Linking Student Learning Outcomes to Instructional Practices – Phase I

Stephanie Cupp, Paolo Davidian Moore, and Norman L. Fortenberry
National Academy of Engineering
Center for the Advancement of Scholarship on Engineering Education

Abstract
This paper begins to test the assumption that stakeholders in engineering education know what set of teaching and learning practices by faculty and students will lead to desired student learning outcomes. The work reported here seeks 1) to identify from published sources, a set of desired engineering student learning outcomes, and 2) to characterize and categorize teaching and learning practices. Desired student learning outcomes identified in published sources mirrored twelve of the engineering accreditation criteria supplemented by five additional outcomes not explicitly addressed within current accreditation criteria: a) multidisciplinary systems thinking, b) business aspects of engineering practice, c) appreciation for diversity, d) good work ethic and commitment to continuous quality improvement, and e) logical thought process. Sixty-one percent (11) of the learning outcomes are categorized as Technical, and 39% (7) are categorized as Social.

With respect to teaching and learning practices, an initial investigation uncovered six published sources that collectively identified 146 practices. It is noteworthy was that all of the identified practices were for actions by faculty and teachers – not students. We place the practices into a five-dimensional taxonomic structure. An effort to link "effective" practices to specific outcomes is suggested for future work.

I. Introduction

Over the past fifty years, the engineering community has engaged in periodic self-examination and issued various calls for reform of engineering and science education [1] within the context of more general calls for education reform [2-5]. A frequently heard comment at recent engineering education meetings is "We know what the problem is, and we know what works – we don't need any more studies, we just need to get on with it." The assumptions imbedded in this statement are that stakeholders in engineering education know not only what set of student learning outcomes we are trying to achieve, but also what set of teaching and learning practices by faculty and students will lead to those learning outcomes. This paper seeks to begin testing these assumptions. Validating the assumptions holds the promise of allowing us to monitor faculty teaching and student learning behaviors to determine if progress, both within individual institutions and nationally, is being made toward widespread use of "effective" practices and, ultimately, to achievement of desired student outcomes.

With respect to the assumption that stakeholders in engineering education know what set of student learning outcomes we are trying to achieve, the work reported here summarizes findings from the review of 47 published sources wherein we seek to identify desired engineering student learning outcomes. With respect to the assumption that stakeholders in engineering education know what set of teaching and learning practices will lead to desired student learning outcomes, we a) characterize and categorize 146 instructional practices collectively identified in six published sources, and b) purposefully seek to examine the research base underlying the application of the term "effective" to many of these practices. The later task is important because it seems to us that many of the most commonly cited reports and studies of needed innovations in engineering education have focused on making the case for "reform," not on presenting evidence of effective practices.

II. Uncovering Fundamental Student Learning Outcomes

A. Determination of Fundamental Learning Outcomes

We identified 44 engineering student learning outcomes from a review of 47 published sources. Twelve of these outcomes were congruent with the ABET EAC criteria 3a-3k and 4 [6]. Before considering the remaining 32 outcomes, we set as a filter that any student learning outcome reported in this paper should have at least the same number of references as the least cited ABET EAC criterion—sixteen. Only five additional engineering student learning outcomes met this condition. The resulting set of 17 engineering student learning outcomes was declared ***fundamental***.

B. Categorization of Fundamental Learning Outcomes

The 17 student learning outcomes are shown in Table 1; since 12 of the outcomes overlap with the ABET EAC criteria, they are only shown in short hand. The learning outcomes shown in Table 1 are categorized as either ***Technical*** or ***Social***. Technical learning outcomes are those learning outcomes that fit within the traditional concept of "hard" skills. They denote the ability to conceptually understand and apply the solid mathematical and scientific tools of analysis, experimentation and design on which the practice of engineering is built. There were a total of 11 Technical learning outcomes. The Social learning outcomes category neither means "hard to characterize" nor "non-essential but a good idea anyway." These outcomes reflect the very real need for engineers to have "soft" people skills in addition to the traditional "hard" cognitive/technical skills. The new global market place demands engineers that are ambassadors for the profession and who are able to convincingly communicate to diverse and non-technical audiences. "An understanding and experience dealing with engineering practices and principles will only get you so far" comments Kerry Hannon in *The Graduate*, adding, "people skills, glad-handing, creative consensus building, business acumen, and, yes, real-world survival skills are *de rigueur* for those engineers regardless of the discipline." [7]. As can be seen in Table 1, there are 7 Social learning outcomes bearing witness to the increasing importance of these "soft" non-technical skills. Note that ABET 3-d, "an ability to function on multidisciplinary teams," is classed as both Technical and Social because it includes a "multidisciplinary" aspect and a "team" aspect.

