AC 2012-3748: TAKING STOCK: PROGRESS TOWARD EDUCATING THE NEXT GENERATION OF ENGINEERS

Dr. Peter H. Meckl, Purdue University

Peter H. Meckl is a professor in the School of Mechanical Engineering, where he has served since 1988. Meckl obtained his B.S.M.E. from Northwestern University and M.S.M..E and Ph.D. degrees from MIT. His research interests are primarily in dynamics and control of machines, with emphasis on vibration reduction, motion control, and engine diagnostics. His teaching responsibilities include courses in systems modeling, measurement systems, and control. In addition, he teaches a course entitled technology and values, which introduces students to the social and environmental impacts of technology through a series of readings and discussions. He currently serves as the Co-chair of a Strategic Planning initiative entitled "Grand Challenge Design" to introduce multidisciplinary design experiences in the College of Engineering.

Dr. Marc H. Williams, Purdue University, West Lafayette
Ms. Carolyn Percifield, Purdue University

College of Engineering

Dr. Monica E. Cardella, Purdue University, West Lafayette
Dr. Michael T. Harris, Purdue University, West Lafayette

Michael Harris is the Associate Dean for Undergraduate Education and professor of chemical engineering at Purdue University. He serves as Program Chair for the Minorities in Engineering Division of ASEE for the 2011 and 2012. He is a Fellow of the American Institute for Chemical Engineers. He earned a B.S. degree in chemical engineering from Mississippi State University, and M.S. and Ph.D. degrees from the University of Tennessee. He has been a researcher at the Oak Ridge National Laboratory and faculty member at the University of Maryland, College Park.

Prof. Leah H. Jamieson, Purdue University, West Lafayette

Leah Jamieson is the John A. Edwardson Dean of Engineering at Purdue University, Ransburg Distinguished Professor of electrical and computer engineering, and holds a courtesy appointment in Purdue's School of Engineering Education. She served as 2007 President and CEO of the IEEE. She is co-recipient of the 2005 NAE Bernard M. Gordon Prize for Innovation in Engineering and Technology Education for the creation and dissemination of EPICS. Jamieson is a member of the American Academy of Arts & Sciences and the U.S. NAE and a Fellow of ASEE and IEEE.

Taking Stock: Progress toward Educating the Next Generation of Engineers

Abstract

At the 2011 ASEE Conference in Vancouver BC, Purdue sponsored two sessions focused on progress toward achieving the aim of adapting engineering education to the new realities of the 21st Century world. Before the conference, a survey was distributed to more than 3000 recipients to collect information about how universities worldwide define the "Future Engineer." It also aimed to uncover challenges and success factors that should be considered in order to effectively and sustainably integrate the ideals of the "Future Engineer" into the curriculum. This paper summarizes the results of the survey as well as the discussions from session participants. A dominant theme throughout was the need for both top-down and bottom-up approaches to engineering curriculum change.

Background

Engineering students graduating in the 21^{st} century will surely face new challenges compared to their counterparts that graduated in the 20^{th} century. Global issues are becoming much more important, and engineers will need to contribute not only to technology but also to public policy. The National Academy of Engineering prepared a report in 2004 entitled *The Engineer of 2020: Visions of Engineering in the New Century*[1]. That report emphasizes the profound changes that are anticipated for the engineering profession, as well as the opportunities for engineers that future challenges in resource allocation, energy use, and environmental stewardship will provide.

Thomas Friedman, in his book *The World is Flat*[2], emphasizes the changes that have occurred in the world toward the end of the last century. The fall of the Iron Curtain, the birth of the internet, the spread of open-source software, and the rise of new economies in Eastern Europe, India, and China have made it easier to outsource service jobs to other countries where labor is cheaper. "The global competitive playing field was being leveled. The world was being flattened." [2, p. 8] These trends have increased the importance of preparing our young people to succeed in this new flattened world.

A more recent book by Pat Galloway, entitled *The 21^{st} Century Engineer: A Proposal for Engineering Education Reform*[3], emphasizes the need for engineering educators to develop "a holistic breed of engineer – one who can work across borders, cultural boundaries, and social contexts and who can work effectively with nonengineers." [3, p. 87] Engineers must become global leaders in their profession. She goes on to say:

> "The engineering curriculum can no longer remain as it has for essentially the past 40 years. The subjects of globalization, diversity, world cultures and languages,

communication, leadership, and ethics must constitute a core component of the overall engineering education just as physics and mathematics do." [3, p. 87]

The important role that engineering education plays in preparing engineering graduates of the future is emphasized in several scholarly publications[4, 5]. In [4], the authors explore the current state of engineering education and provide recommendations for improvement. In particular, they emphasize the importance of giving students a set of professional practice skills that they will need upon graduation. These include ethical reasoning, communications, and multi-disciplinary teaming skills. In [5], the authors emphasize the importance of basing engineering education innovations on scholarly research that defines how students learn. The purpose of that publication is to connect education researchers with practitioners so as to achieve a new culture of innovation in engineering education.

E.T Smerdon[6] wrote an interesting article that emphasizes the dichotomy between current and future best practices in engineering education. In comparing the Analytic Model of engineering education during the time period 1960-1985 with the Integrative Model of 2000 and beyond, he mentions a number of polarities (such as Reductionism vs. Integration, Analysis vs. Synthesis) that contrast the past and the future states of engineering education. What is also clear is that these dichotomies are not really an "either/or" but rather a "both/and", since students will need not only the new future skills, but also the essential earlier skills.

As a result of the perceived importance of this topic, we organized two special sessions for the 2011 ASEE Annual Conference in order to assess the current state of engineering education and to document best practices for engineering education. This assessment took two forms, first a pre-conference survey distributed to a wide email database, with recipients not only from the United States but from all over the world. Several of these recipients were then asked to serve as facilitators at the 2011 ASEE Annual Conference to help guide discussions about future improvements in engineering education, with topics based on the outcome of the survey.

As a basis for the discussions, we selected the formalism of "Polarity Management," which seeks to define both the current state and the change state so as to achieve the benefits of the proposed changes while retaining the best features of the current state. This approach makes it easier to address any resistance from those who advocate the current state. In this way, the approach is also nicely congruent with the nature of the discussion by Smerdon[6].

This paper serves as a description of the process taken to gather information about current and future best practices in engineering education, as well as a summary of pertinent findings.

