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Strategies for Evaluating Engineering Education Research

Workshop Report

Bhavya Lal, Task Leader

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Preface

Each year, U.S. colleges and universities prepare tens of thousands of talented individuals who wish to pursue careers in engineering. In 2006 alone, over 68,000 students earned a bachelor's degree in engineering; another 33,000, a master's degree; and 7,100, a doctorate.[1] As in other technical professions, great care is taken by the engineering community to assure that degree recipients receive their training at programs accredited by peers.[2] Nonetheless, educators have come to recognize that improvements are needed in engineering education to prepare future graduates for the opportunities and challenges facing the profession in the 21st Century – most notably the emergence of the global marketplace and the attendant demand for well-trained high-technology workers who will assure a continuing, strong U.S. presence.[3]

The cadre of scientists who conduct research in engineering education have responded to this concern over the future of engineering education by turning their attention to needed improvements in the curriculum as well as instructional issues involving such topics as cooperative learning and teamwork, the timing of student exposure to new technologies, and characteristics of student learning strategies and styles – especially given the greater diversity of students now pursuing careers in engineering.[4]

The National Science Foundation (NSF) represents a significant source of support for research in engineering education,[5] and recently renewed its commitment to this area following the release of a report by the National Science Board outlining steps that might be taken to improve engineering education.[6] To assure the efficient investment of public funds in the coming years, the NSF Engineering Education and Centers Division (EEC) of the Directorate for Engineering asked the IDA Science and Technology Policy Institute (STPI) to examine a sample of NSF grants programs in engineering education, while also developing a master plan for longer term support for research in engineering education. STPI launched a six-month study in April 2008 to provide the NSF's Engineering Education program with a systematic review of the outcomes and impacts of active grants in three engineering education program areas: How People Learn

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[1] National Science Foundation, Science and Engineering Degrees: 1966 – 2006 Detailed Statistical Tables, NSF 08-321, Arlington, VA.

[2] ABET, Inc. is the recognized national accreditation body for colleges and universities providing training in applied science, computing, engineering, and technology. ABET currently accredits 2,800 programs at more than 600 US colleges and universities. See: www.abet.org.

[3] See, for example, the National Academy of Engineering, Educating the Engineer of 2020, Washington DC: National Academies Press, 2005.

[4] J. Heywood, Engineering Education: Research and Development in Curriculum and Instruction, Hoboken, NJ: John Wiley & Sons, Inc., 2005, provides a useful overview of research in engineering education.

[5] See, for example, program announcement NSF 08-610 "Innovations in Engineering Education, Curriculum and Infrastructure" available at www.nsf.gov/2008/pubs.

[6] National Science Board, Moving Forward to Improve Engineering Education NSB 07-122, Arlington, VA, 2007.

Engineering (HPLE); Department-level Reform of Undergraduate Engineering Education (DLR); and International Research and Education in Engineering (IREE).

As a final element in the STPI analysis, Ms. Bhavya Lal developed a plan for evaluating current and pending engineering education research programs. That plan is the subject of the report that follows.

Pamela Ebert Flattau, PhD
Project Leader
IDA Science and Technology Policy Institute

Acknowledgments

The author would like to thank STPI staff members Drs. Brian Zuckerman, Stephanie Shipp, Seth Jonas and Mary Beth Hughes for their contributions to the development of this report.

Contents

Executive Summary

An evaluation of a portfolio or program of research funded by NSF's Engineering Education and Centers (EEC) Division should be based on a series of principles that sharpen and focus the study questions, data collection approach, and analytical techniques. At the beginning of this brief report, we itemize ten of these principles. Based on these principles, we propose a set of study questions, measures, and data collection and analysis strategies for evaluating engineering education research program. These questions and measures are summarized in the table below.

Our recommendations are evident throughout the brief report. However, three key recommendations stand out:

1. NSF leadership should assess the extent to which a review of the current portfolio reveals that evaluation of ENG education research would be worthwhile. In other words, is there sufficient depth to the engineering education research portfolio that there is beginning to be evidence of the accomplishments discussed above; the scale of the evaluation should be proportional to the size of the program.

2. If the basics of this report are acceptable, NSF staff should conduct internal activities to explicate the Division's Theory of Change and how it maps on to the Division's, Directorate's and Foundation's strategic plans (a program driven by a theory of change will ensure that the program is "doing the right thing"). Further, the evaluation should indeed examine inputs and activities at the program and grantee levels, but through a results-oriented lens (measuring if the program is "doing the thing right").