Table 1. Engineering Student Learning Outcomes [references shown in brackets] (number of references shown in parentheses)

Learning Outcomes	Technical	Social
ABET EAC Criteria	3-a (31), 3-b (27), 3-c (26), 3-d (30), 3-e (28), 3-i (16), 3-k (28), 4 (19)	3-d (30), 3-f (19), 3-j (20), 3-h (28), 3-g (39)
A multidisciplinary systems perspective across breadth of engineering sciences	[8-26] (19)	
A familiarity with business, market-related and financial matters	[8, 10, 12, 14, 17, 18, 20, 23, 24, 26-34] (18)	
An understanding and appreciation of the diversity of students, faculty, staff, colleagues and customers		[7, 10, 14, 16-21, 24, 26, 27, 29, 30, 32, 35-37] (18)
A good work ethic including a commitment to quality, timeliness and continuous improvement		[10, 17, 18, 20, 21, 23, 24, 26, 27, 30, 32, 33, 38-42] (17)
Logical thought process and critical thinking	[8, 10, 11, 17, 20, 23, 26, 29, 32, 38-40, 43-46] (16)	
Total Number of Engineering Student Learning Outcomes	11	7

We have several observations on the five non-ABET statements in Table 1. It might be argued that "a good work ethic, including a commitment to quality, timeliness and continuous improvement" is implicit ABET EAC criterion 4; and "logical thought process and critical thinking" is implicit in ABET EAC criterion 3e. We see the statements in Table 1 as broader and see additional value in their explicit mention. Rosalind Williams, a historian of science and technology at MIT, has suggested that systems thinking, along with design, is becoming one of the defining characteristics of engineering professionals as they seek to rebalance the 1950's swing to engineering science with a return to emphasis on engineering practice [47]. Robert Weatherall, formerly director of MIT's placement office, has been arguing that engineering educators have ignored the business aspects of engineering practice and the potential leadership role that engineers can play in business [48]. The National Science Board has observed that an understanding and appreciation of national and international diversity is increasingly important in our increasingly interconnected global economy[49]. Consideration should be given to recasting the current criteria to more fully explicitly incorporate the 5 additional outcome areas indicated above.

III. A Literature Review of Teaching and Learning Practices

A. Six Key Reports

Using various on-line databases as well as web-based tools, we searched for literature that identified faculty or student practices that might result in specific undergraduate student learning outcomes. The search was not limited to engineering student outcomes. Our search revealed a combination of anecdotal evidence, reports on the results of "trial and error", multiple calls for change, and a little research evidence. In particular, six published sources [50-55]of effective teaching and learning practices were uncovered that explored alternative methods for education; only one [51] of these was specific to engineering education. We consider these reports foundational because they present practical recommendations; other findings of the literature

review discuss the ideas and goals of a reform, but do not discuss how to make those changes. From these six key references we extracted a list of 146 'best" practices for effective teaching and learning.

B. A Taxonomy

We have created a basic taxonomy of educational improvement by which to synthesize the 146 best practices into a more manageable form. Our initial categorization of the practices provided one characterization scheme (see subheading 1 below). Reviewing the literature provided four additional characterization schemes (see subheadings 2-5 below). The resulting set of five categories defines the dimensions of our taxonomy. The possibility remains that further research in this topic will reveal further refinement of this taxonomy.

In order to make clearer the asserted purposes of the various practices and to provide a taxonomy for the lengthy list, we developed several categories to which to assign the various practices. The first category is based on our own observations, the latter four categories were suggested within the literature we reviewed.

1. Category: Application Level
At the highest level, we divide the list into two separate portions, *programmatic* and *classroom*. Programmatic practices are implemented at the level of department, school or institution. Effective practices must be supported at a level higher than the classroom in order to instill an overarching change. The classroom practices are practical recommendations for professors to implement in the classroom and with their students.