Process Overview

Pre-conference Survey Design:
The survey instrument was developed with the assistance of the Director of Learning Assessment for the College of Engineering, Dr. Diane Beaudoin, and an external expert on market research, Kevin Lyons of Lipman Hearne, Inc. Using Qualtrics, an on-line survey was developed (and deployed) at Purdue using both open-ended and closed-ended (e.g., rating scales, drop down menus) questions.

Designed to take about 15 minutes to complete, the survey was sent to a global population of Engineering School administrators (Deans, Associate Deans, Department Heads), faculty (all ranks and disciplines), and staff. Associate Deans, faculty and staff were selected who had demonstrated interest in curriculum and/or engineering education (previous participation in annual ASEE conferences and/or ASEE Global Colloquia, education committees of professional societies, involvement in ABET, or other education-related activities such as diversity programs, service learning, etc.). Invitations were sent to 3,083 individuals of which 673 (22%) were from foreign Universities. 204 individuals responded, representing 135 universities of which 97 are in the US and Puerto Rico and 38 (28%) are international universities. Just over half of the respondents (111) indicated that their institution was engaged in a significant program of change in its curriculum (while the other half indicated that their institution was not engaged in such a change).

Survey Goals:

I. Understanding various dimensions of the curriculum change process including:
   1. The definition of "future engineers" and the attributes needed to be successful
   2. The importance of these attributes and degree to which they are incorporated into the curriculum
   3. The objectives for current or planned curriculum change initiatives and the administrative level of "ownership"
   4. The barriers to success and factors for success

II. Identifying potential topics and facilitators for planned ASEE sessions in Vancouver, June 2011

Preliminary Survey Analysis:
Preliminary analysis was done by Lipman Hearne, which developed the data cross-tabulation tables and provided an initial interpretation of the survey results. Additional preliminary categorization of and interpretation of the open-ended responses was done at Purdue to get a deeper understanding of planning motives and perception of success, as well as critical barriers to and factors relating to success.

A summary of the results from these exercises was shared during the Purdue-sponsored sessions at the June 2011 ASEE Annual Conference. More in-depth analysis was done post-conference (see section headed "Summary of Session Discussions").

Conference Session Design:

The survey was designed to provide insight for the planned ASEE sessions. The session design used principles from a change management process developed by Barry Johnson PhD, known as Polarity Management. Polarity Management acknowledges the paradoxes underlying seemingly intractable problems. A fundamental premise in Polarity Management is that neither side of the paradox (or pole of the polarity) is inherently wrong (or right); they both have merits and pitfalls if pursued to the exclusion of the other. A well-defined polarity will identify the upsides and downsides of both poles and a well-managed polarity will pursue actions to capture the benefits of both poles and pay attention to early warnings (or indicator metrics) to avoid the negative results of each pole. The polarity map in Figure 1 illustrates these principles and uses an infinity loop to show that when a polarity is well-managed, the loop bulges up into the top two quadrants that represent the positive results and barely dips into the bottom two quadrants which represent the downsides.

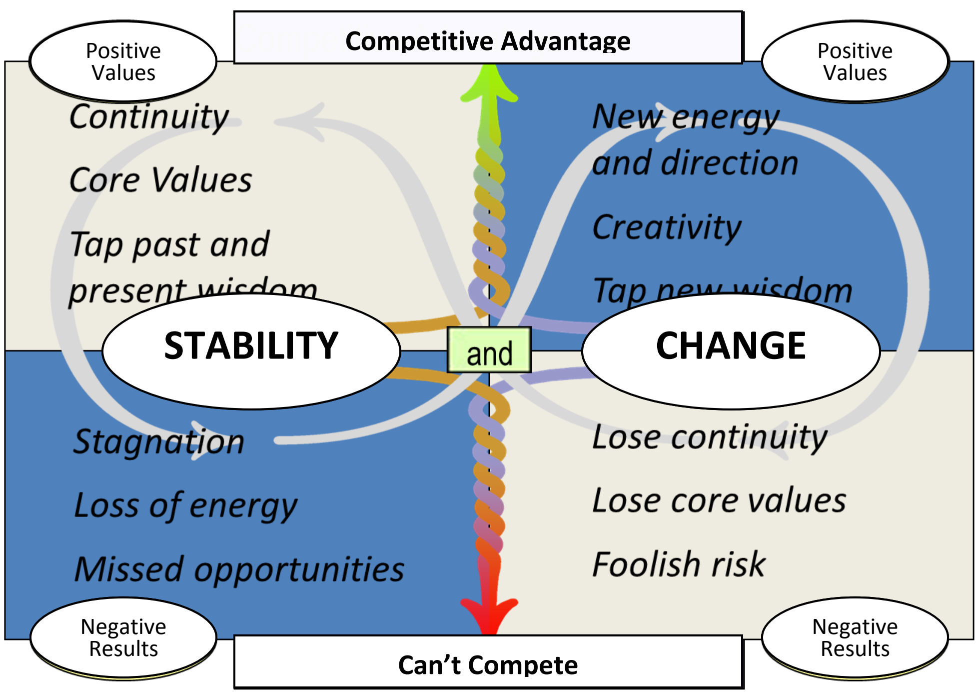

Fig. 1. Polarity Management Map

Given that Curriculum Reform to address 21st Century challenges has been debated for almost two decades[1, 7-9], we believe that many curriculum innovation strategies fail or do not achieve the desired level of success. Polarity Management theory[10] would suggest that there is a fundamental paradox at work – Stability and Change. From our own experience using this process in the College of Engineering Strategic Planning process[11], we found that, by applying it to issues surrounding curriculum change, we gained valuable insights on the factors that hinder or support the success of transformational curriculum change efforts. Figure 2 seems to support this premise if you put the two models through the Polarity lens. Neither is inherently right or wrong, in fact both models have virtues that need to be captured for educational transformation to be fully effective in engineering higher education.