3. NSF staff should also identify questions and measures from this report that are of interest and begin to develop data collection templates and procedures to collect the data required. It is important to note that collection for the evaluation should be orchestrated such that it minimizes burden on grantees; grantees should incorporate evaluation measures in their reporting, and the reports should be planned such that data extraction from them is largely automated. Progress reports could be made more survey-oriented rather than free-form text, for example, to ensure that NSF receives all the information it needs and in the format it needs them, to make informed decisions for the future.

	Evaluation Question (Section 3)	Performance Measures (Section in which discussed)	Data Source (Section 5)	Data Collection / Analytic Method
Investment Efficiency	Q1: What specific and existing problem, interest, or need does the program address? How is this need relevant to NSF's mission?	• Strategic planning at the Division level (section 4.1 below)	- EEC Strategic Planning Documents - Program Staff	- Interviews with NSF/ENG/EEC program staff
Investment Efficiency	Q2: Is the program designed so that it is not redundant or duplicative of any other Federal, State, local or private effort?	• Strategic planning at the Program level (4.2) • Extent and quality of collaborations and networks at the Program level (4.3)	- EEC Strategic Planning Documents - Other programs - Program Staff	- Interviews with NSF/ENG/EEC program staff - Interviews with leaders of comparable programs and other experts
Investment Efficiency	Q3: Is the program design effectively targeted so that resources will address the program's purpose directly and will reach intended beneficiaries?	• Strategic planning at the Program level (Section 4.2 below) • Extent and quality of collaborations and networks at the Program level (4.3)	- EEC Strategic Planning Documents - Program Staff	- Interviews with EEC program staff and grantees
Process Efficiency	Q4: In what way and to what extent does the program collaborate and coordinate effectively with related programs?			
Process Efficiency	Q5: To what extent has the program demonstrated adequate progress in achieving its long-term performance goals?	• Meeting community needs (4.4) • Collaborative research (4.5) • Interdisciplinary research (4.6) • High quality research (4.7) • Translational and use-inspired (4.8) • Potentially transformative – high risk research (4.9) • User-oriented (4.10) • Creating capacity and diversity (4.11)	- Literature (e.g., ASEE, ABET) - EEC funded publications, presentations, and other outputs (e.g., digital libraries) - Select PIs - Users - Experts - Program Staff	- Interviews with EEC program staff, grantees, and other experts - Analysis of literature, survey data//interviews - Network analysis - Data mining - Historical mapping - Citation analysis - CV analysis
Process Efficiency	Q6: Does the performance of this program compare favorably to other programs, including government, private, etc., with similar purpose and goals?			
Process Efficiency	Q7: To what extent are program goals (and benefits) being achieved at the least incremental societal cost and to what extent does the program maximize net benefits?	• Researchers well-networked (and leverage other efforts) (4.5) • Productive networks that grow richer with time (4.5)	- EEC funded publications, presentations, and other outputs (e.g., digital libraries) - Users - Experts	- Analysis of survey data and interviews with grantees - Network analysis - Data mining - CV analysis

1.0 Goals and Motivation

The goal of this report is to present an evaluation plan for the Division of Engineering Education and Centers (EEC) programs in engineering education. Our assumption[7] is that, going forward, EEC is likely to fund individual investigator awards focusing on research in engineering education[8]

> *"We are looking for significant breakthroughs in understanding so that our undergraduate and graduate engineering education can be transformed to meet the needs of the changing economy and society. We are interested in research that addresses: the aims and objectives of engineering education; the content and organization of the curriculum; how students learn problem-solving, creativity and design; new methods for assessment and evaluation of how students learn engineering; and research that helps us understand how to attract a more talented and diverse student body to all levels of engineering study."*
>
> *NSF EEC, Program Description, S. Kemnitzer (Personal Communication, 2008)*

As a result, this report focuses on research rather than implementation programs.

The evaluation concepts outlined below have two primary motivations, one external and one internal. The external motivation stems from a report of the Academic Competitiveness Council (ACC) that included two specific recommendations[9]:

- ACC Recommendation 4: Federal agencies should adjust program designs and operations so that programs can be assessed and measurable results can be achieved, consistent with the programs' goals.

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7 Kickoff meeting with Sue Kemnitzer and Connie Della-Piana, May 2008.

8 In April 2008, NSF EEC announced another program of support, "Innovations in Engineering Education, Curriculum, and Infrastructure" (IEECI). See: PA 08-542 at www.nsf.gov/pubs/2008.

