Promising Practices in Undergraduate *STEM* Education

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This paper reflects insights and experiences from my work with the Project Kaleidoscope (PKAL) community since the early 1990's. The project that became PKAL began by asking some hard questions about the past, present and future of the undergraduate science learning environment in our country. We began with a group of leaders who brought diverse experiences and expertise to the table—faculty, deans, and presidents nationally recognized for success in nurturing learning environments that prepared significant numbers of well-qualified science and mathematics undergraduate STEM majors for entry into graduate school.

Our first question: *what works* in building a learning environment in which undergraduate students come to understand what it means to be part of a natural science community?, was an earlier iteration of that being asked here: what are *promising practices* in undergraduate *STEM* education? As a prelude to answering the initial *what works* question, we sought to distill, from the experiences of those around the PKAL leadership table, the essence of an undergraduate natural science community. Either serendipitously or with great prescience, the definition we arrived at a definition that still rings true today.

> The most important attribute of undergraduate programs that attract and sustain student interest in science and mathematics *(STEM)* is a thriving community of students and faculty. Such "natural science communities" offer students a learning environment that is demonstrably effective, where:
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> > Learning is experiential, hands-on, and steeped in investigation from the very first courses for all students through capstone courses for STEM majors.
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> > Learning is personally meaningful to students and faculty, makes connections to other fields of inquiry, is embedded in the context of its own history and rationale, and suggests practical applications related to the experience of students.
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> > Learning takes place in a community where faculty are committed equally to undergraduate teaching and to their own intellectual vitality, faculty see students as partners in learning, students collaborate with one another and gain confidence that they can succeed, and institutions support such communities of learners.
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> Programs organized around these guiding principles motivate students and give them the skills and confidence to succeed.[1]

My point in rehearsing this PKAL history is to set the stage for an analysis of contemporary promising practices in undergraduate STEM. The stories, illustrations and data that follow are about communities asking hard questions about contemporary challenges facing 21st century STEM leaders: *what to teach, how to teach,* and *who to teach.* They describe campus communities bringing a wide diversity of expertise and experience to the task of identifying and addressing those questions. Perhaps most important for this discussion, my illustrations of promising practices are those that signal a deep understanding of how the changing context influences and is influenced by efforts at the local level.

Although it still rings true today, the PKAL vision of *what works* was shaped in quite a different time. Then the 'success' of the undergraduate STEM learning environment was determined, in large part, by the number of Ph.D. students and graduates prepared as undergraduates at a particular college or university. The era of

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[1] Project Kaleidoscope, *What Works: Building Natural Science Communities*, Volume One, Washington, D.C., 1991.

'how people learn' had not arrived;[2] neither were there widespread calls to transform science and mathematics learning at all educational levels coming from corporate, public and academic leaders. The work of pedagogical pioneers, funded primarily by the National Science Foundation, was done mostly in isolation, within a single discipline, institution, or sometimes even within a single department. Attention to accountability—to monitoring, assessing and documenting the impact of the environment on student learning—was just beginning to surface.

Given the changing context, today's *what works/promising practices* questions are framed more precisely:

- What to teach?
- How to teach?
- Who to teach?

The *what to teach* question is how to bring 21st century science/technology into the undergraduate STEM learning environment, how to facilitate interdisciplinary learning, socialize students into the global S&T community and to prepare undergraduates—as responsible citizens and contributing members of the 21st century workplace—to deal with real-world problems that call for scientific and technological solutions.

The *how to teach* question is how to ensure that research-based pedagogies (constructivist, contextual, student-centered) become standard practice in the 21st century STEM learning environment and are used in ways that enhance the learning of all students, no matter their background, major, or career aspiration.

The *who to teach* question is how to move from a central concern about producing candidates for STEM graduate schools to broader attention to "science for all," recognizing that the skills, capacities and self-knowledge that are desired outcomes from learning in 21st century STEM classrooms and labs are useful for a wide range of 21st century careers and of great value in preparing students for their roles as responsible citizens in a complex and changing world.

Explicit in those questions is another precision for determining promising practices: the focus on learning and on goals for student learning, rather than on teaching. Those institutions now achieving notable progress in strengthening STEM learning of undergraduates have leaders with a clear vision of what graduates should know and be able to do as a result of their engagement within the natural science community on their campus. Moreover, unlike in the late 1990's—and perhaps one of the catalysts for this discussion—these leaders have been prudent in gathering evidence about the efficacy of their efforts in addressing questions about what, how and who to teach.