Components of the Holistic Engineering Education of the 21st Century

Analytic (Science) Model, 1960-1985	Integrative Model, 2000 and Onward
Vertical (In-depth) Thinking	Lateral (Functional) Thinking
Abstract Learning	Experiential Learning
Reductionism – Fractionation	Integration – Connecting the Parts
Develop Order	Correlate Chaos
Understand Certainty	Handle Ambiguity
Analysis	Synthesis
Research	Design / Process / Manufacture
Solve Problems	Formulate Problems
Develop Ideas	Implement Ideas
Independence	Teamwork
Technological – Scientific Base	Societal Context / Ethics
Engineering Science	Functional Core of Engineering

Fig. 2. Table extracted from Smerdon[6] (p. 7), which references Bordogna[12]

The session design was structured to take topics that were surfaced from the survey (see Table 1) and apply Polarity Management mapping principles to better understand each topic. The flow used guiding questions that attempted to surface the two sides of the topic's polarity, the Positive Values and Negative Results of each polarity, as well as a few actions to capture the positive results and alerts or metrics to avoid the negative results (see Table 2). Facilitators were recruited from the survey participants that provided their contact information. They were not trained in Polarity Management techniques, but were given a brief overview of the survey, the topics, and their assignment as facilitators prior to the conference sessions.

Table 1: During the preliminary survey analysis phase, we analyzed the survey responses for insight on curriculum change objectives and the curriculum attributes. Each topic can be viewed as a paradox, for example, Global and Local/Domestic. The topics that emerged are as follows:

Topics
1. Distributing Design through the Curriculum
2. Achieving Truly Multidisciplinary Experiences
3. Achieving Meaningful Global Competency
4. Moving Beyond the Traditional Lecture
5. Integrating Professional Skills into the Curriculum
6. Streamlining the Curriculum
7. Developing Strategies for Effective Change
8. Developing Engineering Faculty for the 21^{st} Century

Table 2: Detailed session timeline:

Timeline	Session
2 minutes	Individuals Describe Current State on Post-its (Pro/Con)
10 minutes	Small Group Discussion of Current State
2 minutes	Individuals Describe Change State on Post-its (Pro/Con)
10 minutes	Small Group Discussion of Change State
2 minutes	Individuals Describe Strategies
10 minutes	Small Group Discussion of Strategies

Two sessions were planned, both taking place on Monday afternoon, each 90 minutes long. The original thought was to have one session focused on research-oriented institutions and the other primarily on undergraduate schools, since the objectives and constraints in those two groups can be rather different. But it became clear that it was not feasible to control attendance, so in the end we decided to make both sessions identical.

The room was set up with 8 café style tables, each with a flip chart and multiple sticky notepads. Each table was designated for one of the selected topics, "Going Beyond Traditional Lecture", "Distributing Design through the curriculum," etc., based on the dominant themes seen in the Survey. Each topic had a Facilitator whose assignment was to guide and focus the discussion.

Both sessions began with a 15 minute summary presentation of the survey results and the selected topics. Attendees were then invited to take a seat at the table of interest. The Facilitator gave a brief summary of the topic, including a rough definition of what the "current state" and "change state" are, and the charge to examine the pluses and minuses of each, in the spirit of Polarity Management. The ensuing discussion was divided in two parts, the first devoted to the current state, the latter to the change state, with the transition called by the session moderator. In each part, participants began by writing their thoughts on sticky notes before any discussion. The Facilitator then directed the discussion and attempted to arrange the notes in a coherent grouping of positive and negative aspects on the flip chart. The session ended with roughly 5 minute report outs from each of the 8 discussion groups. The 16 flip charts were collected for future summary and analysis. Each Facilitator was asked to write a summary of the discussion.

Following the conference, we analyzed responses from both the initial survey (deployed prior to the conference) and the artifacts from the sessions themselves. The session artifacts included the charts created by the session participants and the Facilitator's notes. The goal of the analysis was to determine:

- What are key barriers that impeded curriculum change, across demographically different institution types?
- What are key strategies that facilitate curriculum change, across demographically different institution types?
- What barriers/strategies are specific to the particular curricular changes discussed in the sessions?
- What barriers/strategies are common across the specific curricular changes discussed in the sessions?

In the next section of the paper, we discuss the findings from both quantitative and qualitative analyses of the survey data as well as qualitative analysis of the artifacts from the sessions. The quantitative analysis of the survey data was conducted by Lipman Hearne, the consultants. The qualitative analyses of the surveys and artifacts were conducted in a manner consistent with a grounded theory approach, where key themes emerged from the data sets.

Survey Analysis

As previously noted, 204 respondents representing 135 institutions completed the survey. The quantitative analysis conducted by Lipman Hearne provides insights into the current state of curriculum change across these 135 institutions, as well as a context for considering the open-ended survey responses. Just over half of the respondents (111) indicated that their institution was engaged in a significant program of change in its curriculum (while the other half indicated their institution was not engaged in such a change). 18 respondents indicated that the institution was engaged in curriculum change at the university level, 43 indicated the change was at the college/school level, and 33 indicated that the change was at the department level. The respondents were also asked to rate the effectiveness of the curriculum change: 9 indicated it was extremely successful; 25 indicated that it was very successful; 30 indicated it was moderately successful; 16 indicated that it was somewhat successful; 4 indicated that they had experienced "a few minor successes," 5 indicated that they were "stuck in neutral" and none indicated that they were "not at all successful." Thus 64 indicated that they were moderately/very/extremely successful, and 25 indicated less success, while no respondents indicated "not at all successful" and 115 respondents did not answer this question. Finally, the respondents were asked to indicate to what extent a series of topics was a focus for them/their institution, how important the topic was to their institution, and the progress the institution had made in integrating the particular curricular change. A summary of these responses, in order of decreasing importance, is presented in Table 3.

In this table, five attributes are shaded to indicate that they were judged to have been completely integrated into the curriculum by more than 40% of the respondents: strong engineering fundamentals, strong science and math foundation, analytical skills, teamwork, and a strong work ethic. Three attributes were judged to have only just begun to be implemented into the curriculum by more than 40% of the respondents: innovation, entrepreneurship, and global competency. These would represent attributes that need more time to be incorporated into the engineering curriculum.

Table 3: Percent of respondents indicating a particular topic was a focus for their institution's curricular change.

Topic	Focus	High Importance*	Complete integration*	Beginning integration*
Teamwork	97%	76%	40%	4%
Communication	94%	77%	28%	7%
OpenEnded Design and ProblemSolving Skills	90%	74%	34%	9%
Strong Engineering Fundamentals	90%	89%	58%	2%
Strong Science & Math Foundation	88%	81%	54%	5%
Analytical Skills	88%	75%	43%	5%
Integration of Analytical, Problem-solving & Design Skills	87%	65%	24%	13%
Ethical Awareness	86%	56%	22%	20%
Lifelong Learner	85%	51%	16%	25%
Multidisciplinarity Within & Beyond Engineering	75%	39%	18%	26%
Innovation	73%	56%	17%	46%
Leadership	73%	47%	10%	18%
Global Competency	72%	44%	11%	45%
Strong Work Ethic	70%	72%	40%	15%
Diversity	67%	52%	13%	22%
Decision Making	66%	41%	9%	26%
Entrepreneurship	62%	30%	11%	46%
Synthesize Engineering, Business & Social Factors	58%	31%	6%	36%
Adaptability	52%	38%	13%	26%
Managing Change	34%	40%	2%	24%

* Among those who indicated that attribute is a focus.