2. Category: Modified Boyer model
Within both the program and classroom portions, we have divided the list into five sections derived from the [56] model of scholarship: *Application, Discovery, Integration, Teaching* and an additional augmented class of *Other* [4]. Discovery involves the development of new knowledge; Integration involves the synthesis of different strands of knowledge to reach new understanding; Application is the innovative application of knowledge to achieve new results; Teaching is the transmission of knowledge to others. Practices listed in the "Other" category do not fit strictly within the Boyer model but are still potentially valuable sources of improvement. For example, Chickering's recommendation [55]to "Advise students about career opportunities in their major/field of study" is not describing an innovative application of knowledge, the development of new knowledge, the synthesis of different strands of knowledge, or teaching new knowledge; however, it may be categorized in our remaining dimensions as "Encouraging faculty-student contact" for the purpose of "changing the environment," with the intended goal of enhancing community.

3. Category: Purpose
Three major categories divide the practices into their purposes: improving teaching, redesigning courses, and changing learning environments. In an analysis of the winners of the Theodore M. Hesburgh Award, an annual award for the most effective faculty-development program [3], Cross states that her review of the "finalists could be categorized under three major headings:

- Improving teaching by:
    - applying knowledge about cognition and learning,
    - targeting particular groups of students,
    - targeting particular faculty, and
    - developing a "personal vision" of teaching,
- Redesigning courses to:
    - adapt to new technologies, and
    - implement new curricula or emphases, and
- Changing the learning environment of the institution by:
    - creating "learning-centered colleges",
    - developing a distinctive institutional mission focus,
    - focusing on student learning outcomes, and
    - instituting incentives and rewards for teaching" (Cross, 2001).

4. Sub-category of Purpose: Chickering/Gamson principles

Within the three "Purpose" categories, we find a balance of the seven principles for best practices, as recommended by Chickering and Gamson in their highly referenced article from the American Association for Higher Education Bulletin [57]. Within each of the three aforementioned purposes, we find unique principles suggested by Chickering and Gamson, and we suggest creating an "other" category for those practices that fit within Cross's headings, but not explicitly within Chickering's principles. The principles fit as follows (Chickering/Gamson principles are shown as bulleted items):

1. Changes the learning environment
    - encourages student-faculty contact
    - develops reciprocity and cooperation among students
    - communicates high expectations
    - other

2. Improves teaching
    - gives prompt feedback
    - uses active learning techniques
    - other

3. Redesigns courses
    - emphasizes time on task
    - respects diverse talents and ways of learning
    - other

We note the likelihood of significant interaction and overlap among these categories. For example, changing to a "learner centered classroom" is categorized as both a "change to the learning environment" and the "redesign of a course".

5. Category: Class

The final level of classification is derived from *How People Learn: Bridging Research and Practice* [58]. This widely cited report by the National Research Council depicts a learning

environment that is designed to include an overlapping effect of a learner-, knowledge-, and assessment-centered approaches within a community setting. Each practice is labeled as *Knowledge, Learner, Assessment,* or *Community*. An instructor that implements a given practice intends to enhance that aspect of the environment.

In reviewing the categories above, we note that some categories (i.e., "Application Level," "Purpose," and "Chickering/Gamson principles") aid in understanding educational practices, whereas other categories (i.e., "Modified Boyer model" and "Class") help instructors understand how the practice fits into models provided by the research base. The possibility remains that further research in this topic will suggest additional or alternative categories.

C. Summarizing the Practices

Applying the taxonomy indicated above, we created a summary in the form of percentage breakdowns of the 146 teaching and learning practices within the categories of the taxonomy as shown in Table 2. Note that each group of categories may not total 100%, because every practice did not fit into every group of categories. As noted above, because of the interactions within the "Purpose" category, the percentage of practices falling within that category sum to more than 100%. Table 2 shows that the large majority of the practices discovered in the literature review are applicable at the classroom level. About one-half of the practices fall within the Modified Boyer model of learning and are fairly evenly distributed across the 4 types of learning. Although most of the practices seem to indicate an intention to change the learning environment (rather than improve teaching or redesign a course), caution is required because of the double-counting within the category mentioned earlier. In the Chickering/Gamson principles group, practices recommended to "encourage student-faculty contact" have the highest frequency, closely followed by the number of practices that "use active learning techniques." Every every one of the 146 practices was also classified according to Class as identified in *How People Learn*, the most prevalent Class was "knowledge-centered," closely followed by "learner-centered." "Assessment-centered" was the least prevalent Class.

