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To STEM the Decline: Seeking a National Resurgence Through Coordinated Reform

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Abstract

Despite broad agreement that the United States must educate more of its citizens more effectively, particularly in the sciences, technology, engineering, and mathematics, and that it must provide greater opportunity for those qualified in these disciplines, the political will required to accomplish this priority has not emerged. While educators, opinion makers, public servants, and supporters agree on ambitious goals for degree completion and job creation, US competitiveness with respect to the rest of the world continues to slip. Reversing this trend will require a unified strategy. Grounded in four carefully aligned principles already evident in practice but not yet part of a coordinated plan, such a strategy could engage a wide range of supporters behind a compelling agenda. The principles are as follows: 1) Define the STEM priority so as to emphasize broad competencies critical to effective performance, including those learned primarily in the humanities and social sciences. 2) Clarify through a national framework of educational outcomes the expectations appropriate to each degree level. 3) Seek consensus within the disciplines regarding the cumulative growth in knowledge and experience offered through majors. 4) Create more sensitive and informative measurements with regard to the effectiveness of programs and institutions, apply information gained from assessment to the continual improvement of programs and institutions, and make such information available for purposes of comparing programs and institutions. While each of these principles may be found in some current undertakings, they remain largely discrete. If presented and pursued as a coherent and systematic initiative, with much the same emphasis on coordination as evident in Europe's Bologna Process, these principles could create a unified platform for a successful pursuit of national resurgence.

Key words: Tuning, Bologna Process, physics, learning outcomes

Introduction

Since Judith Ramaley coined the acronym joining the sciences, technology, engineering, and mathematics (1), there has developed a broad consensus regarding the nation's need for well-qualified graduates in STEM disciplines. Speaking at the Pacific Science Center in 2010, Jeff Raikes, CEO of the Bill and Melinda Gates Foundation, defined this consensus well. A growing workforce of STEM graduates "can resurrect the spirit of innovation and economic vitality that has been so important to our prosperity for more than a century." An economy charged with this spirit will offer each year an additional one million openings for high-paying STEM jobs that require some college" (2).

These two priorities—increased economic vitality for the United States and expanded opportunities for individuals educated to sustain that vitality—are recurring themes in more than a decade of reports, legislation, calls to action, and declarations of commitment. A selective list might include a 1996 report by the National Commission on Teaching and America's Future, the 2002 No Child Left Behind legislation, a 2003 summons to "realizing America's potential" from the National Science Board, a 2004 report on a "national innovation initiative" from the Council on Competitiveness, a 2005 summons from the National Academy of Sciences titled "Rising Above the Gathering Storm," a 2006 National Science Board declaration regarding "America's Pressing Challenge" and an American Council on Education poll showing a policy gap with respect to competitiveness in math and science education, a 2007 initiative by the National Governors Association given the name of "Innovation America," a "national action plan" in the same year from the National Science Board, a 2008 "Foundations for Success" statement from the National Mathematics Advisory Panel, an October 2011 webinar and report from the Georgetown University Center on Education and the Workforce, and, most recently, a 2012 report to the President from the President's Council of Advisors on Science and Technology (PCAST), "Engage to Excel: Producing One Million Additional College Graduates with Degrees in Science, Technology, Engineering, and Mathematics."

The PCAST recommendations, which capture many of the major themes of preceding reports, suggest the breadth of an evolving concern and, by focusing on the first two years of college, propose some approaches the could increase the number of STEM graduates. But they hardly appear to embody the sense of urgency that characterizes most STEM discussions. In sum, the PCAST urges that teaching be improved through the broad adoption of "empirically validated . . . practices," that "standard laboratory courses" be replaced by "discovery based research courses," that there be a "national experiment" to improve postsecondary mathematics instruction, that "partnerships among stakeholders" be encouraged so as to "diversify pathways to STEM careers," and, predictably, that one more Presidential Council be created to "provide strategic leadership for transformative and sustainable change" (3, pp. 2-3). To be fair, the detailed explanations for each of these recommendations offer substantive ideas well worth consideration. But it is difficult to avoid the conclusion that a summons to greater emphasis on improved teaching and increased partnership hardly creates a compelling agenda for change.

