LEADERSHIP FOR UNDERGRADUATE STEM REFORM: *WEAVING A COMMUNAL WEB*

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Successful reform of undergraduate science, technology, engineering, and mathematics (STEM) education requires good leaders; therefore, leadership development will be key if the national calls for reform (e.g., *Vision and Change*) are to be answered. The Partnership for Life Sciences Education (PULSE) is focused on whole-department reform, which will require recruiting and supporting grassroots reformers who lead their colleagues through the change process. Department leaders will require (a) support networks that extend within and beyond each institution, (b) development of leadership skills and competencies, and (c) a mutually agreed-upon strategic plan that inspires all to action. The STEM Department Evaluation Rubric is presented here as a tool to help establish that shared vision. Successful leaders will also need resilience, good humor and moral imagination, because the challenges are many but the rewards are substantial and sit at the core of the mission of our institutions.

The National Science Foundation (NSF) has directed over $22 billion to the reform of undergraduate STEM education since 1950, but the model of development and dissemination embraced by NSF has not worked as predicted; i.e., dissemination has not led to widespread adoption of reformed practices. Research evidence refutes several myths that are often blamed for this problem, including the assumptions that faculty members are unaware of the calls for reform, antagonistic or apathetic to their teaching responsibilities, and/or blind to the research on best pedagogical practices; many know what should be done, but for a myriad of reasons, they are not doing it (Dancy & Henderson, 2008).

However, success stories exist, and institutions that have transformed their programs share a key ingredient: effective leadership of reform efforts. Effective leadership of STEM reform requires (a) support networks among the various subsystems within and beyond each institution, (b) development of a broad base of grassroots reformers with good leadership skills, and (c) a shared strategic vision and action plan so that the work of change, although challenging, is inspirational and the risks and rewards are shared broadly.

Taking a Systems Approach: Building a Communal Web Among Subsystems

Application of systems theory to the Academy's traditional structure places the faculty member in the system's center, surrounded by an outwardly expanding

series of rings that affect her/his teaching-related decisions (Austin, 2011). The first surrounding ring is the department, with its particular norms and traditions, the second ring is the institution with its unique expectations and reward structures, and the third ring represents the extramural influences, such as accrediting bodies and scholarly organizations. Brownell and Tanner (2012) point out that most STEM faculty members describe themselves first and foremost as research scholars and view teaching as a lower-status activity; therefore professional societies, which influence professional identity more than institutional affiliation does, must help correct this identity imbalance. Austin's (2011) model of expanding circles of subsystems creates the illusion of a web built by an orb-weaving spider, which is a useful metaphor.

The often beautiful web of an individual orb weaver goes unnoticed by other members of the species; and such is the fate of much of the excellent work of STEM faculty members who pursue exemplary work in the absence of a supportive network or effective leadership. Therefore, broad reform of undergraduate STEM education will require the development of leaders who spin a more extensive web that connects these subsystems more intentionally. To extend the metaphor (with apologies to the arachnophobic), imagine a web constructed by communal spiders that cooperate and collaborate. Unlike orb weavers that expend copious energy to construct a new web daily, communal spiders, such as *Agelena consociata,* work together to establish large, long-lasting, elaborate webs that increase the abundance of captured prey (e.g., students that remain in STEM disciplines), endure harsh conditions (e.g., economic downturns), and result in a shared bounty across the entire colony (e.g., new cadres of creative and collaborative scholars applying their STEM knowledge to help solve world problems).

In 2012 a few change agents within three powerful external subsystems, NSF, the National Institutes of Health/National Institute of General Medical Sciences (NIH/NIGMS), and the Howard Hughes Medical Institute (HHMI), worked across bureaucratic boundaries to launch the Partnership for Life Sciences Education (http://www.pulsecommunity.org). Rather than targeting change at the individual faculty member level, PULSE identifies the whole department as the smallest unit of change required to yield

widespread reform as envisioned in *Vision and Change in Undergraduate Biology Education: A Call to Action* (American Association for the Advancement of Science [AAAS], 2011). Forty PULSE Fellows were selected to lead this effort, including this article's author. A novel experiment in educational leadership, the fellows represent institutions that span the full range of Carnegie Classifications. The fellows agree that transformation of an entire department requires effective leadership and scaffolding among internal and external subsystems.