9 Report of the Academic Competitiveness Council, May 2007, U.S. Department of Education http://www.ed.gov/about/inits/ed/competitiveness/acc-mathscience/report.pdf. ACC is not the first effort to ensure the wise use of taxpayers' money. Since the 1960s, the federal government has undertaken major initiatives to evaluate the performance and results of federally funded programs, including research and development (R&D) programs. In recent years, the initiatives include the Government Performance and Results Act of 1993 and the Office of Management and Budget (OMB) Program Assessment Rating Tool (PART), developed in 2002. The latter was designed in the context of "performance budgeting" and "performance measurement" and focused on evaluating the efficiency of programs. All agencies have experienced difficulties in complying with the PART requirements to measure the efficiency of their research, to use outcome-based metrics in doing so, and to achieve and quantify annual efficiency improvements. Evaluation of R&D programs has especially proved to be challenging for federal agencies. In particular, they have experienced difficulties in complying with the PART requirements to measure the *efficiency* of their research, to use *outcome-based* metrics in doing so, and to achieve *annual* efficiency improvements.

- ACC Recommendation 5: Funding for federal STEM education programs designed to improve STEM education outcomes should not increase unless a plan for rigorous, independent evaluation is in place, appropriate to the types of activities funded.

Both recommendations imply that all Federal programs must be designed to be evaluated, and that evaluation is critical to continued support of programs.

The internal motivation for the EEC Division is two-fold. The first is to ensure that the research it funds using taxpayer dollars is producing expected outcomes and impacts. This is being done not only through the preparation of a long term plan for the Division (building on the thought leaders' workshop as well as this report), but also preliminary evaluations of its current programs. The second is to stimulate the development and use of new and appropriate frameworks, tools and methodologies that will serve not only the engineering education research and evaluation community, but the broader NSF community as well.

The sections below are organized as follows. This section provides a motivation for developing an evaluation plan for engineering education programs in the EEC Division. Section 2 outlines a basic set of principles that should guide a future evaluation of EEC-funded research programs. In Sections 3 and 4, we propose a conceptual framework and performance measures that could help operationalize the framework. The sections also provide illustrations of how data could be analyzed and presented visually. The intent in including these exhibits is not to study them in detail (after all, they apply to different situations) but to give an idea of how data mining and visualization tools can increasingly be used for data analysis as well. Section 5 proposes data collection activities that result from the frameworks and measures. In Section 6, we summarize the evaluation questions and the primary data collection methods for each, and outline some next steps for the Engineering Education Division.

2.0 Guiding Principles

This evaluation plan was guided by the following ten principles:

1. Any activity, government-funded or otherwise, often is driven by a *theory of change*[10]. The best way to evaluate the program therefore is to examine the design and implementation of this theory. Figure 1 below illustrates how this theory can be made explicit. Figure 2 applies the theory roughly to the EEC-funded research program *How People Learn Engineering*.

2. The evaluation must make the distinction between process and investment efficiencies[11]. Simply put, a distinction must be made between: doing the right thing (investment efficiency) and doing the thing right (process efficiency).

3. Often times, evaluators are carried away with intricate methodological issues, and as a result, sponsor needs – to understand the outcomes of their program – are not fully met. The evaluation design must be simple, and directly address program purpose and results. Einstein is quoted to have said: *Not everything that counts can be counted and not everything that can be counted counts*. Traditional evaluators tend to excessively focus on things that can be counted. It is better to answer the right question poorly than the wrong question comprehensively.

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[10] "A theory of change approach to evaluation assumes that underlying any intervention is an explicit or latent "theory" about how the intervention is meant to change outcomes. Further, having an explicit theory about how various processes and outcomes might be linked can direct data collection and analysis. With this map in hand (so the argument goes), evaluators and their clients can measure near-term outcomes with some confidence that observable change in those outcomes will be followed by changes in longer-term outcomes. They can also measure the processes that link (and perhaps cause change in) those outcomes. In short, theory can help evaluators pull apart and understand interventions." **www.aspeninstitute.org/Programt3.asp?bid=1263**

[11] In the context of this framework, the trickiest concept is that of efficiency. A recent National Academies' Report *Evaluating Research Efficiency in the U.S. Environmental Protection Agency* (Available at: http://www.nap.edu/catalog/12150.html) makes a useful distinction. We will look for *Investment efficiency* to indicate whether EEC is "doing the right research and doing it well". The term is meant as a gauge of portfolio management to measure whether EEC program managers are investing in research that is relevant to NSF's mission and long-term plans and is being performed at a high level of quality. The Academies report distinguishes between *investment efficiency* and *process efficiency.*

- *Investment efficiency* focuses on portfolio management, including the need to identify the most promising lines of research for achieving desired outcomes.
    - It is best evaluated by assessing the program's research activities, from planning to funding to midcourse adjustments, in the framework of its strategic planning architecture. *Because these questions cannot be addressed quantitatively, they require judgment based on experience and should be addressed through expert review.*
- *Process efficiency involves inputs and outputs.*
    - Its evaluation asks how well research processes are managed.
    - It monitors activities, such as publications, grants reviewed and awarded, and laboratory analyses conducted whose results can be anticipated and can be tracked quantitatively against established benchmarks by using such units as dollars and hours.