Yet one important conclusion arises from the decade's fusillade of reports, recommendations, and calls to action, and that is that the STEM priority is one of the few that can attract broad, nonpartisan, unambiguous lip service. Even voices critical of an exclusive focus on STEM at the expense of the liberal arts do not object to the priority as such.

Why, then, has so little been accomplished? Obvious answers include a sustained economic downturn that has meant less money for education at all levels, a highly partisan and largely unproductive Congress, and concerns about the costs and effectiveness of higher education. Less obvious reasons lie in the attrition that Carnevale and his colleagues detect from high school to college (4, p. 4). They found that 75% of high school students with preparatory education in STEM do not choose STEM majors, that within college 38% of those choosing STEM majors shift to non-STEM majors, that following graduation 43% of STEM graduates do not take up STEM positions, and that for ten years thereafter, STEM workers choose alternate vocational tracks (4, pp. 5-6). Beyond the immediate need for more STEM workers, they identify a "deeper problem," namely, "a broader scarcity of workers with basic STEM competencies across the entire economy" (4, p. 4).

But a more persuasive explanation for why not more has been done to address the problem may be found in the very multiplicity of the proposals, declarations, agendas, and projects that have been advanced. The overriding problem may lie not in a lack of commitment, but in an inchoate range of commitments with varying emphases; not in the dearth of good ideas, but in the flurry of competing ones; and not in a scarcity of concerned organizations, but in their lack of coordination with one another. We offer by contrast a simple assertion: if we are to mobilize the public support required to achieve meaningful progress in STEM education, we must organize the most promising initiatives into a realistic, well coordinated, and coherent process, one that supporters will perceive to be a whole greater than the sum of the parts.

Such initiatives should be selected according to five criteria. First, they should be directly (not tangentially) germane to the dual objective, more effective education in the STEM disciplines and expanded opportunity in the STEM professions. Second, they should promise a reasonably efficient approach to achieving timely results. While proposals for the creation of additional federal grant programs and the convening of yet another advisory council may be well intended, such pursuits can offer the appearance of progress without creating actual gains. Third, such initiatives should offer promising preliminary returns. That is, they should already be proven to an extent, not purely speculative or aspirational. Fourth, while clear in their focus on higher education, such initiatives should also demonstrate some consideration of all relevant arenas: higher education, K-12 education, and public policy making. Finally, such initiatives should invite a good fit with one another. Their interdependence should be patent, their potential synergy, easily grasped.

A tall order? To be sure. Yet there are at present just such initiatives under way. If more fully coordinated as elements within a single coherent undertaking, they could coalesce as a compelling agenda directed towards making real progress. Such an agenda would offer advantages the disparate initiatives cited above lack: a single, multifaceted time line, a mechanism for regular review and renewal, a platform for informative and widely accessible reporting, and lucid criteria for accomplishment. Such an agenda could attract the substantive bipartisan support essential to getting things done at both state and federal levels.

There is an instructive model for such an undertaking, Europe's Bologna Process. Arguably the most successful reform in the history of higher education, since its inception in 1999 the Process has achieved its considerable gains less through the appeal of disparate initiatives than through its promise of a coherent and coordinated effort. It is difficult to imagine that the 47 participating nations would have found it possible to agree on an extensive palette of unrelated efforts. To the contrary, their making common cause demonstrates the conceptual strength and political appeal of a single, multifaceted program, the elements of which stand clearly in a mutually dependent relationship. Success is so defined as to assume and in fact depend on progress on all fronts. Even the current slackening of Bologna's pace of reform, which the European Students Union (ESU) has attributed to a "lack of commitment" on the part of many of the participating countries "to fulfilling even the simplest Bologna goals" (5), appears less the result of problems associated with particular initiatives than the consequence of an erosion of coherence. That is, as the ESU has said, an increasing number of participating countries appear to be taking an a la carte approach to a menu intended as table d'hôte.