Table 2. Teaching and Learning Practices placed in Categories

Category	Percentage
Application Level	
Programmatic level	19
Classroom level	81
Modified Boyer Model	
Application model	12
Discovery model	10
Integration model	13
Teaching Model	15
Purpose	
Changes the learning environment	51
Improves teaching	37
Redesigns courses	27

Table 2. Teaching and Learning Practices placed in Categories (continued)

Chickering/Gamson Principles	
Encourages student-faculty contact	16
Develops reciprocity and cooperation among students	12
Communicates high expectations	10
Gives prompt feedback	7
Uses active learning techniques	14
Emphasizes time on task	7
Respects diverse talents and ways of learning	8
Class	
Knowledge-centered	36
Learner-centered	32
Assessment-centered	11
Community	21

A critical observation is that each of the 146 practices identified were for action by teachers and faculty – not students. Indicating that we may have a way to go before the transition to the learner-centered classroom is complete. It may be the case, but is not our assertion here, that the practices are invertible for students and teachers. That is, a practice stated as "Expect your students to complete assignments promptly." [55], might be reasonably be restated as "Students, complete your assignments promptly."

To conserve space, the full table showing the 146 practices within the taxonomic categorization is not shown. However, a schematic (limited to the subset we call the "Programmatic" application level) is shown in Table 3 in order to provide an example of the structure of the full table. The first column in Table 3 represents the various subcategories within the major category of Modified Boyer Model. Each row in the table corresponds to a given subcategory within the Modified Boyer Model (e.g., "Application"). The next 10 columns represent specific Chickering/Gamson Principles (e.g., "Encourages student-faculty contact). within the more general Purpose subcategories (e.g., "Changes the Learning Environment"). The second column shows the references from which specific instructional practices were identified; the third column shows actual instructional practices. These practices are grouped by Application Level; in Table 3 only "Programmatic level" practices are shown. Specific entries in the body of the table show an assignment of Class (e.g., Knowledge-centered) that helps explain the nature of learning environment in which a specific instructional practice is used to achieve the indicated Purpose with a specific Chickering/Gamson Principle. For example, within the "Discovery" category of the Modified Boyer Model, an instructional practice is to "involve undergraduates in the research process". This instructional practice is declared to foster a Knowledge-centered learning environment through the "Encouragement of student-faculty contact."

Table 3. Instructional Practices Inventory

			Changes the learning environment				Improves teaching			Redesigns courses		
Boyer Model	**Ref.**	**Practices**	**Encourages student-faculty contact**	**Develops reciprocity and cooperation among students**	**Communicates high expectations**	**Other**	**Gives prompt feedback**	**Uses active learning techniques**	**Other**	**Emphasizes time on task**	**Respects diverse talents and ways of learning**	**Other**
		Programmatic										
Application	53	Become institutionalized and self-sustaining				Knowledge						
	50	Construct an inquiry-based freshman year						Learner				
Discovery	50	Involve undergraduates in the research process	Knowledge									
	50	Make research-based learning the standard				Knowledge						
Integration	50	Internships				Learner						
	50	Synergy of teaching and research				Knowledge						
	50	Seminar learning						Knowledge				
Other	50	A mentor for every student	Community									
	50	Diversity as an asset									Community	
Teaching	50	Evaluate teaching							Knowledge			
	50	Solve the teaching crisis				Knowledge						

IV. Conclusions and Next Steps

Based on a review of relevant literature, we have identified five engineering student learning outcomes not currently within the ABET EAC criteria as frequently cited within the literature as desirable. We suggest that consideration be given to expanding the criteria to incorporate these new outcomes.

As a result of a separate literature review, we have identified, from within six key published sources, 146 practices asserted to enhance teaching and learning. It is noteworthy was that all of the identified practices were for actions by faculty and teachers – not students. This may imply that we have a way to go before achieving the goal of student-centered classrooms.