The descriptions of promising practices that follow are part of a collection built over the past several years from experiences of forward-thinking campuses involved with an NSF-funded PKAL Leadership Initiative (LI).[3] The premise of this PKAL LI was that just as lessons learned from practices of individual pedagogical pioneers informed and advanced efforts of "early adapter" faculty within peer communities, so could lessons learned at the institutional level be models that leaders at other colleges and universities could adapt. We appropriated the *forward-thinking institutions* mantra from the Business Higher Education Forum:

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[2] John D. Bransford, et al., *How People Learn: Brain, Mind, Experience, and School*, Washington, D.C., National Academy Press, 1999.

[3] The Project Kaleidoscope Leadership Initiative, http://www.pkal.org/activities/LeadershipInitiative.cfm.

Higher education must redesign itself to meeting the learning standards of today's world. Education must be engaging, flexible, and interactive. Forward-thinking institutions that can lead the way must pioneer innovative new efforts and become champions of redesign and learning.[4]

From the perspective of the PKAL LI community, an overriding *promising practices* in undergraduate STEM is when there is attention, at the institutional level, by a diverse leadership team, to identifying and addressing hard questions about:

- goals for student learning in STEM fields from the perspective of the institution, the world of science and technology, and society
- the entire STEM learning experience of all students, from the very first day through capstone courses for STEM majors
- the kaleidoscopic nature of institutional transformation, given their institutional identity, mission, and circumstance.

I. A. Promising practices: connecting to larger student learning goals at the "institutional" level.

Two of the many stories that could be told here are those from the University of Maryland Baltimore County (UMBC) and Harvey Mudd College.

The identifiable elements that contribute to systemic and sustainable reform are all visible at UMBC.[5] This institution is nationally recognized for the strength of its undergraduate STEM programs and for its effectiveness in working as a community to ensure the success of all students—particularly African American students—in the study of STEM fields. How did it happen?

It started with leadership from the top, with the provost (now President Freeman Hrabowski) asking the entire community a provocative question—*what do we know about how our African American students are doing in science?*

The initial answers painted a dismal picture, one that galvanized everyone from admissions officers to physical plant staff to give attention to systems from admissions through career counseling to faculty development. This group identified and addressed a larger set of questions about student learning, questions about the individual and collective experiences of all UMBC students:

How are our students doing academically? Where are they succeeding, or not?
How do our students feel about their classes and about the academic support available outside the formal classroom/laboratory experience?
Do students feel isolated or connected to a larger learning community?
Do our students know what to do to succeed?

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[4] Business-Higher Education Forum, "Building a Nation of Learners," *Transforming America's Scientific and Technological Infrastructure: Recommendations for Urgent Action*, Project Kaleidoscope 2006 Report on Reports II, pp. 14-15, http://www.pkal.org/documents/2006ReportOnReports-National.pdf.

The Business-Higher Education Forum Website, http://www.bhef.com.

[5] Project Kaleidoscope, *Building a Research Rich Learning Environment: University of Maryland, Baltimore County*, Project Kaleidoscope Volume IV, http://www.pkal.org/documents/hrabowski_working-toward-and-ensuring-the-success-of-African-American-students-in-STEM-fields.pdf.

University of Maryland, Baltimore County: The Meyerhoff Scholarship Program, http://www.umbc.edu/meyerhoff/index.html.

The core group took answers to these questions and began to unravel the reasons for the lack of success which—for their African American students—were no different than at other colleges and universities across the country. This was one of the contextual reasons for the urgency of the UMBC initiative. The system needed to work for all students so that the STEM workforce of the future would mirror our nation's changing demographics and so that diversity would become a celebrated factor in the 21st century workforce.

After examining all the dimensions of the UMBC learning environment, changes began. Tutorial centers were strengthened at the departmental level. Faculty were urged to become more directly involved in all aspects of student learning, in formal and informal settings. Admissions and orientation programs were examined and enhanced. The academic and the social lives of students were integrated, including more contact with faculty, peer group involvement, and a comprehensive mentoring program. Evaluation and assessment were embedded in program activities from the beginning.

In all of this, the UMBC community applied a laser-like focus on the student. It was assumed by everyone that students from all backgrounds have the academic ability to succeed, and high expectations for student learning were set for students from the very first day. Students were given realistic experiences with what scientists and engineers do as a means to incorporate them into the larger STEM community—within and beyond the campus.

