Meeting the Challenges in Emerging Areas: Education across the Life, Mathematical and Computer Sciences

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Judith A. Ramaley[1]

As we enter a new era of science, there are signs that the disciplines are converging, drawn together by common mathematical and computational paradigms. As this happens, the areas of greatest interest transcend traditional academic disciplines and the structure of the academic department and draw increasingly from many disciplines.

What is a discipline?

- A body of concepts and key ideas held together by a common vocabulary.
- Distinctive ways of talking about these concepts and ideas: a "syntax."
- Characteristic ways of establishing a warrant for the validity of ideas and claims of truth
- Distinctive forms of inquiry and a set of specialized tools and methodologies used to generate the knowledge that will contribute to the enhancement of professional practice.

The new science transcends these definitions. Consider the emerging structure of research on learning and teaching for example.

It is important to develop the capacity to conduct research that

[1] The ideas expressed in this document are those of the author and do not necessarily reflect the official views of the National Science Foundation.

- Is "rooted in practice in both its inspiration and its application"
- That "seeks to coordinate progress in basic knowledge with multiple forms of empirical inquiry, interventions and the wisdom of experience"
- Conducted by a "multidisciplinary professional community of people who have experience and expertise in different parts of the enterprise"
- In order to develop "an approach that would coordinate the resources of research, development and experience"
- To build up a systematic base of knowledge
- Generated by a research infrastructure that has the capacity to do this kind of engaged work[2].

What kind of undergraduate education can prepare students for careers in a world where boundaries cease to have meaning?

I will turn to the recently released report of the **Greater Expectations Panel**, which I had the honor to chair, for answers to this question.

Greater Expectations envisions a higher order of learning that prepares our students for a complex world. The panel urged the adoption of an invigorated and practical liberal education as the most appropriate kind of learning for the 21st century.

The core concept is that our students must become intentional learners who can adapt to new environments, integrate

[2] Source: Mathematical Proficiency for All Students: Toward a Strategic Research and Developmental Program in Mathematics Education. Prepared by the RAND Mathematics Study Panel, March 2002

knowledge from many sources, and continue to learn throughout their lives. The students we prepare today are standing at the beginning of a new era of science. Unless we dedicate ourselves to their intellectual, emotional and social maturity, they will not have the capacity for discovery, learning and true engagement that will characterize successful scholars in years to come.

Our job is to prepare people who will lead productive, creative and responsible lives. They will do Good Work.

<u>Good Work. When Excellence and Ethics Meet</u> by Howard Gardner, Mihaly Csik-zent-mihalyi and William Damon lays out a portrait of engaged scholarship that is compelling . It is an exploration of work of expert quality that benefits the broader society, work that exemplifies

- creativity,
- intellectual leadership and
- social responsibility

in a time of constant change. The book, in fact, offers a faithful portrait of our best young scientists today, the ones who receive CAREER Awards from NSF, for example.

To develop an understanding of what good work means, the authors picked two highly contrasting fields that none the less turn out to share some common concerns about the meaning of excellence and responsibility

Genetics
Journalism

Given our shared commitment as representatives of the scientific community

to support the development of a diverse and well-prepared workforce of scientists, technicians, engineers, mathematicians and educators and a well-informed citizenry that have access to the ideas and tools of science and engineering and to support science that will benefit society and ensure the health, prosperity, welfare and security of the nation

it is interesting to examine the experience of good work in science by looking at what Good Work means.

1. the excitement of scientific inquiry---the experience of being at the frontier and out there in uncharted territory

2. the pleasure of working with scientific materials—

   this goes back a long way. On its title page, the Encyclopedie, the greatest compilation of knowledge of the 18th century philosophes printed an epigraph by Horace: "What grace may be added to commonplace matters by the power of order and connection."

3. pleasure in the kind of thinking that goes into the practice of science—the formulations, analogies, metaphors, ways of looking at the world, the language of discovery and inquiry

4. the belief that science as a rational way of thinking and learning can bring order and integrity to the exploration of life's challenges and can ultimately enrich the human condition

Good work in science is characterized by a few simple and compelling principles, all of which can guide our approach to thinking about the undergraduate curriculum.