Ingredients of an agenda

As suggested above, initiatives appropriate to a coordinated effort to improve STEM education and the opportunities it promises must meet logical, practical, and political criteria. They must be compatible, of course, but they must also be cumulative: gains with respect to one should support and perhaps even prompt gains in others. They should offer modest incremental gains rather than simply promise the extraordinary at some point down the line. Their process should be clear and the intended returns easily understood. Above all they should invite support from many sectors and so discourage identification with particular political persuasions. The initiatives proposed below were framed in the light of these criteria and should be considered accordingly.

Defining the ingredients of STEM success

In the December/January 2012 issue of Technology and Engineering Teacher, Scott Bevins, director of institutional research at the University of Virginia-Wise, observes that "the the liberal arts and STEM [disciplines] must work together to ensure that our students are given the greatest opportunities for success in a global economy" (6). He thereby revives a call made in the Spring/Summer 2004 issue of The Journal of Technology Studies by Oscar Plaza, who recommends "a continuum model of education" that draws on both the liberal arts and technology. While maintaining "their own identities," teachers in STEM and liberal arts disciplines should collaborate in educating students. Just as those within the liberal arts might appreciate more fully how "tools not only enhance human physical abilities, but also shape human comprehension abilities," so those teaching STEM should understand that "liberal arts is not only about reflecting reality, but also about seeing reality" (7). Such voices are not isolated. A particularly thorough and persuasive case appears in a 2012 Washington Post blog by three members of the National Council on the Humanities (8). They argue that science and technology become "meaningful" only when taught in the context of other disciplines. Memorably, they observe that "a STEM, without its bloom, quickly withers in the forest of everyday life." Because Bevins and Plaza are prominent voices within the technology community itself, they deserve particular attention.

Such arguments for a richer characterization of STEM education, one that emphasizes the broad competencies critical to effective performance, call into question prominent demands for emphasis on STEM disciplines to the exclusion of supporting disciplines. President Obama's announcement in October 2010 of "Educate to Innovate," his identification three months later of $250 million to invest in education, and his 2011 State of the Union call for increased rigor and quality in education have in common their exclusive focus on science and mathematics. While well intended, such statements express a limited vision that overlooks the importance for success in the STEM disciplines of problem-solving ability, group work aptitude, and ethical awareness, for instance—capacities closely associated with education in the humanities and social sciences. A generous explanation for simplistic emphasis on the STEM disciplines may lie in a preference for more easily quantified outcomes that can be readily associated with economic and social gains. But a more compelling view may be that the academy itself, by preserving the traditional distinction between STEM and the humanities in structural and curricular terms, has failed to make a persuasive case for their integration.

Even before STEM became a household acronym, educators with vision proposed an agenda reflecting the affinity of STEM and humanistic disciplines. Most notably, the Association of American Colleges and Universities (AAC&U) has for more than a decade promoted an inclusive commitment to learning outcomes requiring the integration of technical and humanistic learning. General education programs should be informed by expertise within the majors, and majors should build on the gains achieved through general education. And a liberal education requires not only knowledge of and experience with the sciences, technology, the humanities, and the social sciences, but a deep awareness of the dialogue among them. But as John V. Lombardi has observed, large universities, especially, have encountered "real practical and economic challenges" in approaching any reform as thorough as that proposed by AAC&U (9). While the number of institutions pursuing such an integrative view of learning continues to grow, the fact is that not enough of them—large, medium-sized, or small—are doing so.

Nevertheless, if we are to achieve meaningful progress towards greater competitiveness through creating more effective STEM education and expanding the opportunities for the well educated, we must seek on several different levels a definition of STEM education that is both focused and comprehensive. While widespread curricular and structural reform within the academy may be difficult to complete in the near term, there are reasonable pragmatic steps that could be taken now. First, both regional and professional accreditation associations might articulate more publicly a shared expectation that technical curricula incorporate liberal arts education in their pursuit of appropriate abilities and capacities. How many of those making public statements are aware that the Accrediting Board for Engineering and Technology (ABET) defines explicit expectations closely associated with the liberal arts and sciences? For instance, among the student learning outcomes that accredited programs must document are "an ability to function on multidisciplinary teams," "an understanding of professional and ethical responsibility," "an ability to communicate effectively," "a knowledge of contemporary issues," and, most notably, "the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context" (10).