One way to view the PULSE initiative is as a tenuous but strengthening thread that extends outward to link together the web's various agencies and disciplinary societies and inward toward the department and faculty members to build the leadership and support necessary for department-wide reform. Although PULSE is working to create networks among all subsystems in Austin's "web," the main focus of this article is on developing the leaders needed for department reform.

Leading Intramural Web Building: The Department as a Refuge for Reform

Although this paper argues in support of a distributed model of grassroots leadership for undergraduate STEM education reform (May, Susskind, & Shapiro, 2013; Kezar, Bertram Gallant, & Lester, 2011), it also acknowledges that whole-department reform usually requires *at least* one especially dedicated and socially adept leader, perhaps the department chair, who, with seemingly endless resilience, patience, and encouragement, can keep the goals for reform in the forefront—especially during the inevitable episodes of strife, uncertainty, and failure when retrenchment is most seductive.

Department chairs are uniquely situated to be able to create a safe refuge for reform to unfold. One might imagine the department as the web's safe (nonsticky) retreat within which instructors can explore new strategies without fear of punitive action during the most vulnerable stages of change. A chair's dual administrative/faculty position provides an opportunity to educate other top leaders on the goals of the reform and garner their support; creating what Allan and Estler (2005) call an "attention magnet," which helps to ensure that implemented changes will be given the time and support to take hold. However, this increased attention brings increased scrutiny, which heightens

anxiety among a department's instructors. Therefore, it is important to both acknowledge and calm charged emotions through empathetic dialogue and reassurance that no one will be penalized for accepting the risks associated with change. For example, a good chair must protect colleagues from misinterpretation of evidence from ineffective assessment instruments, such as standard course evaluations that haven't kept up with the pedagogical reform agenda. A student comment such as "the instructor didn't lecture, I had to teach myself," may be reason to applaud the use of engaging pedagogies rather than cause for concern. In addition, a good chair celebrates small wins (Weick, 1984), such as setting aside a few minutes at a department meeting for a colleague to share the outcome of a new, course-embedded research project, in order to build a sense of shared purpose, appreciation, and camaraderie.

Chairs and other key change agents must also maneuver the hierarchies within their department. For example, leaders who actively seek the wisdom and advice of their long-time colleagues will build powerful allies as opposed to a cadre of contrarians. In addition, shared sacrifice—and shared vulnerability—is an especially effective strategy for building trust and respect. As noted by May et al. (2013), many potential "grassroots leaders needed the extra motivation of seeing one of their most respected peers accepting the challenge of course reform" (p. 29) before engaging in their own; therefore, chairs who reform their own practices are compelling role models.

New and part-time faculty members should also contribute their experiences and ideas for improving teaching and learning, and thus become leaders in this collaborative reform effort. For example, an increasing focus on pedagogical training in PhD programs (Pfund et al., 2012) means that new hires may arrive ready to share pedagogical practices unknown to their senior colleagues, so chairs need to tap into this leadership potential.

Finally, although students are not included as a subsystem in Austin's (2011) systems approach, they should be, as they are an underused source of grassroots leadership and creative energy to support reform efforts. In two major curriculum reform initiatives at Wofford College, groups of students were invited to partner with faculty members to develop new curricula, and

these students then served as teaching and lab assistants and peer tutors for the new courses. These students energized and stretched their faculty partners, garnered campus support for the work, and developed remarkable leadership skills of their own (Goldey, 2004; Goldey et al., 2012).

Tempered Radicals: Leadership Development of the Web Spinners

Although there are stories of successful reform led by already powerful "organizational catalysts" (Meyerson & Tompkins, 2007), the premise of this paper is that more widespread reform of STEM undergraduate education will come from grassroots leadership (Kezar & Lester, 2009; Kezar et al., 2011; May et al., 2013). Grassroots leaders view leadership as a democratic and collective process and work from the theory that good leadership inspires collaborative teams to work toward outcomes for the common good (Komives & Dugan 2010).

The term "tempered radical" describes the type of grassroots leader who "quietly challenges prevailing wisdom and provokes cultural transformation" (Meyerson, 2001, p. 1). Embedded within their institutional context (i.e., they know the institution well and are dedicated to its mission), these leaders are able to critique the "taken for granted beliefs about how schools should be organized" (p. 305) because they have an awareness of what is going on beyond their own institutional context (Meyerson & Tompkins, 2007). Kezar and Lester (2009) note that faculty members who "get out more" and attend academic conferences are more likely to build leadership skills and networks of support, which they draw on to enact change, and the PULSE Fellows typify this finding.