1. honesty and integrity
2. an openness to the unexpected, supported by a free flow of information and a receptivity to the unexpected
3. the ability to dream and to imagine a different and better future supported by the results of scientific inquiry
4. responsibility to society---expressed as

    - a willingness and ability to inform the public,
    - take into account the possible consequences of the study for individuals, groups, the environment and society at large, and
    - educate students and the general public about the meaning of scientific research and its implications for their lives.

To return to the ideas of Greater Expectations, our students must be

- **Empowered** through the mastery of intellectual and practical skills
- **Informed** by knowledge about the natural and social worlds and the forms of inquiry basic to these studies
- **Responsible** for their personal actions and willing to work toward the public good.

There are many ways to talk about the qualities of an educated person. While we consider how the changing conduct of science will reshape the way we prepare our undergraduates, we must keep in mind that our primary purpose is to help them become educated and responsible people.

Design of an undergraduate education.

A pattern is emerging that can provide a "conceptual backbone" for liberal learning that both captures the traditional goals of liberal education and addresses contemporary concerns about the meaning and purpose of an undergraduate education. (AAC&U, 1997) In a recent report, AAC&U outlined the learning goals underlying the recent curricular reform movement.

1. acquiring intellectual skills and capacities
2. understanding multiple modes of inquiry and approaches to knowledge
3. developing societal and civic knowledge
4. gaining self-knowledge and grounded values and a sense of social responsibility and leadership skills
5. concentration, integration and application of learning
6. career exploration and transition planning through a variety of modes of inquiry and hands-on learning opportunities including direct experience in field settings, service learning, internships, and research or problem-based learning.

In the old modular form of curricular design, there were three basic components (1) general education in the lower division, in the form of distribution requirements; (2) a concentration of study in a major and one or more minors in the upper division; and (3) electives. Success was measured by the completion of a prescribed number of credit hours with an acceptable grade point average. Where appropriate, a student would fit in additional experiences such as an internship or study abroad or an undergraduate research experience.

The new learning and curricular design is more **continuous** and always **active**, emphasizing both mastery of a body of knowledge and progressively more complex scholarly work as a student moves through levels of the of learning (the major and minors), all of the design components are present from freshmen to senior year, with a greater emphasis on student-initiated work in the upper division as a preparation for the transition to a lifelong pattern of learning and educational planning. In a model like this, scholarly work is an integral part and our efforts to engage our students in research becomes not a co-curricular activity or embellishment, but a matter of the core of the undergraduate experience for all students.

A learning Centered Model

The core assumption upon which this model is built is that learning is more likely to occur when students play an active role in the learning process. (Chickering & Gamson, 1991; Garvin, 1995). The seven principles originally defined by Chickering and Gamson are

a. frequent faculty-student contact and intellectual engagement
b. collaborative inquiry in which learning and problem-solving is done in group settings, either through direct contact or on-line
c. active learning and reflection either in the field (experiential learning) or focused on challenging societal problems that community groups or organizations are working on in order to enhance their quality of life (service learning)
d. prompt feedback and reflection and an on-going consideration of the purposes and results of the

educational experiences, including the gradual formation of a personal educational philosophy and personal goals
e. time on task and effective time management
f. high expectations met through research or problem-based learning that allow students to demonstrate that they can achieve the highest purposes of an education, the ability to organize and begin to deal with an unstructured problem in a competent and ethical way
g. respect for diversity of talent and ways of learning

Together, these elements employ six critical forces in education:

- active learning
- cooperation
- diversity
- high expectations
- interaction with others
- responsibility.

All of these elements are necessary to support academic excellence.

Reform of Undergraduate education in science, technology, engineering and mathematics

1. Major curricular reform must be grounded in a clear institutional mission and a coherent educational philosophy that together create a framework and aspirations to guide the curricular reform process.

Peter Ewell: Any curricular reform must be guided by an overall vision of learning itself, established through systematic research and the wisdom of practice (both hallmarks of an 'expert culture. Most reform efforts tend to be particularistic and mechanical. They result in add-ons rather than rethinking from within.

The curriculum must be designed with a knowledge of how people learn and focused on those circumstances and strategies that promote learning.

- The learner is not just a passive "receptacle" of knowledge but rather creates his or her own learning actively and uniquely.
- Learning is about the making of meaning for each individual learner by establishing and reworking patterns, relationships and connections.
- Everyone learns all the time, both with us and without us.
- Direct experience decisively shapes individual understanding.
- Learning occurs best in the context of a compelling and interesting problem.
- Learning requires time and opportunity for reflection.
- Learning occurs in a cultural context tat provides both enjoyable interaction and personal support for all learners as well as a chance to experience collaborative learning and teamwork.