Second, associations promoting liberal education, such as the AAC&U, and those that represent different sectors of the STEM community, such as ABET, the American Chemical Society (ACS), and the Mathematical Association of America (MAA) could undertake the task of explaining to a wary public the risks of a simplistic and reductive understanding of STEM.

Finally, effective information sharing and politic approaches to staff members at state and federal levels should lead opinion leaders to appreciate the complexity of the STEM priority and to give their support to an integrated initiative likely to produce more meaningful results.

A framework of educational outcomes

Given that the goal is more effective STEM education leading to more opportunities for those who are educated in STEM disciplines, any credible effort would have to express an understanding of what "more effective" means. By what standards should effectiveness be measured? The answer must lie in wide agreement on a framework of outcomes, a structured description of what students are expected to learn and be able to do at each educational level.

Such a framework should offer far more than the aspirational statements routinely offered through college view books and catalogs of institutional goals. It should define what knowledge, capacities, and skills students should be able to demonstrate at each degree level according to carefully chosen but clearly permeable categories. Models for such a framework include the 2005 European Qualifications Framework developed as an umbrella for the Bologna Process, the 2008 Framework for Higher

Education Qualifications in England, Wales and Northern Ireland, and the remarkably detailed 10-level Australian Qualifications Framework that was revised in 2011. The second phase of this Bologna initiative, the completion of national frameworks by each of the Process participants, is not yet complete but remains integral to the design of the Process.

In the light of these efforts internationally, in 2010 Lumina Foundation sponsored work to reduce to writing the identification and elucidation of expectations appropriate to each degree level across five sectors of learning. The result of this effort, the Degree Qualifications Profile (DQP), was published in January 2011. While not focused solely on STEM outcomes, the DQP defines expectations germane to STEM disciplines in considerable detail. For example, at the baccalaureate level, the DQP specifies that a graduate should possess specialized knowledge sufficient to the demonstration of “fluency in the use of tools, technologies and methods common to the field” and should be able to develop a project “that draws on the current research, scholarship and/or techniques in the field” (11, p.10). The graduate should also be able to demonstrate “broad, integrative knowledge” by explaining a challenge “in science . . . or technology from the perspective of at least two academic fields” (11, p. 11).

Quantitative fluency, expected of all baccalaureate recipients, is shown to be especially critical for STEM graduates, who must be able to demonstrate their ability to translate “verbal problems into mathematical algorithms” and to develop “valid mathematical arguments using the accepted symbolic system of mathematical reasoning” (11, p. 13). Indeed, an expectation at the master’s level directed exclusively to students “seeking a degree in a quantitatively based or quantitatively relevant field” calls on them to present “multiple appropriate applications of quantitative methods, concepts and theories within their field of study” (11, p. 14).

The emphasis of the DQP on applied learning as one of the five discrete areas of qualification is especially congruent with the principle that ample practice is essential to the development of skills in the STEM disciplines. Hence, among other requirements, a baccalaureate recipient should be expected to complete “a substantial field-based project” that expresses command of the “core concepts, methods [and] assumptions in his or her major field” (11, p. 15).

Yet for all of its many direct applications to STEM disciplines, the DQP finally emphasizes how important integration of the disciplines is to understanding how STEM competencies may provide greater opportunity for graduates while contributing to national economic and scientific progress. There may be no more sustained demonstration of the interrelationship between STEM disciplines and the liberal arts and social sciences disciplines that inform and enrich them. As a result, the broadly inclusive but highly specific DQP serves the cause of STEM education far more fully than analyses and proposals focused narrowly on technical disciplines.