> *The research experiences have been very valuable. I worked with….my first year and he set a basis for everything I was going to be using later on. [Most valuable has been] the thinking process, how scientists go about trying to solve a problem, and all the different techniques you can use to get around problems.* (A UMBC student)

What happened at Harvey Mudd College,[6] as reported by Gerald Van Hecke, was a similar rethinking of what students should know and be able to do upon graduation. At this highly specialized institution, the implicit question that catalyzed attention to change was: *is our program—as it now stands—adequate preparation for an S&T career in a future in which practicing engineers and other S&T professionals will use similar skills and capacities in their laboratories, will need the same higher order thinking skills, and will be working across traditional disciplinary boundaries*?

Over a two-year period a leadership group of HMC faculty designed, implemented, assessed and ultimately retained an investigative, interdisciplinary, introductory laboratory taught collectively by faculty from physics, chemistry and biology. These faculty designed laboratory experiences that featured common lab practices of these disciplines—practices that were open-ended, involved hypothesis testing and were long enough to allow repeat measurements. For example, *consider the thermal properties of an ectothermic animal: are lizards just cylinders with legs?* Or, *using digital logic to time a simple pendulum: What makes a good clock?*

Functional guidelines were set for developing these laboratories—that they would build from the research expertise and enthusiasm of current faculty and that pedagogical objectives and goals needed to be determined and with a timeline for the achievement of those goals embedded in the planning. Attention to the availability of major pieces of equipment and to opportunities for equipment sharing, teaching assignments across departments, use of student assistants and assessment of individual laboratory experiences was carefully orchestrated throughout.

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[6] Gerald R. Van Hecke, *How to Design, Implement, and Sustain an Investigative Interdisciplinary Laboratory*, presented at the Western Regional ACS Meeting in San Diego, October 2007, http://www.pkal.org/documents/DesignImplementIDLab.cfm

Gerald R. Van Hecke, *Interdisciplinary: The Harvey Mudd College Story*, Project Kaleidoscope Volume IV, 2008, http://www.pkal.org/documents/Interdisciplinary-%20Harvey%20Mudd%20College.pdf.

Their deliberative process of assessment had several dimensions, including a "special exercise" that compared students in the normal core labs with the ID lab students:

> *The special exercise showed that relative to the normal core students, ID lab students "…proposed a greater variety of hypotheses to test, exhibited a greater ability to design experiments that would adequately test their hypotheses and greater creativity in their experimental design and analysis of results. In evaluating the data provided in the exercise, ID Lab students were consistently able to cite more potential sources of experimental error."* (Analysis by the external evaluator)
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> *What was most challenging in ID lab was to learn how to break down the barriers among the different disciplines because most people apply knowledge from only one particular subject.* (Comment by ID Lab student)

Both these stories offer evidence of one critical promising practice, the feed-back loop through which faculty understand what students think they are learning. Indeed, at the 2005 meeting of principal investigators of major NSF-funded assessment projects, the most persistent warning to the larger community was that: *faculty should be warned that students are never learning as much as they think their students are*.

I. B. Promising practices: connecting to larger student learning goals at the "science" level.

For STEM leaders, understanding what your students should know and be able to do upon graduation requires powerful connections to the communities of STEM practitioners—particularly to the disciplinary, interdisciplinary and professional communities that have established goals for student learning that are both generic to STEM fields and specific to a particular field of practice/study. That such communities are visibly attending to student learning goals is one of the most notable points of progress over the past two decades.[7] Perhaps more important is that such communities of STEM professionals are themselves seeking and spotlighting forward-thinking departments/institutions whose efforts are models for others.

So, another promising practice is when local agents of change make explicit and persistent connection to what their professional communities (note the plural) have articulated as goals for student learning. The influence of professional, disciplinary and academic societies on shaping and sustaining promising practices cannot be underestimated and needs greater attention at the local and national level.

Leaders at the University of Arizona[8] connected their reform agenda in another way to shaping scientific and technological communities of the future. The question they addressed was:

> *Recognizing that today's STEM students will have the opportunity to become members of a global STEM community, how can we capitalize on the unique capacities of the University of Arizona (a Research I*

[7] For examples, see: 2004 Curriculum Guide from the Committee on the Undergraduate Program in Mathematics http://www.pkal.org/documents/CUPMOverview.cfm, National Academy of Engineering: Center for the Advancement of Scholarship on Engineering Education (CASEE) http://www.nae.edu/nae/caseecomnew.nsf, Faculty in Undergraduate Neuroscience (FUN) http://www.pkal.org/documents/GoalsUndergradNeuroscience.cfm and the American Sociological Association http://www.asanet.org/.