Tempered radicals may not expect to find themselves in leadership roles. As principal investigator on two NSF grants for curricular reform at Wofford College (Goldey, 2004; Goldey et al., 2012), I developed leadership skills as a byproduct of learning beyond my disciplinary training. As I overcame my ignorance and negative biases regarding pedagogy and assessment, my view of what defines and supports excellence in teaching and learning expanded dramatically. As I learned, I was motivated to become a better teacher and to inspire others to do the same because I believe deeply in our

shared mission to educate students. Becoming a leader, in and of itself, is not, I think, what motivates most members of the faculty to lead; nor are we comfortable with thinking of our colleagues as "subordinates" within a context of "participant leadership" (Woods, 2007), even if that is what we are doing. Instead, grassroots leaders emerge when we have a destination that we believe in, and we want others to pursue the same goal.

Leading With Shared Vision: The Unique Structure of Each Department's Web

Advocating for change without clear, widely shared aspirations may be justifiably interpreted as change for change's sake, and outward protest or quiet entrenchment may derail good intentions. Although external forces may encourage change (e.g., the new Medical College Admission Test) (Ferren & Ferren, 2012), intellectual autonomy is a highly valued tradition in the Academy, and leadership is most effective when it is freely shared and all have participated in identifying the strategic vision and path forward (Henderson, Finkelstein, & Beach, 2010).

The STEM Department Evaluation Rubric (see Appendix A) was developed to stimulate honest conversation about current strengths, serve as a guidepost for setting aspirational goals, and build the grassroots leadership of all members of a department, regardless of experience level or particular area of expertise. The rubric is intentionally brief, and it can help make the most of limited face time by establishing a common language and a baseline of knowledge about its topics.

Running down the left of the rubric is a list of factors that optimize student learning and faculty performance. Across the top from left to right runs a scale, from baseline to exemplary, with corresponding descriptions of increasing departmental achievement for each factor. "Baseline" should not be perceived as anything but an opportunity to grow, as it represents the common starting point for reform at most institutions. The Exemplary category is intentionally ambitious, and it may be unlikely that any institution will ever achieve Exemplary in all factors, nor should Exemplary be confused with some fixed target, lest it justify complacency. Users may argue justifiably that the rubric leaves out factors too important to ignore for their context, and such users are encouraged to add those factors and to

struggle with articulating a continuum from baseline to exemplary for each new factor.

Concluding Comments on Communal Web Building: Weaving in a Little Fun

Any major change initiative requires extra work and shared sacrifice, and reform efforts will fail if the workload isn't distributed among many and if the high stress levels that surround major change drag on for too long. There is one particularly inspiring prediction that leaders need to make when promoting reform: "Once we get through this challenging time, teaching is going to be much more rewarding and a lot more fun." Therefore, leaders should establish realistic but ambitious timelines for implementing reform so that everyone, especially the key leader(s), can envision a not-too-distant return to normalcy. Stories from those who have made it through to the other side can add credibility to the "fun" prediction. At Wofford we undertook a dramatic transformation of our first-year curriculum, and the pain of shared sacrifice lasted about two years, after which the change had become the new norm and stress had been replaced by a refreshing sense of job satisfaction. Now, five years out, we enjoy lively discussions among colleagues and students. We have fun planning which follow-up experiments should be pursued next year based on the results of this year's class research projects, and it is a joy to have to tell students to pack up and leave class because they were so engaged in an activity that they lost track of time. The changes have continued to spread throughout the department's four-year curriculum, and the robust assessment plan has provided converging lines of evidence that indicate achievement of desired learning outcomes, as well as broad, positive impacts throughout the college and beyond (Goldey et al., 2012).

John Lederach, a long-time peace negotiator in regions of the world torn by religious conflict, identifies "moral imagination" as the essential trait required of successful leaders in his field, and he notes it has four characteristics: the creativity to imagine beyond what others deem possible, relationships with those they fear, paradoxical curiosity in probing complexity, and willingness to be vulnerable and accept risk (Lederach, 2005). Although the stakes of STEM education reform may not be as high, Lederach's ideal of

moral imagination can be a guiding premise in our work, too. The work of undergraduate STEM education reform at the department level is done by tempered radicals with moral imagination, like the small cadre within NSF, NIGMS, and HHMI who bridged the bureaucratic boundaries between their organizations to create PULSE. The other PULSE Fellows and I imagine a national effort to develop leaders who are connected across cultural and institutional boundaries in a shared mission to best educate *all* students to become scholars, engaged citizens, and positive change agents in the world. Perhaps with a little more moral imagination, we can reach inward and outward throughout the subsystems to weave a more communal web and share in the benefits, and the fun, of our combined efforts.