Consensus within the Disciplines

If students are to progress through traditional university programs in the STEM disciplines to the kind of technical competence envisioned by the nation’s STEM aspirations, degree-level expectations, however essential, are not sufficient. Consistent with outcomes expected of all students, there must also be clear curricular paths along which students progress from entry-level qualifications to the beginnings of professional competence. In other words, there must be cumulative outcomes expectations at the disciplinary level as well.

In Europe, Latin America, and, more recently, in some US states, such outcomes are being defined through a process known as “Tuning,” a European coinage pointing to the goal of recognizing the diversity of programs within a discipline (by analogy to the different instruments in an orchestra) while ensuring that all “tune” to the same pitch, that all play in harmony, that all are in some sense synchronized.

In 2009, Lumina Foundation initiated “Tuning USA” with a clear goal, “to better establish the quality and relevance of degrees in various academic disciplines” (12). The first phase of this undertaking engaged faculty members in three states from disciplines including chemistry (Indiana), physics (Utah), and Biology (Minnesota). In a more recent second phase, Texas has tuned civil and mechanical engineering and initiated tuning of biochemical engineering and mathematics. Kentucky is convening faculty members in several branches of learning, among them the STEM disciplines of biology and nursing.

As in Europe and Latin America, a consensus on degree ladder steps in these disciplines is meant to lead to gains in transparency, efficiency, and quality. And the evidence is promising. The Utah effort in physics, for instance, has produced a detailed outline of expectations for the bachelor's degree that illustrates both a close focus on the cumulative nature of study in physics and recognition of the importance of the dialogue of the discipline with other fields (13). For instance, physics graduates must be able to "write essays on physics topics and problem explanations in complete, correctly punctuated sentences that are well organized and clearly express careful arguments." Graduates are also expected to be able to identify ethical standards, to describe the history of the discipline, and to explain "how science is a community effort."

Such efforts are already proving influential—and not just within the participating states. By one scenario we might envision, professional accreditors and organizations representing the academic disciplines could reach consensus on a qualifications framework defining their common expectations of degree recipients. They might then lend their support to Tuning by participating in defining and explaining the expectations for cumulative learning within their respective disciplines. The gains for all students would be considerable, but students considering exacting, lengthy STEM programs would benefit particularly from being able to learn clearly in advance exactly what they should expect of their programs—and what their programs should expect of them.

Assessment

Clear statements of outcomes at the degree and disciplinary levels should define explicit expectations as common reference points for students, their teachers, their institutions, and those responsible for attesting to the effectiveness of institutions. But unless credible and reliable measurements of effectiveness are routinely and consistently deployed, expectations alone will have little impact. Assessment, therefore, thoughtfully conceived and appropriately managed, represents the critical link in the proposed matrix of reform.

The good news is that assessment has evolved since the 1980s into a sophisticated, multi-faceted discipline with an impressive track record. At the institutional, disciplinary, and program level, assessment and the artful use of assessment results have offered accrediting associations at both the regional and professional level an opportunity to focus less on "inputs" (learning resources, section size, physical plant maintenance) in favor of "outputs," i.e., student learning as measured by performance and success.

The problem is not that those most engaged with assessment have done too little—but that they may have been asked to do too much. Should assessment offer a means of documenting institutional effectiveness for purposes of public accountability? By all means. Should assessment enable monitoring of productivity in state-supported institutions? Of course. Should assessment inform the evaluation of probationary faculty members seeking tenure and promotion? It should. And should assessment enable the individual faculty member to improve her or his effectiveness in the classroom? Yes, to be sure. And might assessment results support differential or incentive unit level funding so as to promote competition and greater unit effectiveness? Perhaps.

This remarkable spectrum of both normative (evaluative) and formative (constructive) applications testifies to the pervasive influence and vitality of the so-called "assessment movement." Yet despite all of this activity on so many fronts—or perhaps because of the proliferation of so many applications—no coherent narrative has emerged. Instead, critical voices, themselves often limited by the narrowness of their focus and the stridency of their rhetoric, often have dominated public discussion. Positive institutional outcomes have been obscured by confused attempts at institutional comparisons. Substantive learning gains by students have been called into question through the application of standardized examinations that cannot ensure motivated test-takers and that may measure only simplistic surrogates for complex learning. And efforts to build confidence in assessment as a means of improving instruction have run afoul of efforts to use the results of such assessment in making personnel decisions. As a result of these and other conflicting priorities, increasing concerns about the costs and effectiveness of higher education have discouraged the confidence required if the additional investments necessary for expanded STEM education are to win support.