[8] Carol Bender, *Biomedical Research Abroad: Vistas Open (BRAVO!) A Program to Prepare Science Students for the 21st Century*, Council on Undergraduate Research Website, 2003, http://www.cur.org/Publications/AIRE_RAIRE/arizona.asp.

Carol Bender, *Building Global Research Rich Connections: Introducing Undergraduates to Research in the Global Village*, Presented at a 2005 Project Kaleidoscope Leadership Institute Seminar: Research-Rich, 2005, http://www.pkal.org/documents/2005UMBCWorkshopBender.cfm.

university) to give our undergraduates the kind of research-rich, international opportunities for learning that would ensure their successful socialization into that community?

What has evolved over many years in response to this question is BRAVO! (Biomedical Research Abroad: Vistas Open!), an initiative of the biology department to provide an integrated, four-year experience for undergraduate majors that incorporates research experiences both on campus and abroad. The students are introduced to the international scientific community through an opportunity for paid summer internships during their junior year in the lab of a foreign collaborator of a member of the UA biology department. BRAVO director Carol Bender writes that these students become scientific and cultural ambassadors from the UA community, in addition to advancing the research of their faculty colleagues both at home and abroad.

This is again an effort requiring wide-spread departmental effort and support, as the BRAVO experience is basically four years. During the first two years, which is designed as preparation for the junior year abroad, undergraduates have deep experiences in a UA lab with mentors of graduate students, post-docs and senior faculty, as well as with near-peer mentors who are the returning BRAVO senior level students. The lab experience is enhanced by scientific seminars through which students are exposed to cutting edge research and introduced to how research is communicated in diverse fields.

BRAVO builds from and extends the unique capacities of an RI university to draw undergraduates into a natural science community that includes local and international scholars at the junior and senior level, together with peers and near-peers on different rungs in the educational ladder. Because research is a year-long activity on these campuses, with a substantial research infrastructure, undergraduates easily learn the value of networking. They develop communication skills and the ability to work in teams that include people from diverse cultural backgrounds—all skills and abilities needed to succeed in today's global S&T community.

Again, feedback from students validates the premise on which BRAVO is constructed – that such opportunities socialize undergraduates more effectively and immediately into a 21st century S&T community. This is many ways mirrors the Harvey Mudd story, in which members need a common set of skills and abilities, particularly in understanding how boundaries are dissolving in scientific and technological communities within and across geographic boundaries.

> *I feel now more open toward and prepared for collaborating at an international level. Moreover, I have become more convinced of the necessity of such collaborative endeavors in facing the challenges that our increasingly 'globalized' economy poses.* (BRAVO Student at INSERM in Paris)

> *Before I zoomed up to Tokyoite speed, I felt like I had lived my whole life in slow motion. I quickly realized that space and time were very valuable commodities for the Japanese people; neither was ever wasted.* (BRAVO Student at the National Institutes of Infectious Disease in Japan)

> *One of the most valuable things I learned was that there is more than one way to skin a cat. The lab here often had different protocols and often I was not able to use my protocols due to a lack of equipment, etc. Often I incorporated two techniques to get a sound result.* (BRAVO Student at the Institute of Parasitology in the Czech Academy of Sciences)

I. C. Promising practices: connecting to larger student learning goals at the "societal" level.

The stories from the University of Maryland Baltimore County, Harvey Mudd College, and the University of Arizona illustrate how the changing context influences and is influenced by the work of agents of change—those working to increase the persistence and success of students from groups currently underrepresented in the study and practice of STEM fields, and those working to prepare graduates for an S&T environment of practice that is becoming both increasingly non-disciplinary and global. Connecting campus-based change initiatives to the current (and future) reality beyond the campus is a significant promising practice as leaders address the key questions of *what to teach, how to teach,* and *who to teach.*

Education in the nation's service has always been a hallmark of a robust undergraduate learning environment, and increasingly science (STEM) learning is being seen in its rightful place as a central 'liberal art.' Even a cursory review of an inventory of student learning goals articulated by national scientific, academic, and/or corporate entities[9] signals how the skills, capacities and understandings gained through involvement in a research-rich natural science community prepares students well for life beyond the campus.