Before achieving the overall goal of our current work—connecting the achievement of student learning outcomes to specific instructional practices, several intermediate steps are required:

1. Identify or create assessment tools for the student outcomes reported in Table 1 and the instructional practices reported in Table 2.

2. Attempt to link the student outcomes reported in Table 1 to the instructional practices reported in Table 2.

3. Examine the body of research underlying Table 2 for adherence to the principles contained in the NRC report on Scientific Research in Education[59]. A key decision to be made in such an examination is the choice of acceptance criteria. The point here is to further strengthen the linkages identified in Step 2 above, by gaining greater confidence in the underlying research on effective teaching practices.

Acknowledgements

Ms. Tracy Blake, doctoral candidate in education at the University of Florida, assisted in the execution of this research and the preparation of this paper. Dr. Myles Boylan provided useful discussions to clarify the presentation of this work. Preparation of this paper was partially supported by the National Science Foundation through grant EEC-0232554.

Bibliographic Information

1. Atman, C., R. Felder, T. Sigafoos, and P. Mead. *A Center for Scholarly Research in Engineering Education at the National Academy of Engineering.* Sub-Committee on the National Academy of Engineering Education Retreat of the Committee on Engineering Education. National Academy of Engineering, Washington, DC, 2001.

2. Gardiner, Lion D. "Redesigning Higher Education: Producing Dramatic Gains in Student Learning." *ASHE-ERIC Higher Education Report,* vol. 23, no. 7 (1994).

3. Cross, Patricia K. "Leading-Edge Efforts to Improve Teaching and Learning: The Hesburgh Awards.", pages 31-37. Washington, DC: American Association for Higher Education, 2001. Available at http://www.aahe.org/change/AUG2001.pdf

4. Dunkin, Ruth, Vice Chancellor. "Rejuvenating Academic Life." Web page, July 2001 [accessed July 2003]. Available at http://www.rmit.edu.au/browse?SIMID=aco3kgeirehu1.

5. Feldman, Kenneth A., and Michael B. Paulsen. *Teaching and Learning in the College Classroom,* 2nd ed. ASHE Reader Series Bruce Anthony Jones (ed.). Boston, MA: Pearson Custom Publishing, 1998.

6. Accreditation Board for Engineering and Technology, Inc. *2003-2004 Criteria for Accrediting Engineering Programs.* Baltimore, MD: Accreditation Board for Engineering and Technology, Inc., 2002. Available at http://www.abet.org/images/Criteria/E1%2003-04%20EAC%20Criteria%2011-15-02.pdf

7. Hannon, Kerry. "The Graduate", *ASEE PRISM*, vol. 12, no. 9, May/June 2003, page 20. Washington, DC: American Society for Engineering Education, 2003.

8. National Research Council. *Engineering Education and Practice in the United States: Foundations of Our Techno-Economic Future.* Committee on the Education and Utilization of the Engineer of the Commission on Engineering and Technical Systems. The National Academy Press, Washington, DC, 1985.

9. Ertas, A., T. Maxwell, V. P. Rainey, and M. M. Tanik. "Transformation of Higher Education: The Transdisciplinary Approach in Engineering." *IEEE Transactions on Education,* vol. 46, no. 2 (2003): pages 292-93.

10. Splitt, Frank G. "The Industrial Needs of the Engineer in the 21st Century: An Update", *ASEE New England Section 71st ASEE Annual Fall Conference.* Boston, MA: Northeastern University, 1993.

11. Al-Holou, Nizar, Nihat M. Bilgutay, Carlos Corleto, John T. Demel, Richard Felder, Karen Frair, Jeffrey Froyd, Mark Hoit, Jim Morgan, and David L. Wells. "First-Year Integrated Curricula Across Engineering Education Coalitions" *Proceedings of the Frontiers of Education 28th Annual Conference*. Session 1240, Piscataway, NJ: Institute of Electrical and Electronic Engineers, 1998.

12. Cortese, Anthony. "Engineering Education for a Sustainable Future." *Engineering Education and Training for Sustainable Development: Towards Improved Performance.* Boston, MA: Second Nature, 1997.

13. King, C. Judson. "Comments on Engineering Education "Engineering the Future" at the Yale Engineering Sesquicentennial Symposium." Web page, October 2002 [accessed 27 June 2003]. Available at http://www.ucop.edu/acadaff/yale.html.