Qualitative Analysis of the Survey Responses:

Responses to two of the open-ended questions were analyzed using a qualitative, constant-comparison coding method (Glaser and Strauss[13]). Each survey response was read to identify the key point or key points (the key themes) present in each individual response. In most cases, each individual response was labeled with one key theme (one code). However, in a few cases, two or more distinct points (themes) were present in a single response; thus multiple codes were applied to those responses. As each survey response was reviewed, it was compared to the prior survey responses and the themes that had already emerged to determine if the survey response could be coded with one of the existing themes, or if the survey response presented a new point (a new theme/code). Using a constant comparison method, or "grounded theory" approach, where the codes emerge from the data, can be a powerful way to capture new insights or factors that may be missing from existing theoretical perspectives, or in this case when there is a paucity of theoretical perspectives on a particular topic.

The two questions analyzed in this manner were: "What are the 3 most significant barriers that you had (or have) in the change process?" and "What are the 3 most critical success factors that you had (or have) in the change process?" A total of 83 respondents answered the first question with one to three barriers (each of the 83 respondents may have provided 1 to 3 different responses) for a total of 223 barriers. A total of 81 respondents answered the second question with one to three success factors for a total of 223 success factors. Table 4 presents a summary of the barriers (and frequency of that response) identified in the responses and Table 5 presents a summary of the success factors identified in the responses.

Table 4: Barriers in curricular change encountered by survey respondents

Barrier	**Frequency**
Inertia, resistance, fear of change	34
Resources	31
Concerns about quality, rigor & consistency	29
Faculty, staff, admin., student buy-in	26
Faculty development/new competencies	22
Bureaucracy: policies, paperwork, approvals	21
Differing views	21
Faculty time	16
Stakeholder involvement	11
Admin. support & coordination, leadership & vision	8
Dealing with complexity of change	8

Table 5: Factors for success in curricular change encountered by survey respondents

Success Factor	Frequency
Key stakeholders committed to success	***64***
faculty buy-in	39
other key stakeholders	8
industry support	7
alumni	5
staff support	5
Leadership	***59***
admin. leadership/support	36
faculty leadership	20
new/young faculty	3
Students & Teaching	***45***
student interest	28
new pedagogies	17
Communication and Collaboration	***42***
cooperation and collaboration	22
cross-disciplinary collaboration	7
communication	7
dedicated team/teamwork	6
Process	***32***
clear goals	15
knowledge of what works (literature or past experiences)	13
having a process	4
Adequate Resources	***28***
other resources (e.g. government funding)	19
workable timeline and time to implement	9

Several of the factors for success that were suggested by the survey respondents related to conversation, collaboration and discussion. The survey respondents discussed collaboration and discussion with their own unit as well as with other units/departments:

> *Having discussions to create consensus.*
>
> *If it significantly affects other Departments keeping open lines of communication so that questions can be answered and appropriate compromises can be made.*

Some survey responses included elements of discussion and collaboration coupled with affective factors, such as energy and enthusiasm:

> *Enthusiastic participation from faculty in discussions and getting the help of appropriate faculty in preparing the documents that are sent to the college level committees.*

Other survey responses highlighted other attributes of the faculty involved in the change process – that "young faculty" who were open to change and "dynamic faculty" were particularly instrumental:

> *Young faculty willing to experiment and try new things.*

> *Dynamic faculty with grounding in teaching-learning literature. Incorporation of active learning and meta cognition strategies improve student engagement and appreciation in multidisciplinary courses.*

This second response also highlights the importance of connecting curriculum change to literature and research that can provide an empirical and theoretical grounding for the curriculum changes. Other survey responses also pointed to the need to connect curriculum change with either the literature, or if not the literature then key tenets of instructional design that have been published in the literature that suggest that learning experiences should be developed around learning objectives and assessments of learning (e.g., Wiggins and McTighe[14]):

> *Structuring and phasing the development of the curriculum development with well defined formats of deliverables and their planning.*

> *Maximum freedom to the developers of the courses and educational projects, within well defined framework of attainment targets, learning objectives, and distribution of study loads over the various disciplines and skills to be attained.*

Other survey respondents suggested that curriculum changes should be grounded in empirical data as well as other evidence of prior success:

> *Having data (e.g. a comparison of other curricula) to support decisions.*

> *Past success --- ECE department here at Our University changed its curriculum in a dramatic way about twenty years ago and became a symbol for change in electrical engineering undergraduate curricula. Given the positive effects of that effort, we find faculty more willing to go outside their comfort zone.*

One survey response combined aspects of the ideas of collaboration and discussion with the need for connecting curriculum development to larger educational/learning experiences by simply stating that a "family orientated learning community" was a key factor for success.

Finally, many survey responses pointed to a variety of monetary resources, such as funding from the government, from foundations, or from the university. A specific form of financial support that some survey responses pointed to was support for faculty development:

> *Some financial support from the central administration for special training for faculty implementing these changes.*

A more holistic analysis of the responses can be summarized in one of the survey responses: The most critical success factor in the change process is:

> *Both bottom up and top down forces acting at the same time.*

Looking across all of the survey responses, including the barriers and the success factors, the combination of faculty buy-in and faculty leadership with administrative leadership and/or support led to a change process that could overcome any combination of barriers.

Summary of Session Discussions

Based on the survey results, 8 topics pertinent to curriculum change were identified, and used as basis for discussions at the 2011 ASEE Annual Conference. Detailed summaries of each of the 8 topics covered, generated from the Facilitators' summaries and the Flip Chart notes, are included in the Appendix. Also included there is a "Summary of Summaries" which attempts to capture the common threads across all the specific topics. The current discussion is based on this summary of summaries.

Current State Positives:

First and foremost, the current state of engineering education does supply industry with graduates who have the technical competence they need. This is seen as an absolute necessity which must not be lost sight of when seeking change. In a closely related vein, the current state successfully addresses most of the core demands of accreditation, particularly those "professional criteria" set by the sponsoring agencies (not to be confused with the "professional skills" required of all programs).