A most compelling set of "essential learning outcomes" has been articulated by the Association of American Colleges and Universities (AAC&U) through their initiative on Liberal Education & America's Promise (LEAP).[10] Each category of learning outcomes can be directly related to the what, how and who questions noted earlier.

> Beginning in school, and continuing at successively higher levels across their college studies, students should prepare for twenty-first-century challenges by gaining:
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> > *Knowledge of human cultures and the physical and natural world* through study in the sciences and mathematics, social sciences, humanities, histories, language and the arts; focused by engagement with big questions, both contemporary and enduring.
> >
> > *Intellectual and practical skills,* including inquiry and analysis, critical and creative thinking, written and oral communication, quantitative and information literacy, teamwork and problem solving, practiced extensively across the curriculum, in the context of progressively more challenging problems, projects, and standards for performance.
> >
> > *Personal and social responsibility*, including civic knowledge and engagement—local and global, intercultural knowledge and competence, ethical reasoning and action, foundations and skills for life-long learning, anchored through active involvement with diverse communities and real-world challenges.
> >
> > *Integrative and applied learning,* including synthesis and advanced accomplishment across general and specialized studies, demonstrated through the application of knowledge, skills and responsibilities to new settings and complex problems.[11]

These LEAP learning outcomes emerged from extended conversations among academic and corporate leaders and recent alumni of undergraduate institutions. A key area of concern for both employers and recent graduates is that higher education should give students more experience with real-world applications of their knowledge and skills through hands-on learning. Employers, in particular, believe that the areas most in need of increased emphasis by higher education institutions are 1) science and technology, 2) teamwork skills in diverse groups, 3) applied knowledge in real-world settings, 4) critical thinking and analytical reasoning skills, 5) communication skills, and 6) global issues.

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[9] Council on Competitiveness, "Council on Competitiveness: National Innovation Initiative Summit and Report, 2005," *Transforming America's Scientific and Technological Infrastructure: Recommendations for Urgent Action*, Project Kaleidoscope 2006 Report on Reports II, pp. 6-7, http://www.pkal.org/documents/CouncilOnCompetitiveness.cfm.

[10] American Association of American Colleges and Universities' (AAC&U) Liberal Education & America's Promise (LEAP) initiative website, http://www.aacu.org/leap.

[11] "The Essential Learning Outcomes," from *College Learning for the New Global Century*, 2007, the Liberal Education & America's Promise (LEAP) initiative, AAC&U, http://www.aacu.org/leap.

This AAC&U LEAP template of goals for student learning, together with those from national communities of scientists and engineers, provide invaluable benchmarks against which teams of institutional agents of change can consider their own goals for student learning within the larger scientific and societal context. Engaging in national conversations about STEM student learning and having those conversations reflected in institutional policies, programs and practices is a clear best practice for undergraduate leaders in STEM fields.

II. Promising practices: focusing on the student.

The above stories and reports make it clear that all promising practices focus on the student, on what he or she is prepared to do upon graduation. Storytelling is an emerging promising practice at the level of institutional transformation of undergraduate STEM.[12] This is a practice commonly described in dissemination literature as a means to promote and advance similar efforts within a community of peers.[13] The BHEF understood this clearly in its calls for forward-thinking institutions to become *champions of redesign and learning* beyond the boundaries of their campus. These stories, and those that follow, are from campuses that have gone through the iterative process of setting learning goals in the context of the institutional mission and vision (perhaps—as with the UA story, within a major department), designing learning experiences based on those goals, and then assessing if, how and for whom such experiences are making a difference.

Unlike twenty years ago, stories of today can be documented with data about what works. Leading the way in figuring out how to gather such data were pioneers in the emerging world of research-based pedagogies, faculty intent on linking theory of learning to the practice of learning. The seminal report, *How People Learn (HPL)*, published in 1999, authenticated the work of those like Lillian McDermott and her colleagues within the physics community, John Jungck and his colleagues within the biology community, and others who in the mid-1980's were becoming visible transformers of how undergraduate STEM was to be learned and thus how it was to be taught.

