as their course evaluation instrument and use its group functions to assess curricula, programs, and pedagogical innovations. SALG data are also increasingly accepted by accreditation agencies as prima facie evidence of student learning for program review purposes.

4. We have also pointed to the need for research data to understand why 20% of STEM entrants nationally leave college without a degree and which students are most at risk of such departures. As we have illustrated from our own analysis of data provided by the six participating institutions, it is entirely possible that institutions already have access to data that can answer these questions. Using existing institutional records data, we were able to identify which students are lost from "weed-out" foundation courses. Thus, departments and colleges could also keep track of what students, with what characteristics, enter and leave their

majors and monitor improvements in these patterns as a result of changes in course teaching and assessment methods. It is possibly a task for ethnographic researchers to discern the instructor beliefs that underpin and perpetuate the pedagogy, course design, and grading practices typical of “weed-out” courses. This undertaking would also underpin departmental consideration of more effective, alternative ways to introduce students to important disciplinary content. Recent research on effective transformation (Weaver, Burgess, Childress & Slakey, 2016) points to the effectiveness of departmental self-study combined with faculty learning communities in creating educational improvements at the departmental level.

The most serious implication from our findings is the need to address the chronic pattern of under-preparation of talented students from working-class families of all races and ethnicities who enter undergraduate STEM education from under-resourced schools from across the nation’s educational system. To adequately address this problem requires considerable rethinking of state and national policy. However, awareness of this significant cause of losses from STEM majors might also prompt or reinforce ameliorative interventions by higher education institutions and STEM departments. The success of summer bridge programs and of math-readiness assessment and remediation prior to and upon entry encourage such ameliorative remedies until larger problems in the education system can be addressed. It is also possible that institutional leaders can use their platform and communication channels to raise this problem to the consciousness of state and national political leaders. Other topics for such conversations might also be the impact of financial debt on students’ degree course and career decisions.

Not only do many of the issues that inhibit STEM persistence lie within the scope of institutions but the strategies by which to address them are already available to the leaders of IHEs and to their departments and colleges. The pioneering work of many STEM instructors has provided the educational means for nationwide improvement in the loss rates of STEM majors. To make further progress in resolving the problems that we have described will require the collaborative engagement of institutional and departmental leaders. It would seem timely to pick up the baton and carry it forward.

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