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Appendix A

STEM Department Evaluation Rubric*

	Baseline	Beginning	Developing	Accomplished	Exemplary
Authentic Course-embedded Research[1,2]	Laboratory experiments have known outcomes. Students perceive that experiments have "right" answers and will often attribute unanticipated findings to "human error."	Only a small fraction of students gain practice in authentic, open-ended inquiry, analysis, and evaluation; usually through optional, low enrollment courses. These courses can easily be avoided entirely.	Authentic inquiry occurs in several courses; 50% of students gain some experience applying primary literature, predicting outcomes of open-ended experiments, analyzing data, and interpreting results.	"Accomplished" builds on "Developing" in that **all** students have the opportunity to engage in authentic inquiry, and the majority design and carry out novel, open-ended experiments, often of their own design.	Students are accustomed to predicting outcomes of open-ended research projects (often of their own design) and interpreting results. Articulating probable explanations and ensuing research questions is the norm.
Student Cognitive Skills[3,4]	Across the curriculum, students practice "recall," the lowest-level cognitive skill (LOCS[3,4*]), and assignments/exams target this level. Students' perception is reinforced that learning is limited to memorization of facts.	Students typically practice lower-level cognitive skills (recall, understand, apply), especially in beginning courses. Few instructors consider cognitive level of assignments or exam questions.	Students practice higher order cognitive skills (HOCS; e.g., synthesize, evaluate, create) in some courses, although tests may still assess LOCS. Instructors may find creating HOCS questions difficult.	A majority of courses help students move beyond LOCS by emphasizing the development and regular practice of HOCS. Exams and other high-stakes assignments assess students' ability to utilize HOCS.	Students regularly practice HOCS throughout the curriculum, and instructors are adept at giving students practice in preparing for exams and other graded assignments requiring HOCS.
Student Metacognitive Skills[5,6]	Students are unreflective of their own learning strategies and there is no effort to improve metacognitive awareness and empowerment. Attrition risk of underprepared students is acute due to unfamiliar early failure.	Rarely are students encouraged to reflect on their learning strategies and skills. Study strategies, when discussed, may not be specifically geared to STEM learning or the particular student's needs.	Students are encouraged in some courses (e.g., first year courses) to reflect on their learning skills and encouraged to use appropriate learning strategies[5] that are supported by research.[6]	Instructors typically engage students (esp. first year) in metacognitive reflection and *practice* of research-based, cognitive strategies. A learning center may further support student metacognitive growth.	Instructors regularly integrate practice of effective metacognitive strategies within assignments. Most students become adept at reflecting upon, and improving, their own learning and coaching their peers.
Student Core Competencies[7]	Courses designed around content delivery (e.g., chapter by chapter of text), with no opportunities to practice/build core competencies.	Course descriptions include goal of building students' skills (e.g., use of scientific inquiry), but students rarely practice such skills. Top students who take many STEM courses may build competencies serendipitously.	Attempts to design curriculum around core competencies rather than content coverage yield mixed success and/or face some resistance. Efforts may be limited to first year or senior "capstone" experiences.	Core competencies are targeted learning outcomes practiced in over 50% of courses across all levels, although efforts may still be confined within disciplinary department(s) and not integrated throughout, and beyond, STEM.	Fully integrated curriculum prioritizes competencies (methods of inquiry, quantitative reasoning, modeling/simulation, transdisciplinary thinking, communication, collaboration, applying knowledge to civic problems, etc.) at all levels.
Independent Research[2,8]	Students are unaware of, and don't participate in, independent mentored research.	A few well-prepared students may seek intra- or extramural research opportunities (e.g., REU) on own initiative, but most students are unaware of such opportunities.	*Ad hoc* advising/encouragement is given to top students to consider research opportunities, but better coordination would extend such efforts to more students.	Many students encouraged to seek research opportunities, but earlier preparation would increase acceptance/readiness. Products (e.g., posters) of student research are showcased.	From first year, all students are prepped for mentored research opportunities, and over 40% participate in one or more. Student research posters and symposia regularly showcase student scholars as role models.