Since my focus is on promising practices at the level of institutional transformation, here I offer two stories about pedagogical transformations that affected significant populations of students. Stetson University was one of the PKAL Leadership Initiative (LI) campuses. Their LI report, submitted by Dean Grady Ballenger, outlined a sequence of promising practices (a sequence that is in itself a promising practice).[14] First, the STEM faculty asked themselves a key question:

> *Does the way that we teach the introductory STEM course for all students serve students who are not science majors as well as it does those who are majoring in STEM fields?*

In addressing that question, they pursued carefully crafted strategies over an extended period of time. These included: bringing a non-scientist (religion professor) onto their LI team; developing a vision statement for curricular reform from which they gave attention to the 150-level courses for non-majors and to teaching methods that would serve those learning goals. They built from strength—recognizing the value of the twelve goals for the existing 150-level courses as they sought to balance teaching demands required by general education requirements and demands of the major sequence. Faculty used those 12 goals in several

[12] Stephen Denning, *The Springboard: How Storytelling Ignites Action in Knowledge-Era Organizations*, Boston: Butterworth Heinemann, 2001.

[13] Everett M. Rogers, *Diffusion of Innovations, 4th ed.*, New York: The Free Press, 1995.

[14] Grady Ballenger, Stetson University Leadership Initiative Report to Project Kaleidoscope (private communication).

ways, beginning with a survey to STEM faculty about their perceptions of the relative merit of those goals and if/how they were serving those goals in their classes. (It is of interest to note that "the development of a curiosity about and interest in science" was the highest-rated goal in the survey.) They also surveyed non-STEM Stetson faculty to determine if their rankings of the value of goals matched those of the STEM faculty (they did). Their careful tracking of whether and how goals for student learning were being met also included pre- and post- surveys of students participating in the revised course.

Like Stetson, the University of Texas, El Paso had questions about the earliest learning experiences of their entering students. Their driving question was:

> *Recognizing the challenges in serving a student population that is increasingly diverse both culturally and economically, how can the University of Texas, El Paso (a public university on the U.S. Mexican border) ensure that entering students have a successful first-year STEM learning experience, one that motivates them to succeed and persist in STEM learning?*

Their responses to this question led to the development of CirCLES (Circles of Learning for Entering Students Program)[15] based on a unique early orientation program, intrusive advising and mentoring, as well as course clustering and learning communities. As with other stories presented here, their efforts engaged persons from across the campus, including from the offices of admissions and recruitment, student assessment and testing, financial aid, and the registrar, as well as faculty from Developmental Mathematics and Composition programs.

A longitudinal evaluation process was implemented that began with the summer orientation program and a comparison group was used to assess the impact of CirCLES on academic performance of participating students.

Among the several threads of interest in their story is the documented impact on student success and persistence—the two major project goals. CirCLES students have attempted and earned more credit hours, achieved a higher GPA, and place higher into subsequent math courses when compared to non-CirCLES students. First-year retention of first-time, full-time clustered students is up to 80% from 68%. Another interesting thread, as noted by Benjamin Flores, is the ripple-effect of faculty leadership, with strong support (recognition and rewards) by senior administrators for involved faculty. At the first, cultures at the departmental level still valued faculty research efforts more than faculty teaching efforts, but with intentional new hires and robust faculty development efforts tied to CirCLES and similar initiatives, the culture is now aligned with the mission of the institution to serve a more diverse student population.

That there is a logical process to shaping a STEM learning environment that serves general and specific goals for student learning is clear from these and other stories in the PKAL archive. From these we can posit that a compelling best practice is faculty taking hard questions seriously, from *what do we want our students to know and be able to do upon graduation*? to *how can we make certain that it happens here, given our institutional mission, vision, and circumstances?,* followed by asking *how will we know we are making difference?* It does no good to ask questions about student learning if there are no next step strategies being implemented or no subsequent monitoring to determine if pilot/new approaches are serving their intended purpose.

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[15] Pablo Arenaz, "Building Learning Communities," in *Then, Now, & In the Next Decade*, Frank C. Rothman and Jeanne L. Narum, eds., Project Kaleidoscope, 1999, p. 8, http://www.pkal.org/documents/then-now-and-in-the-next-decade.pdf.

Benjamin C. Flores, *Science for All: The University of Texas at El Paso Story*, Project Kaleidoscope Volume IV, http://www.pkal.org/documents/ScienceForAllUTEP.cfm.

Further, *what works* is when STEM faculty make informed connections about what students should know in their fields, what skills they will need as STEM professionals in the field to contemporary pedagogies that can advance such understandings and promote such skill development.