Second, the current state has the weight of tradition behind it. Students and faculty are used to, and comfortable with, the system and it is sustainable (marginally) within the current institutional constraints.

Current State Negatives:

Engineering education has had longstanding problems with retention and recruitment, especially of underrepresented groups. The curricula are traditionally more faculty-centered than focused on the student. Many programs are short on the professional skills that industry is now demanding (through accreditation criteria). Finally, design and synthesis often play secondary, or after-thought, roles to analysis, which in most cases suits the faculty more than the needs of students and industry.

Change State Positives:
Essentially the potential benefits of the "Change State" are to negate the aforementioned deficits of the current state. Specifically, by making the curriculum more student-centered, more design focused, the problems with retention and recruitment will be addressed. By increased attention to professional skills, graduates will be better prepared to work effectively in industry and programs will be better equipped to satisfy the demands of accreditation (which, of course, ultimately come from industry).

Change State Negatives:
Most of the concerns about the change state were about finding the resources to accomplish it, and being able to accomplish it without lowering the technical competence of graduates.

Possible Actions:
Each of the discussion groups was asked to come up with a set of suggested actions for their topic. These are summarized in the Appendix. The discussion here will attempt to summarize the common themes in those action item lists.

Firstly, change cannot happen without the active support and encouragement of the administration. That is necessary, though hardly sufficient. Secondly, the faculty needs to be on board, which will likely require substantial changes in the reward structure and hiring goals. Much greater use of non-traditional instructors and instructional modes and technologies will be required, all of which require additional resources. In order to make the curriculum more engaging and socially relevant, efforts should be made to tie it explicitly to national priorities, like the Grand Challenges, and to better integrate the engineering curriculum with the general education component, for example through co-taught courses.

Feedback from Participants:
In an effort to gauge the effectiveness of the session format, we asked all participants to fill out an exit questionnaire. We collected 54, some of which were only partially filled out. Participants were asked to rate the quality of the session overall on a 3 point scale, from which we got: 50% "Great", 30% "OK", 20% No response. A similar question on the quality of the small group discussion format in particular resulted in 60% "Great", 20% "OK", 20% no response. While gratifyingly positive, it is undeniable that people with a positive reaction may have been more inclined to fill in the questionnaire than those with a negative reaction.

The organizational strategy for the conference sessions had the advantage of keeping the discussion reasonably focused on topic, but it was not without its problems. There was a general consensus that between the introduction and time required for the report outs from 8 tables, there was really too little time for discussion in the middle. One participant commented in his feedback that "every time the discussion got interesting, the moderator called Time". In fact 40% of those who responded to the question about "aspects least liked" about the session mentioned the lack of time specifically (No other item came close.) It is likely that 8 topics were simply too many for the allotted time.

A common criticism in the exit questionnaires referred to a lack of “clear takeaway” from the session, although that notion was phrased in a great variety of ways. There seem to be two reasons for this response. Firstly, the session was designed more as an open forum than for the dissemination of specific information. We didn’t know what the outcome would be. Secondly many of the issues addressed were inherently fuzzy, so that it was sometimes difficult to know what was being discussed. For example, in many cases the “current state” was ill-defined, since different institutions were at vastly different stages of implementation (e.g., in “multidisciplinary design”). So any discussion of the current state was likely to be confused by the spectrum of the participants’ perspectives. Similarly, in many cases, the definition of the “change state” was unclear. The topic “Achieving Meaningful Global Competency” illustrates that dilemma simply by use of the word “meaningful”. It was hoped that by focusing on a cost/benefit analysis of potential changes, more light might be shed on the question than if the discussion had been aimed directly at agreeing on a universal definition of the change state.

In response to our exit question of whether the participants would be interested in attending a future session along the same lines, 61% said “Yes”, 20% “Maybe”, 2% “No”. It is hoped that any future attempt to revisit these issues will benefit from the lessons learned in Vancouver.

Conclusions

Two sets of discussions on engineering curriculum change were held at the 2011 ASEE Annual Conference to identify success factors and barriers. A pre-conference survey was analyzed to identify main themes. Then, polarity management techniques were used for the conference session discussions to identify the pros and cons for the current and change states of engineering education. The idea of polarities requires us to acknowledge the upsides of both the current state and the change state. Therefore, the action plans should address how to get the top benefits of both states. It is not an “either/or” but a “both/and.”

The key barriers to curricular innovation were identified as lack of resources, inertia and fear of change, faculty resistance, concerns about quality, rigor and consistency. The key success factors were support from the administration and faculty buy-in. Both bottom-up and top-down leadership is critical for success; it doesn't just take faculty initiative and creativity and it can't just be pushed by administration, it requires energy, creativity and leadership from both.

Future sessions are planned to continue the dialogue on how best to implement curricular change processes in the academy.

References:

[1] National Academy of Engineering, *The Engineer of 2020: Visions of Engineering in the New Century*, The National Academies Press, Washington, DC, 2004.

[2] Thomas Friedman, *The World is Flat*, Farrar, Straus, and Giroux, New York, NY, 2005.

[3] Patricia Galloway, *The 21st Century Engineer: A Proposal for Engineering Education Reform*, American Society of Civil Engineers, 2008.

[4] Sheri D. Sheppard, Kelly Macatangay, Anne Colby, and William M. Sullivan, *Educating Engineers: Designing for the Future of the Field*, The Carnegie Foundation for the Advancement of Teaching, Jossey-Bass, 2009.

[5] Leah H. Jamieson and Jack R. Lohmann, *Creating a Culture for Scholarly and Systematic Innovation in Engineering Education*, American Society for Engineering Education, 2009.

[6] Ernest T. Smerdon, "An Action Agenda for Engineering Curriculum Innovation," presented at the 11th IEEE-USA Biennial Careers Conference, Nov. 2000, San Jose, CA, pp. 1-10.

[7] Earl Dowell, Eleanor Baum, John McTague, "The Green Report - Engineering Education for a Changing World," American Society for Engineering Education, 1994.

[8] Review of Engineering, et al., *Changing the Culture: Engineering Education into the Future*, Institution of Engineers, Australia, 1996.

[9] National Academy of Engineering, *Educating the Engineer of 2020: Adapting Engineering Education to the New Century*, National Academies Press, Washington, DC, 2005.

[10] Barry Johnson, *Polarity Management: Identifying and Managing Unsolvable Problems*, HRD Press, Amherst, MA, 1996.