14. National Research Council. *Engineering Education: Designing an Adaptive System*. Board on Engineering Education. The National Academy Press, Washington, DC, 1995.

15. ———. *Undergraduate Education in Science Mathematics Engineering and Technology: From Analysis to Action, Report on a Convocation.* Center for Science, Mathematics and Engineering Education. The National Academies Press, Washington, DC, 1996.

16. Wright, Jeff . "UC Merced Dean Jeff Wright Calls for Diversity in Engineering." Web page, [accessed 27 June 2003]. Available at http://www.ucmerced.edu/academics_research/wrights_vision.asp.

17. IDEA Quality Management Group. "Specification of a Qualification Profile in Engineering ." Web page, January 2003 [accessed 27 June 2003]. Available at http://www.ee.ethz.ch/master/mscqualification21Jan03.pdf.

18. Koen, Peter, and Pankaj Kohli. "ABET 2000: What Are the Most Important Criteria to the Supervisors of New Engineering Undergraduates?"*1998 Annual Conference and Exposition Proceedings.* Session 3257. Washington, DC: American Society for Engineering Education, 1998.

19. Benefield, Larry D., Landa L. Trentham, Karen Khododadi, and William F. Walker. "Quality Improvement in a College Engineering Instructional Program." *Journal of Engineering Education.* vol. 86, no. 1, (1997): pages 57-64.

20. Mastracchio, Robert. "Assessment of Professional Performance Expectations and Measures." *National Conference on Outcomes Assessment*. General Session #4. Washington, DC: American Society for Engineering Education, 1997.

21. Brewer, Terry. "Brewer Science."*National Conference on Outcomes Assessment*. General Session #4. Washington, DC: American Society for Engineering Education, 1997.

22. The Boeing Company. ""Desired Attributes of an Engineer"." Web page, 1996 [accessed 19 May 2003]. Available at http://www.boeing.com/companyoffices/pwu/attributes/attributes.html.

23. Hissey, Ted W. "Enhanced Skills for Engineers." *Proceedings of the IEEE.* vol. 88, no. 8 (2002).

24. American Society for Engineering Education. *Engineering Education for a Changing World: A Joint Report of the Engineering Deans Council and Corporate Roundtable*. American Society for Engineering Education, Washington, DC, 1994.

25. Layton, R. A., and M. W. Ohland. "Peer Evaluations in Teams of Predominantly Minority Students."*2000 Annual Conference and Exposition Proceedings.* Session 2330. Washington, DC: American Society for Engineering Education, 2000.

26. McGourty, Jack. "Strategies for Developing, Implementing and Institutionalizing a Comprehensive Assessment Process for Engineering Education." *Proceedings of the Frontiers in Education 28th Annual Conference.* Session T2A. Piscataway, NJ: Institute of Electrical and Electronic Engineers, 1998.

27. Lockheed Martin Corporation. "Life@Lockheed Martin." Web page, [accessed 27 June 2003]. Available at http://lmpeople.external.lmco.com/careers/life.asp.

28. Dunn-Rankin, Derek, James E. Bobrow, Kenneth D. Mease, and J. Michael McCarthy. "Engineering Design in Industry: Teaching Students and Faculty to Apply Engineering Science in Design." *Journal of Engineering Education,* vol. 87, no. 3 (1998): pages 219-222.

29. Morell de Rameriz, Lueny, and Gerson Beauchamp. "Intergration of Skills Development Across the Engineering Curriculum."*1995 Annual Convention and Exposition Proceedings*. Session 2213. Washington, DC: American Society for Engineering Education, 1995.

30. Evans, D. L. , G. C. Beakley, P. E. Crouch, and G. T. Yamaguchi. "Attributes of Engineering Graduates and Their Impact on Curriculum Design." *Journal of Engineering Education,* vol. 82, no. 4 (1993): pages 203-211.

31. Greiling, Paul, and Frank Brady. "High-Tech Engineering Research in the 90's."*National Conference on Outcomes Assessment*. General Session #2. Washington, DC: American Society for Engineering Education, 1997.

32. Cohen, Andy. "Evaluating Engineering Graduates in "Business Consulting." *National Conference on Outcomes Assessment.* Washington, DC: American Society for Engineering Education, 1997.