Two stories illustrate this point—one from Clemson University and one from Georgia Institute of Technology—addressing the need to develop students into effective problem-solvers by engaging students in open-ended, complex problem-solving experiences. Melanie Cooper, in her work at Clemson, developed a system that provides reliable and repeatable measures of student problem solving which can be used to determine effective teaching strategies or to evaluate research studies in chemistry.[16] Cooper's work began with a provocative set of questions:

- How do we assess "higher-level" problem solving? (Answer: with great difficulty, but if you test it they will come)
- What is the purpose of a typical test question? (Answer: understanding what the end should be—creative problem solving, critical thinking, analysis, synthesis, and evaluation)
- What makes for a good problem solver? (Answer: metacognition)
- What are persisting myths about getting students to be better problem solvers? (Answer: #1. Practice makes perfect; #2. Group work doesn't promote individual improvement; #3. In group-work "good" students carry the others); #4. Explicitly teaching algorithms and heuristics improves problem solving; #5. It is the instructor's job to provide clear, explicit and unambiguous instructions)

The major theme of Cooper's work, debunking those myths, is that faculty need to provide learning environments and instruction that provide opportunities for students to develop the skills we value. She reports:

> *…Private empiricism—where we believe something because of our own experience—is not appropriate for scientists; yet when it comes to education, personal experience seems to be an acceptable substitution for evidence. Unfortunately, most scientists' beliefs about education are rarely based on objective evidence, but rather on what they imagine to be true. While personal experience in the classroom can give valuable insights, it is not data.*

This, obviously, is a 21st century promising practice, given that even in the latter years of the 20th century data presenting objective evidence were not widely accessible, but Cooper's deeper insight reflects that of many other leaders, including Nobel Laureate Carl Weiman. Weiman's persisting argument is for tackling the hard work of reform of undergraduate STEM in the same manner one would use in tackling a tough research question, from the point of identifying the right questions to analyzing and disseminating results of experiments. The work of Weiman and Cooper each provides strong evidence of the efficacy of this approach—a significant promising practice.

However, to continue the pattern of presenting what students think about new approaches:

> *The labs are much better than ones in high school chemistry. In high school chemistry labs, we were given a value that we had to achieve. If we did not, we lost points depending on how far off we were. This is a problem since error is inevitable in a lab setting, even under the most controlled conditions. The labs in this log manual focus on how you carry out the experiment. You are not given target results.*

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[16] Melanie Cooper, Ron Stevens, and Thomas Holme, "Assessing Problem-Solving Strategies in Chemistry Using the IMMEX System," in *Proceedings of the National STEM Assessment Conference*, edited by Donald Deeds and Bruce Callen, 118-129, Washington, D.C.: Open Water Media, Inc., 2006.

Melanie Cooper, *Assessing and Improving Problem Solving*, presented at a Project Kaleidoscope event, 2008.

> *Instead, you derive a method of solving the given problem (separating a mixture, synthesizing a compound, etc.) This method is more similar to what scientists do, and it makes the lab experience more rewarding.* (Student in the Clemson cooperative chemistry lab)

My final story is from Georgia Institute of Technology, about their problem-driven learning (PBL) initiatives within their biomedical engineering (BME) program.[17] Their story is one of promising practices that incorporates all of the above, with attention to:

- what the students for whom the BME faculty are responsible should know and be able to do upon graduation as a result of their learning experiences as undergraduates
- what happens from the very first day in the very first class for entering students that reflects deep thinking from the BME faculty about goals for student learning
- advances in how science/engineering is practiced that require new approaches in how science/engineering is learned
- bringing a diverse group of faculty to the table, including a group of cognitive scientists
- shaping a program firmly grounded in pedagogical approaches that give graduates experience with the kind of model-based reasoning similar to what engineers do
- establishing a visionary program that was an innovative response to current calls from and for the engineering community to be preparing the *engineer of 2020*
- how to capitalize on an emerging discipline, BME—one with no tradition, no textbooks, no baggage, no faculty saying, 'but we've never done it that way before,' a discipline that takes the tools of engineering and applies them to the biosciences, and then leads to clinical applications
- experimenting with (and assessing) a variety of approaches to scaffolding student learning
- contemporary research on learning from the work of theoreticians and practitioners.