[11] Monica Cardella, Robert Davis, Shripad Revankar, Loring Nies, Carolyn Percifield, and Leah Jamieson, "A Multi-Faceted Strategic Planning Process for Innovation," *Proceedings of the 2010 ASEE Annual Conference*, Denver, CO, 2010.

[12] Joseph Bordogna, Making Connections: "The Role of Engineers and Engineering Education." *The Bridge*,NAE, 27(1):11-16, 1997.

[13] Barney Glaser and Anselm Strauss, *The Discovery of Grounded Theory: Strategies for Qualitative Research*, New York: Aldine de Gruyter, 1967.

[14] G. Wiggins and J. McTighe, *Understanding by Design*, Expanded 2nd Ed, USA: Association for Supervision and Curriculum Development, 2005.

Appendix

Summaries of topic discussions at the 2011 ASEE Annual Conference in Vancouver, BC, Canada.

Distributing design through the curriculum

Facilitators: Brian Frank, Director of Program Development, Queen's University, Canada
Eric Constans, Associate Professor and Department Chair, Rowan University

Guiding thoughts:

- How can design experiences be integrated into the curriculum?
- How do you teach design to Freshman students? Sophomores?

Greater Purpose: Graduates prepared to meet societal needs

Current State: Design in 4th Year only	**AND** **Change State: Design in years 1-4**
Positive Values	
Strong emphasis on analysis	Graduates better prepared for industry
Curriculum focused on grad school prep	Enhanced team work/communication skills
Design taught by dedicated Design faculty	Improved recruitment/retention, esp URM's
Design courses are transferable	Students better understand analysis by using it for design
Most faculty are more comfortable with analysis	
Negative Results	
Students less motivated by analysis than design	Faculty Lack training
Industry prefers more design experience	faculty don't appreciate value
Lack of early design causes retention problems	Open ended (design) problems are hard to grade
Design experiences not well coordinated with the rest of the curriculum	Decrease in analytical skills
Design courses are disjoint, lack follow on	Lack of resources to support (e.g., PE staff)
	Promotes split of teaching/research faculty

Deeper Fear: Engineering graduates whose education lacks societal relevance

Possible Actions:

1) Identify key innovators and give release time to develop/implement
2) Find ways to encourage truly multi-disciplinary teams
3) Push for "design in every course"
4) Reward faculty for instructional accomplishments on a par with research
5) Seek increased support from Dean, external sources (Industry)
6) Benchmark progress in curricular change
7) Strengthen "Design" criteria in ABET
8) Hire non-faculty PE's or "Professors of Practice", more grad student support
9) Use vertical team structure
10) Tie in new curriculum with national priorities ("innovation", "creativity")
11) Expand opportunities for Design-Build-Test or CDIO… hardware implementation of design concepts.

Achieving truly multidisciplinary experiences

Facilitators: Shannon Ciston, Lecturer in Chemical & Biomolecular Engineering, University of California, Berkeley
Mike Murphy, Director and Dean, College of Engineering & Built Environment, Dublin Inst. of Technology

Guiding thoughts:

- How can you get faculty in different departments, or even different colleges, to work together?
- Why would liberal arts students join an engineering class?

Greater Purpose: Graduates prepared to meet societal needs

Current State: Limited or no Multidisc Projects in Curriculum	**AND**	**Change State: Multidisc Projects throughout the Curriculum (1st yr to senior)**
	Positive Values	
Focus on one discipline is easier to manage		Develop "real world" skills valued by industry/ABET.
Can emphasize core discipline concepts		Projects provide more collaboration with industry.
Faculty and students are comfortable dealing with others in their own disciplines		Fewer students leave the profession; better program retention.
Students are just becoming part of their discipline and need time to acculturate		Students value opinions of all stakeholders, diversity.
Even engineering disciplines can be quite diverse		Students find unexplored solutions.
		Students can do open-ended, ill-structured problems.
		Students can synthesize info from multiple sources.
		Students can collaborate w/ people in other disciplines.
	Negative Results	
Limited to engineering projects		Students may resist or resent these experiences
No liberal arts projects available		Faculty may resist teaching these courses as they are not generally trained to maximize these experiences
Students may change majors, perhaps leave engineering		Many opportunities are overlooked because of disciplinary silos, credit unit limits, or rigid curricula
Silos of engineering		No room in the curriculum
Students focused on "one right answer"		Less mastery of disciplinary knowledge?
ABET requirements on capstone design are rigid		Students may resist or resent these experiences

Deeper Fear: Engineering graduates whose education lacks societal relevance

Possible Actions:

1) Considering accreditation criteria and criteria events provides an effective mechanism to support curriculum change towards multidisciplinary activities.
2) Focus on faculty: development and broadening initiatives. Consider adjunct appointments in two directions. Find and incentivize champions. Embed non-engineering faculty, e.g., put a non-engr faculty member on every program team.
3) Provide faculty training, development, and resources to support multidisciplinary teaching. Do fundraising.
4) Provide adjunct appointments from other disciplines (esp. outside engineering).
5) Find and reward champions.
6) Develop the arguments for how truly multi-disciplinary experiences will benefit students.
7) Convince humanities faculty that engineering is important to them.
8) Examine how programs can be changed. This might include mandatory non-engineering electives. Capstone projects should be "real world" projects with non-engr majors on capstone project teams. College-wide policies will be easier to implement than program or dept. initiatives.
9) Leverage co-curricular activities, interdisciplinary faculty research, and industry partnerships.

Achieving meaningful global competencies

Facilitators: Ivan Esparragoza, Associate Professor; LACCEI leadership, Penn State University-Brandywine
Maria Larrondo Petrie, Assoc. Dean for International Affairs, Exec. Dir. of LACCEI, Florida Atlantic Univ.

Guiding thoughts:

- Does a student have to travel abroad? Study abroad?
- What is the real goal or "global competency" and how do we know if a student has achieved it?