Here, then, a modest four-part proposal for this important element in a coherent initiative. First, assessment efforts should be classified according to a frame of reference that makes clear a) who is doing the assessment, b) who or what is being assessed, c) the purposes of the assessment, d) the methods being employed, e) the ways in which the results will be reported, and f) the possible consequences of such results. It should be possible to develop a classification that would allow the descriptive labeling of assessment initiatives. One among several advantages of such an approach would be the helpful separation of assessment intended as evaluative from developmental applications of assessment—the confusion of the two representing a persistent complicating factor both within and beyond the academy in terms of understanding the value and influence of assessment.

Second, assessment should respond to an understanding of STEM education that sees important relationships between technical expertise and liberal and social learning. Unless the assumptions and applications of assessment keep pace with the evolving appreciation for the ways in which disciplines inform one another, there will be little incentive for institutions to reconsider their confining curricular and organizational structures. On the other hand, assessment could take the lead in encouraging such reconsideration precisely by measuring outcomes that clearly transcend such limiting structures.

Third, assessment should participate in and respond to the discussion surrounding the definition of learning outcomes at both the degree and programmatic levels. Indeed, only if qualifications frameworks and assessments evolve together will either exert the kind of influence necessary to the strengthening of STEM education. There may be no clearer illustration of potential synergy, but if such synergy is actually to develop, there must be a conscious and systematic approach that involves both those engaged in framing outcomes and those with expertise in assessing them.

Finally, it must become clear that assessment, whether normative or formative in concept and application, results in improvement. If assessment is used only to document compliance with an arbitrary threshold, it will have little influence on public opinion and political will. However, if assessment were able to show incremental gains in the effectiveness and productivity of STEM programs, there could be several positive results. Given their greater awareness of the opportunities to be realized, more students would consider entering STEM programs. Armed with evidence for the value of aligning liberal and social studies with STEM offerings, faculty members in all disciples would be able to enhance the coherence and educational effectiveness of their offerings. And if made well aware of the contributions expanded STEM programs would make to a growing economy, opinion leaders and legislators would be the more inclined to allocate the resources essential for expanded educational offerings of high quality.

An integrated agenda

Taken one by one, the four initiatives described above—agreeing to a more inclusive definition of STEM education, gaining consensus behind degree-level outcomes, developing discipline-level outcomes, and using assessment to measure broad STEM attainment relative to degree-level and discipline-level outcomes—are each well worth pursuing. But taken together, as elements in an integrated and coherent agenda, they can offer a compelling blueprint for fundamental systemic reform leading to more effective STEM education for more students.

That the options for organizing the pursuit of such an agenda are myriad may represent an impediment to prompt action in the near term, but a decisive, top-down approach, such as that evident throughout the Bologna Process, would align poorly with the structure and culture of higher education in the US. Instead, we envision a coalition of existing alliances, a "mega-alliance," that would claim the STEM agenda as a reflection of their shared concerns. This alliance could express a common cause, develop structural links (e.g., between assessment and a degree framework, for instance, or between assessment and a more inclusive view of STEM education), and frame realistic timelines for coordinated rollouts. By so doing, we could begin at once the lengthy, critical task of rebuilding public confidence in the creativity, responsiveness, and resourcefulness of American higher education. We would provide assurance that US higher education is equal to the challenge of educating the STEM graduates that the domestic and international economies require. And we would be able to offer many more students a path leading to expanded opportunity.

Note

Please see Evenson W. Strengthening student learning through "Tuning", in this thematic issue for a focused address of "Tuning".

Competing interests

The authors declare that they have no competing interests.

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