This latter point is critical in the context of considering promising practices. Wendy Newstetter, the embedded cognitive scientist involved with planning the program, said,

> *…We did not want to recreate ourselves in the students who come through the program; we are engineers who started working on biology programs late in our lives, without experience in crossing the boundaries between biology and engineering. Thus, the goal we articulated was to prepare students who can be truly integrative thinkers, who can move seamlessly between these three worlds and be prepared to develop the next generations of clinical applications—whether the applications be at the frontier or closer at hand. So, our self-imposed charge was to create a curriculum that supported the development of truly innovative thinkers.*

To emphasize another point, one that is also explicit or implicit in the stories above, the key strategy to reach their goals for student learning was that students were engaged in activities—solving problems at the frontiers of science that others are trying to solve at the same time that socialized them into the community of biomedical engineers. Newstetter describes how this has a very interesting impact on identity. "When you give students a complicated, multi-dimensional, interdisciplinary problem out of the real-world, their imagination is sparked and they begin to say, 'I can see myself doing this.' So problem-solving is about motivation and identity."

Quantitative data are available from technology that tracks the efficacy of the BME PDL curriculum from its initial days. Two pieces of more qualitative data: as first-year students experience the PDL learning

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[17] Project Kaleidoscope, *Problem-Based Learning at Georgia Tech: An Interview with Wendy Newstetter*, Project Kaleidoscope Volume IV, http://www.pkal.org/documents/PBL_GeorgiaTech.cfm.

Problem Driven Learning in Science and Engineering Education, Georgia Institute of Technology Website, http://bme.gatech.edu/pbl/ http://bme.gatech.edu/pbl/.

environment and as more faculty become involved, PDL is being adapted in other courses and classes across the BME program. Perhaps more important is the increasing number of contacts by potential employers for graduates from the Georgia Tech biomedical engineering program.

From stories like these and others in the PKAL archives my list of *practices that work* is being distilled, and in preparing this paper I was reminded of comments by Jose Mestre (another contributor to this *promising practices* discussion) at the 2005 PKAL Roundtable on the Future.[18] Mestre challenged us to see the inherent complexity and interrelationships of questions to be addressed if academic renewal is to be aligned with the best understanding of how people learn, calling our attention to hard questions such as these:

- How do we break the 'teach as you were taught' cycle in STEM education?
- How do we get STEM faculty to apply "scientific method" to their teaching?
- How can research and teaching spaces be designed to encourage instructors to become coaches of learning and not transmitters of information, as well as encourage the integration of teaching and research?
- How do we get STEM faculty, college and university leaders to promote the teaching of interdisciplinary courses, cross-disciplinary collaborations via design of policies and spaces?

And finally:

- How can we promote the use of metacognitve strategies in STEM learning and how do we get students to view pedagogies of engagement as superior ways of learning?

The stories I have not told (they will be told by others in this assembly) relate to the work of contemporary communities of pedagogical pioneers, assessment practitioners, learning theorists and others whose work is being carefully developed, documented and disseminated. From their experiences we can distill answers to Mestre's questions that help us all understand better how to answer the initial questions about what, how and how to teach can be addressed? The stories presented here have pedagogical transformation as part, but only part, of the kaleidoscope of approaches that must be attended to if systemic and sustainable transformation of the undergraduate STEM learning environment is to be achieved.

III. Promising practices: taking the kaleidoscopic perspective.

Creativity is a lot like looking at the world through a kaleidoscope. You look at a set of elements, the same ones everyone else sees, but then reassemble those floating bits and pieces into an enticing new possibility. Innovators shake up their thinking as though their brains are kaleidoscopes, permitting an array of different patterns out of the same bits of reality. Changemasters challenge prevailing wisdom. They start from the premise that there are many solutions to a problem and that by changing the angle on the kaleidoscope, new possibilities will emerge. Where other people would say, "That's impossible. We've always done it this way," they see another approach. Where others see only problems, they see possibilities.

Kaleidoscope thinking is a way of constructing new patterns from the fragments of data available— patterns that no one else has yet imagined because they challenge conventional assumptions about how pieces of the organization, the marketplace, or the community fit together.[19]

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[18] Jose Mestre, *Translating "How People Learn" into a Roadmap for Institutional Transformation: Framing Some of the Issues*, presented at the 2005 PKAL Roundtable on the Future at Cranbrook, http://www.pkal.org/documents/Mestre_HPL.cfm.

[19] Rosabeth Moss Kanter, *Evolve!: Succeeding in the Digital Culture of Tomorrow*, Harvard Business School Press, 2001.

From the perspective of our work with PKAL, the most effective promising practice for contemporary changemasters within the undergraduate STEM community is to be kaleidoscopic thinkers. It is to take the kaleidoscope to examine all facets of the learning environment, to bring light in from the outside (and from outliers) and to search for new patterns into which policies, practices and programs, faculty, spaces and budgets all come together in new ways, in the service of students, science and society.

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