Greater Purpose: Graduates prepared to meet societal needs

Current State: Limited or no global experience AND	Change State: Significant global experiences
Positive Values	
Large international population on campuses (students and faculty)	Cultural diversity appreciated and understood by students
Some programs focus on global opportunities	All students have multiple global experiences
Global programs recognized by administration	Graduates more competitive and successful in careers
	Global accreditation competencies
	Students learn about ISO standards
	Education transformation is valued
	Companies doing international business need students with global perspective
Negative Results	
Not preparing student with global perspective	No coordination of schedules for global design teams
Costs prohibit diversity participating of students from low economic background	Semester or year abroad tends to extend time to graduation
Lack of sensitivity to cultural issues	Loss of culture
No assessment of usefulness of global program experiences.	Faculty development competes for money resources
Many students are not sufficiently aware of opportunities to enhance global competency.	Loss of expanding global education (if focus is on experiences abroad)
USA dominance does not equal future awareness	Resistance to change
Global competency poorly integrated in most curricula	
Isolation during global experiences	

Deeper Fear: Engineering graduates whose education lacks societal relevance

Possible Actions:

1) Make sure global impact of projects are considered in classes.
2) Utilize technology to "travel" → Virtual travel
3) Careful construction of Engineering teams on projects to allow for cultural exchange
4) Use Grand Challenge projects/ Design projects with "other" context
5) Grant a general Engineering degree with global specialization
6) Instruct engineering students that they will work on multidisciplinary, global design teams
7) Have more interactive cooperative teaching courses
8) Make it easier/less expensive to study abroad
9) Provide well-defined outcome assessment and definition of global competency
10) Better allocation and distribution of financial resources toward intern experiences.
11) Fund-raising to support global programs
12) Articulation agreements with increased number of institutions in different countries

Moving Beyond the Traditional Lecture

Facilitators: Sheldon Green, Head of Department of Mechanical Engineering, University of British Columbia
Jenna Carpenter, Associate Dean, Administration and Strategic Initiatives, Louisiana Tech University

Guiding thoughts:

- A host of alternatives to the traditional lecture format exist, including problem-based learning, project-based learning, new technologies, social media, etc. Yet most courses continue in the old ways.
- What can be done? What should be done?

Greater Purpose: Graduates prepared to meet societal needs

Current State: Traditional Lecture AND	**Change State: Project-Based (Active) Learning**
Positive Values	
All course material can be covered	Students learn more and deeper
Comfortable & familiar to faculty & students	Students are more engaged
Efficient for covering many topics	Helps recruitment and retention
Lecture material is presented in a logical order	Appeals to more learning styles & diverse students
Easy for administrators to know work load	Allows multiple paths through the content
Materials available to support lectures	Students tackle more open-ended problems
Lectures & exams are easy to prepare	Students will be more creative & confident
	Fosters professional skills
	Closer to later on-the-job projects
	Students can see real-world application
Negative Results	
Don't foster deep or long-lasting learning	Takes more time (for faculty & students)
Don't appeal to diverse learning styles	Requires more space, money, and equipment
Don't appeal to diverse student groups	Requires faculty training & student adjustment
Can be boring	Hard to find good material and problems
Faculty-centered	Limits coverage
Students don't actively interact with material	Assessment may be more difficult

Deeper Fear: Engineering graduates whose education lacks societal relevance

Possible Actions:

1. Need administrative buy-in/support (time and costs).
2. Adapt successful models vs. reinventing the wheel.
3. Gradually change (have faculty change one thing each year).
4. Train faculty, convert all classes (to counter student push back), pilot first, share and reward successes of the faculty who are interested in nontraditional methods.
5. Have students purchase less expensive software, technology, use open source software.
6. Create banks of good problems, exam questions, concept inventories.
7. Assess and use data to make the case.
8. Support change with grants/funding to ease change.
9. Celebrate, reward, promote change/success and participants.
10. Use as a recruiting tool.
11. Integrate student competitions

Integrating Professional Skills into the Curriculum

Facilitators: Robert Chin, Professor of Technology Systems, East Carolina University
Richard Schoephoerster, Dean of Engineering, University of Texas at El Paso

Guiding thoughts:

- These include ABET outcomes like Ethics and Communications skills, as well as things that go beyond a-k, like Innovation and Leadership.
- What are the best strategies for ensuring that these skills are an integral part of the engineering student's toolkit?

Greater Purpose: Graduates prepared to meet societal needs

Current State: Emphasis on Technical Skills AND	**Change State: Integration of Professional & Technical Skills**
Positive Values	
Strategic Importance	Ability to Communicate with Clients
Accreditation Emphasis	Self Awareness
Required by Industry & licensing bodies	Employer Demand for graduates with these skills
	More effective in teams
	More Balanced well rounded engineer
	More adaptable Engineer
	New ABET requirements
Negative Results	
Students won't be able to maximize opportunities	Faculty lack training
Less effective in teams	Students and faculty don't appreciate value
Less flexible and adaptive as an engineer	Increased faculty time – teaching, curriculum development
	Sacrifice of technical content
	No room in curriculum
	Hard to do

Deeper Fear: Engineering graduates whose education lacks societal relevance

Possible Actions:

1) Clarify strategic need for integrating Professional skills
2) Engage others in the process, possibly have industry-based instructors
3) Mentor & train faculty
4) Provide or require faculty to have professional experience
5) Help students develop appreciation for professional skills
6) Make it relevant and real – provide more real life experiences, engage industry, tie course material to community based projects, include PBL project base course
7) Provide a supplemental course tied to internships and coops (professional experience)
8) Give students responsibility to practice new skills
9) Integrate with other courses as well as technical courses
10) Spread across all years and many subject areas

Streamlining the Curriculum

Facilitators: Sheldon Greene, Head, Department of Mechanical Engineering, University of British Columbia
Lelli Van den Einde, Lecturer (LPSOE), Dept. of Structural Engineering, UC San Diego

Guiding thoughts:

- Examples cited include: reducing the number of required courses; reducing the number of credits; eliminating "redundancy"; replacing 3cr 15 week classes with 1cr 5 week classes.
- What are the pros and cons of these measures?