33. Black, Kent. "An Industry View of Engineering Education." *Journal of Engineering Education,* vol. 83, no. 1 (1994): pages 26-28.

34. Body of Knowledge - Curricula Committee of the Task Committee on Academic Prerequisites for

Professional Practice. *Civil Engineering Body of Knowledge for the 21st Century: Preparing the Civil Engineer for the Future*, Draft 6 for review. American Society of Civil Engineers, 2003.

35. Massachusetts Institute of Technology, Leland Stanford Junior University, E.I. Du Pont De Nemours and Company, International Business Machines Corporation, National Academy of Sciences, National Academy of Engineering, and Inc. National Action Council for Minorities in Engineering. "Amicus Brief to the Supreme Court of the United States in Re: Nos. 02-241, 02-516**,** Barbara Grutter V. Lee Ballinger & Jennifer Gratz and Patrick Hamacher V. Lee Ballinger."Cambridge, MA: Massachusetts Institute of Technology, 2003. Available at http://www.umich.edu/%7Eurel/admissions/legal/gru_amicus-ussc/um/MITfinal-both.doc

36. Denison University. "Improving The Economics Curriculum With Laboratory Experiments." *Lessons Learned From FIPSE Projects II*. Fund for the Improvement of Post-Secondary Education of the U.S. Department of Education. U.S. Department of Education, Washington, DC, 1993.

37. Sullivan, W. G. Daghestani S F. "Multivariate Analysis of Student Performance in Large Engineering Economy Classes."*1997 Annual Conference and Exposition Proceedings.* Session 1239. Washington, DC: American Society for Engineering Education, 1997.

38. National Research Council . *Careers in Science and Engineering: A Student Planning Guide to Grad School and Beyond*. Committee on Science, Engineering, and Public Policy. The National Academies Press, Washington, DC, 1996.

39. McCray, Richard, Robert DeHaan, and Julie Ann Shuck. *Improving Undergraduate Instruction in Science, Technology, Engineering, and Mathematics: Report of a Workshop*. Committee on Undergraduate Science Education of the National Research Council. The National Academies Press, Washington, DC, 2003.

40. Lahndt, Leslie. "Industry Mentored Engineering and Engineering Technology Curricula." *The Technology Interface, The Electronic Journal for the Engineering Technology,* vol. 2, no. 3 (1998).

41. Department of Industrial Engineering, Florida A&M University - Florida State University College of Engineering. "BSIE Graduate Attributes." Web page, [accessed 27 June 2003]. Available at http://www.ie.eng.fsu.edu/academics/abet2000/iii.html.

42. Civil and Environmental Engineering Department. "Attributes and Competencies of CEEn Graduates." Web page, July 2000 [accessed 27 June 2003]. Available at http://www.et.byu.edu/ce/ceweb/objectives/objectives.htm.

43. Woods, Donald R., Richard M. Felder, Armando Rugarcia, and James E. Stice. "Future of Engineering Education III. Developing Critical Skills." *Chemical Engineering Education,* vol. 34, no. 2 (2000): pages 108-117.

44. Hanesian, Deran, and Angelo Perna. "Industry Input into Curriculum Change."*1998 Fall Regional Conference of the Middle Atlantic Section of the American Society of Engineering Education (ASEE).* Washington, DC: Howard University, 1998.

45. Cabrera, A. F., C. Colbeck, and P. Terenzini. "Teaching for Professional Competence: Instructional Practices That Promote Development of Design and Team-Building Skills ." *ASHE Conference Documents.* Washinton, DC: Association for the Study of Higher Education, 1998.

46. Kostic, Milivoje. "Integration of New Technologies in Engineering Experimentation Courses."*1998 ASEE Illinois-Indiana Section Conference.* Carbondale, IL: Southern Illinois University, 1998.

47. Williams, Rosalind. "Education for the Profession Formerly Known As Engineering." *The Chronicle of*

Higher Education, 24 January 2003, sec. The chronicle review, page B12.

48. Weatherall, Robert K. "Let's Stop Selling Ourselves Short.", *ASEE PRISM,* vol. 9, no. 5 (2000). page 76. Washington, DC: American Society for Engineering Education, 2000. Available at http://www.asee.org/prism/jan00/html/lastword.cfm

49. National Science Board. *The Science and Engineering Workforce: Realizing America's Potential.* NSB 03-69. National Science Board, Arlington, VA, 2003.