Best Pedagogies[9,10]	Lecturing without student engagement is the norm in courses and labs. Information is passively received, and there is little need to read text or other sources. Instructor is "authority."	Traditional lecturing during class time is the norm, and all engaging activity occurs during laboratory sessions. Information received in class may often be repeated in lab.	Instructor pedagogies fall into teacher-centered or learner-centered categories. Students may pick among instructors who "deliver" information and those that require active learning.	All instructors are attempting to adopt best pedagogical practices, and lecturing for 50% or more of class time is rare. Students actively learn on own and from each other in most classes/labs.	Students are engaged in discussion, guided inquiry, and other activities in classes/labs, and instructors intersperse brief lectures if needed. Knowledge is actively constructed by students. Instructor is "coach."
Faculty Development[11,12]	Faculty members are unfamiliar with STEM/Higher Ed pedagogical research, and there is no structure/support/incentive for development of their knowledge and/or skills.	Some members of the department are seeking new knowledge/skills needed for transforming their program, but they lack support/time/incentive for this work.	Faculty learning community and/or Center for T&L may aid cadre of practitioners in building knowledge, skills, and leadership capacities. Administrative support is minimally sufficient.	Faculty groups discuss pedagogical literature. A few contribute to the scholarship of teaching and learning (SoTL). Incentives available to learn through Center of T&L, attendance at conferences, etc.	Pedagogical excellence is esteemed by the institution rather than perceived to be in conflict with disciplinary scholarship. Contributing to SoTL is highly valued in T&P decisions and supported with incentives.
Assessment[13]	Tools do not assess learning outcomes (e.g., course evaluations judge instructor performance rather than student learning). Assessment perceived as punitive and compulsory.	Novel assessment tools may be used in one or two courses, but there is minimal administrative and/or peer interest for these efforts and findings, and the focus remains on faculty performance.	The assessment portfolio may emphasize quantitative, direct measures (e.g., Major Field Test) and lack insight from qualitative measures (e.g., surveys, interviews).	Periodic (e.g., every 5 years) integration and reflection on variety of direct and indirect assessment evidence inspires episodic reform. Assessment viewed as essential by some, necessary evil by others.	Regular (e.g., yearly) reflection on evidence from diverse assessment tools guides continuous efforts to improve student outcomes. Assessment perceived as essential and inspiring.
Faculty and Administration Dispositions Toward Change[14]	Faculty is change-averse. There are no safe places for trial and error. Changes in curriculum may be dictated to the faculty and driven by market forces. There may be an ethos of fear, frustration, and/or apathy.	There is no shared vision for change, and/or there are strong voices that resist change, and/or there is poor communication between administrators or faculty members leading to inertia and/or distrust.	Pockets of reform may be under heightened scrutiny, thus increasing anxiety. Retrenchment may occur without encouragement and opportunities to learn from early failures. The ethos may reflect both anxiety and excitement.	A faculty majority is collaborating with administrators to implement reform. Financial/market realities are taken into consideration, but do not dictate approaches. An ethos of pride is developing as learning outcomes improve.	Instructors and administrators are reflective, open to change, appropriately skeptical of change for change's sake, and risk-tolerant. Reflection on assessment evidence drive continuous reform. There is a collaborative ethos of "positive restlessness."
Integration of Department Program with Gen Ed Goals & Institutional Mission[13]	Faculty members (full or part time) are unaware of general education (GE) goals, institutional mission (IM), or how the department supports these broader issues.	The department chair or a committee determines which courses fulfill GE requirements, but instructors may not know, or know how to achieve, GE goals. IM is rarely considered in department's program.	The department's faculty members work to align courses to meet GE learning goals, but IM goals may be overlooked or perceived as outside the department's duties.	GE goals are well integrated, and some courses target the capacities valued in the institution's mission (e.g.., civic engagement, advancement of knowledge; cultural pluralism; social justice).	All full and part time faculty regularly discuss and engage students in practice and development of specific GE learning goals and institutional mission-based outcomes. Department goals are positioned within institutional context.

*This rubric was developed for the Partnership for Life Sciences Education (join at www.pulsecommunity.org) for use in workshops led by PULSE Fellows and for use by departments engaged in self-study at their home institution. It is intended to stimulate discussion, identify department strengths and opportunities for improvement, and introduce just a few of the abundant resources about the topics. Help us assess its effectiveness by contacting Ellen Goldey at goldeyes@wofford.edu.

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