Greater Purpose: Graduates prepared to meet societal needs

Current State: Overloaded, expensive programs (AND)	**Change State: Cheaper, better, faster**
Positive Values	
Programs work now- why rock the boat?	Enhance cross-disciplinary experience
Good in engineering fundamentals	Increase program flexibility = better retention
Faculty are comfortable with it	More flexibility for faculty
Programs tailored to each discipline/profession	Increased creativity
	Less repetition of material
Negative Results	
State legislatures pushing to cut costs/time	Loss of control by faculty
Some topics better handled in < 1 semester	More administrative burden
Most curricula are by inheritance, not by intelligent design.	Less technical competence
Students deficient at problem formulation	Must convince faculty that change is beneficial to students re jobs/grad school
Students weak on "professional skills"	Faculty will resist eliminating "their" courses
	Change may decrease learning

Deeper Fear: Engineering graduates whose education lacks societal relevance

Possible Actions:

1) Increase use of info and communications tech. More online courses. Credit by exam.
2) Develop common lab facilities
3) Break courses into smaller parts
4) Identify and eliminate redundancy: instruct more students with fewer faculty without sacrificing learning
5) Better use of learning assessment to measure effectiveness of changes
6) Reduce credits required by eliminating/combining courses;
7) Reduce faculty burden by removing required courses and replacing with electives
8) Work with sponsoring professional societies to broaden ABET professional criteria
9) Soften pre-requisites, especially for non-majors
10) Urge faculty in different departments who teach similar material to coordinate/share resources
11) Dean/University must provide resources to enable. Increased efficiency is not free.

Developing Strategies for Effective Change

Facilitators: Chris Sahley, Director, Center for Faculty Success, Professor of Biological Sciences, Purdue Univ.
Pradeep Khosla, Dean of Engineering, Carnegie Mellon University

Guiding thoughts:

- There are many well-known barriers to fostering change in any academic institution, including reluctance of faculty to buy in, administrative resistance, infrastructure limitations, and student conservatism.
- What strategies are best suited to overcoming those barriers and achieving your goals?

Greater Purpose: Graduates prepared to meet societal needs

Current State: Traditional curriculum design and change process AND	**Change State: Integrative curriculum design and inclusive change process**
Positive Values	
Students are highly sought after	Students graduate in four-years
Stable program taught by very good faculty	Students are Self-learners
Topics covered by lecture	Faculty facilitate learning
Lots of experience to solve problems	Curriculum is integrated & effectively uses technology
Materials fine-tuned over long time period	Graduates are prepared to meet society's needs
Dedicated faculty are focused on education	New faculty are chosen for ability to teach
Programs are benchmarked with others	Education transformation is valued
Faculty creativity and academic freedom	Dean facilitates vision discussions
Negative Results	
Low student accountability, students not as engaged	Many people involved slows process
Low faculty involvement in curriculum development	Lack of incentives
Lack of good learning spaces	Lack of investment/not enough resources
Lack of good teaching/ Low value of teaching	Lack of depth
Lack of continuity class to class	High level of effort
Lack of breadth	Lack of faculty skill as facilitator

Deeper Fear: Engineering graduates whose education lacks societal relevance

Possible Actions:

1) Involve as many stakeholders as possible and all faculty involved in instruction
2) Envision multi-stage transition; multi-term plan
3) Invest core group with decision-making authority and responsibility for assessment
4) Invite practicing engineers to serve as mentors; involve alumni
5) Institute a process for review and revision
6) Focus on higher goals to overcome short-term barriers
7) Communicate a lot; seek input (inclusive and fair dialog) and provide feedback
8) Develop common ground; share common course materials
9) Ensure deans/leadership team are aligned
10) Recognize/celebrate accomplishments
11) Follow med school model and include teaching and clinical faculty
12) Partner with industry and government to effect change
13) Commit and follow-through
14) Align P&T with faculty incentives to make positive change
15) Collaborate globally
16) Make the process fun

Developing engineering faculty for the 21st century

Facilitators: Alan Cheville, Associate Professor, Oklahoma State University;
Bart Sinclair, Associate Dean of Engineering, Rice University

Guiding thoughts:

- Creation of the engineer of future requires the Faculty of the future.
- Can we retool existing faculty?
- Should we be looking to hire a new breed of faculty?
- Does a research I institution need separate research and teaching faculty to be successful in both arenas?

Greater Purpose: Graduates prepared to meet societal needs

Current State: Traditional Faculty	AND Change State: Faculty of 2020
Positive Values	
Less preparation time for lectures	Faculty are better able to engage in "fuzzy studies"
Faculty can decide new directions themselves	Faculty development addresses both teaching and research
Teaching efficiency of large lecture classes	Faculty are comfortable with technology
What we have done works	Faculty mentor each other in teaching/learning approaches
Faculty satisfaction	New faculty are chosen for ability to teach
	Education transformation is valued
Negative Results	
Some Faculty are great researchers not good teachers	More disparities between universities
Large lectures are not good learning environments	Faculty spend less time on research
Two classes of faculty (research and teaching)	Faculty develop competes for money resources
Faculty have not been taught how to teach	Faculty need more research money to stay employed
	Undergraduate research opportunities are reduced

Deeper Fear: Engineering graduates whose education lacks societal relevance

Possible Actions:

1) Retrain faculty and provide resources to make training sustainable.
2) Incorporate more active learning by moving from classes to studios.
3) Create opportunities for senior faculty who are ready to change course.
4) Begin future faculty development during graduate education; Include more industry experience in Ph.D. curriculum.
5) Support new faculty members' enthusiasm for educational innovations.
6) Team teach science/engineering and humanities.
7) Add more design faculty with experience
8) Provide more incentives for educational innovation such as educational seed grants.
9) Devise a different reward structure that balances the importance of research and teaching in the promotion and tenure process e.g. Structure faculty member's first year to include faculty development w-lower load and let faculty redefine their appointments every three years.
10) Dean facilitates vision discussions.
11) There needs to be a National imperative for change in engineering education.

Summary of Summaries

Greater Purpose: Graduates prepared to meet societal needs

Current State: AND	**Change State:**
Positive Values	
Manageable/sustainable	Students better prepared for “real world”
Comfortable for faculty	Better retention/recruitment
Comfortable for students	Education transformation is valued
Technically competent graduates meet industry/ABET requirements	Graduates have both technical and professional competence as per industry/ABET requirements
Negative Results	
Lack of student engagement/retention	Lack of depth, weaker technical competency
Weak on professional skills & design	Insufficient resources/room in curriculum
Faculty-centered	Faculty lack training/skills/motivation

Deeper Fear: Engineering graduates whose education lacks societal relevance.

Possible Actions:

1) Provide faculty development/training
2) Incentivize faculty; revise reward structure
3) Provide administrative leadership
4) Re-envision who serves as instructors; consider non-engineering faculty or professors of practice from industry
5) Consider cooperative teaching with instructors outside engineering
6) Repackage the curriculum; leverage co-curricular activities
7) Make better use of instructional technologies
8) Integrate learning assessments into instruction to serve as early warnings of negative outcomes
9) Tie change efforts to national priorities/Grand Challenges
10) Make it fun