50. Boyer Commission on Educating Undergraduates in the Research University. *Reinventing Undergraduate Education: A Blueprint for America's Research Universities.* State University of New York at Stony Brook, Stony Brook, NY, 1998.

51. Wankat, Phillip C. "Improving Engineering and Technology Education by Applying What Is Known About How People Learn." *Journal of SMET Education: Innovations and Research.* vol. 3, nos. 1 & 2 (2002): pages 3-8.

52. National Research Council. *Evaluating and Improving Undergraduate Teaching in Science, Technology, Engineering, and Mathematics.* Committee on Recognizing, Evaluating, Rewarding, and Developing Excellence in Teaching of Undergraduate Science, Mathematics, Engineering, and Technology. National Academies Press, Washington, DC, 2002.

53. ———. *Improving Undergraduate Instruction in Science, Technology, Engineering and Mathematics*. Steering Committee on Criteria and Benchmarks for Increased Learning from Undergraduate STEM Instruction. National Academies Press, Washington, DC, 2003.

54. Butt, David and Edward Reutzel. "Professors Review Best Teaching Practices." Web page, January 1997 [accessed June 2003]. Available at http://www.esm.psu.edu/practices.html.

55. Chickering, Arthur W., and Zelda F. Gamson. *Applying the Seven Principles for Good Practice in Undergraduate Education*. San Francisco, CA: Jossey-Bass, 1991.

56. Boyer, Ernest L. *Scholarship Reconsidered: Priorities of the Professoriate.* Princeton, NJ: Carnegie Foundation for the Advancement of Teaching, 1990.

57. Chickering, A. W., and Z. F Gamson. "Seven Principles for Good Practice in Undergraduate Education." *American Association for Higher Education Bulletin.* vol. 39, no. 7 (1987): pages 3-7.

58. National Research Council. *How People Learn: Bridging Research and Practice*. Committee on Learning Research and Educational Practice. National Academy Press, Washington, DC, 1999.

59. ———. *Scientific Research in Education*. Committee on Scientific Principles for Education Research. National Academies Press, Washington, D.C., 2001.

Biographical Sketches

STEPHANIE CUPP is a candidate for a Master of Science degree in Computer Science at The George Washington University. She served as an intern in the Center for the Advancement of Scholarship on Engineering Education at the National Academy of Engineering for Summer 2003. Her background is in human-computer interaction, including collaborative learning environments and user interface design. The interdisciplinary nature of this academic work encouraged her involvement in the reform of engineering education.

PAOLO DAVIDIAN MOORE is currently working towards a Master of Arts in Instructional Systems Development at the University of Maryland Baltimore County. His current interest is the reformation of pre-college educational systems so as to increase the public visibility of engineering disciplines. This increased visibility should result in an increase in the number of pre-college students that study mathematics, science and engineering. He graduated from the University of California Davis in 2001 with a Master of Science degree in Electrical and Computer Engineering. Paolo received his Bachelor of Science degree in Electrical and Computer Engineering from the University of Maryland College Park in 1996. He served as an intern at the National Academy of Engineering during Summer 2003. He has conducted research on the attitudes of Baltimore County middle school students towards mathematics and science, automated digital hardware testing, computer memory subsystem optimization and novel computer architectures. Paolo is a member of IEEE and the National Society of Black Engineers.

NORMAN L. FORTENBERRY is the founding Director of the Center for the Advancement of Scholarship on Engineering Education (CASEE) at the National Academy of Engineering (NAE). He is responsible for designing and developing the programs, organizational linkages, and personnel required to implement an ambitious effort to achieve and maintain excellence in engineering education. Prior to joining NAE, Dr. Fortenberry held managerial positions within the National Science Foundation's Directorate for Education and Human Resources including Senior Advisor and Division Director. He has also served as executive director of the National Consortium for Graduate Degrees for Minorities in Engineering and Science, Inc. (The GEM Consortium) and as a member of the mechanical engineering faculty at the Florida A&M University/Florida State University College of Engineering.

Address: The National Academies, 500 Fifth Street NW, NAS 224, Washington, DC 20001; telephone: 202.334.1926; email: <nfortenb@nae.edu>