The process must not be piecemeal. It must be guided by an overarching philosophy and principles and accompanied by a culture of evidence as well as a sense of purpose and a recognition that knowledge must have consequences in order to be meaningful.

Given what we know about learning, STEM is especially well suited as a means to promote deeper learning and understanding.

According to the participants in the AAHE 1998 Conference on Institutional Change, learning "involves a change in attitudes as well as aptitude" and is a process that culminates in the ability

- To ask the right questions and frame good problems
- To acquire information and evaluate sources of information
- To critically investigate and solve problems
- To make choices among many alternatives
- To explain concepts to others (verbally and in writing)
- To generalize to new situations.

2. Faculty must understand who their students are, their backgrounds and preparation and their educational goals.

3. There must be a supportive environmental for curricular change.

- Faculty roles and responsibilities must be compatible with a major investment of time and energy in curricular reform.
- The P&T process should incorporate rigorous standards that can be applied not only to traditional research and creative activity but also to the evaluation of what Boyer called "the scholarship of teaching."
- Faculty must be supported by an effective infrastructure and policies that promote collaboration, provide technical assistance for the introduction of new pedagogical approaches, and encourage the evaluation and

dissemination of the results of reform as it is being attempted and not simply after the fact.

- Sufficient resources must be provided to validate the priority of curricular reform and to support it. This will require reallocation from other priorities and the utilization of strategic thinking and budgeting at institutional levels.
- Time must be taken to understand the process of change itself and to explore what can be done to ensure that reform can be sustained and enhanced on an institution-wide scale.

4. It takes a long time to change a campus culture and to install significant curricular changes. New approaches to STEM must be aligned with other coordinated efforts to introduce a coherent educational philosophy that guides the design and delivery of the undergraduate curriculum and defines the expectations for the undergraduate experience. Such reform is unlikely to succeed when undertaken either on a an individual course by course basis or without articulation with a broader curricular reform agenda.

5. Undergraduate experiences in STEM for both majors and non-majors should be approached from the perspective of a liberal arts education.

- All undergraduates should have an in-depth exposure to the modes of inquiry and significant theoretical and practical aspects of each domain of the liberal arts. The sciences frequently are approached differently from other fields. In English, a student learns to write while simultaneously studying the work of others. In History, a student learns to work with original materials and to analyze and interpret them in the context of historical reasoning while reading the work of historians. In the sciences and mathematics, however, undergraduates are often not allowed to engage in original inquiry until they have mastered a significant body of knowledge developed by others. Reforms that introduce undergraduates to discovery and application early in their education can correct this disparity and ensure that students acquire the capacity for moral and ethical reasoning (open-mindedness, an insistence on evidence and empathy for others) as well as a propensity for lifelong learning.

- All undergraduate majors in STEM fields should be designed to prepare students not only for graduate study in that field but also to provide a broadly based liberal education that can be a foundation for a variety of later career directions. This is expected in English, History or Political Science. It should be equally true of Biology, Chemistry, Geology, Physics or Mathematics.

6. Reform in undergraduate STEM can benefit from a close articulation with both K-12 reform and the reform of graduate education, both in teacher preparation programs and in traditional STEM doctoral programs. There is a logical relationship between K-12 reform and the redesign of undergraduate science curricula. Both require that faculty members have experience with curricular change and with the introduction of different pedagogical strategies and that they be skilled in collaboration, both with other faculty on campus and with community partners who can offer off-campus opportunities for original research (e.g. environmental studies).

To quote from 1998 AAHE Conference participant Karl Smith, "the greatest reform will come when faculty view themselves as reformers in their immediate spheres of influence, especially in their classrooms."

The stimulation and sense of purpose that is provided by the remarkable advances we are seeing today in genetics, cell biology, ecology, medicine, and evolution and systematics are beginning to generate new and exciting interdisciplinary fields, new methodologies, new kinds of questions that we could not even have asked ourselves a few years ago. We cannot define our task as simply to develop strategies for integrating biology, mathematics and computer science in our curriculum. In fact, these goals are on the path to a much more important, a much more profound set of goals---to rethink what we mean by an undergraduate education and to use the excitement of the new science as a starting point for engaging our students in the greatest intellectual adventure we have ever seen.