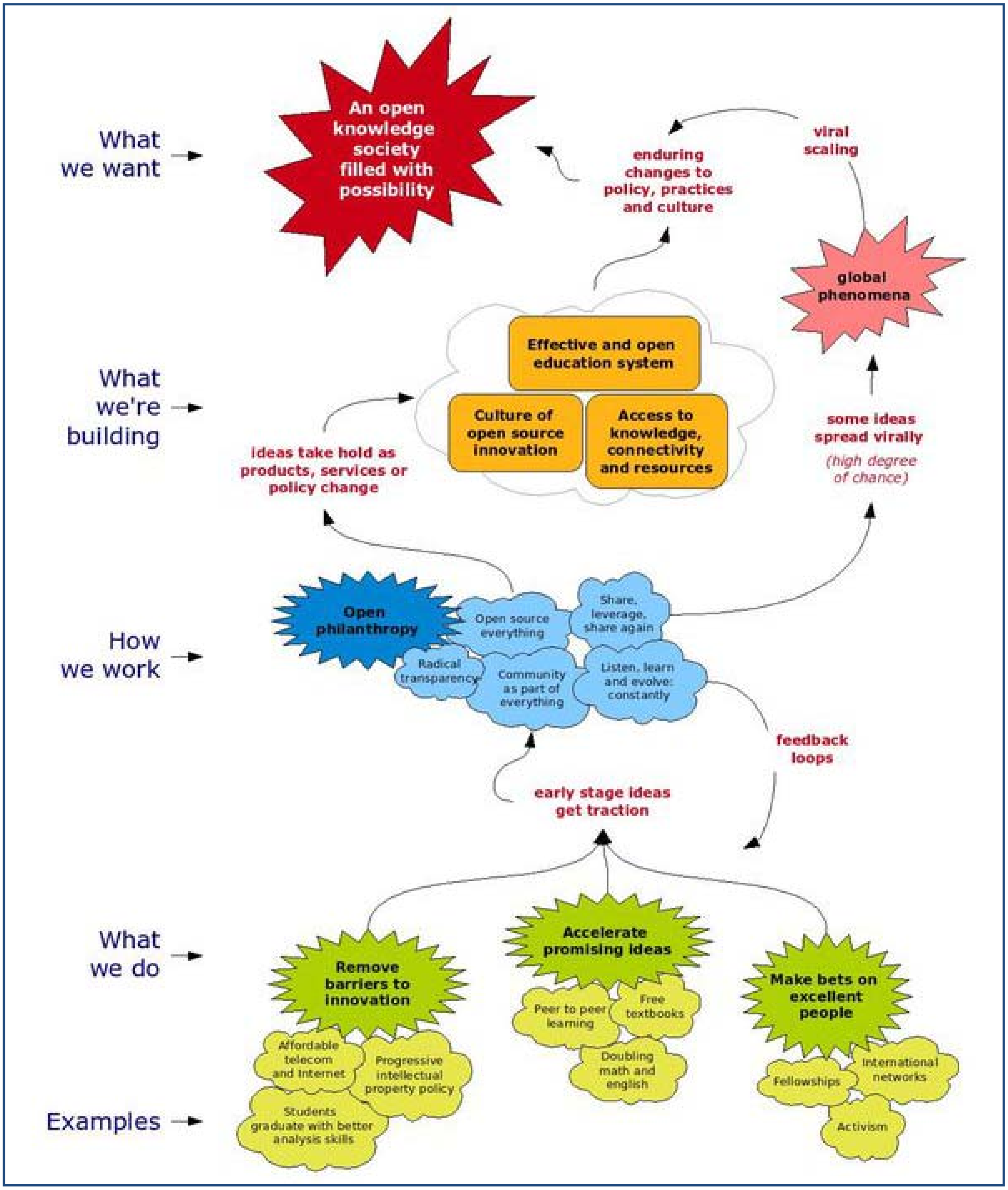

Figure 1: Explicating Theory of Change/Logic Model of a Program

SOURCE: Shuttleworth Foundation Theory of Change, January 2008

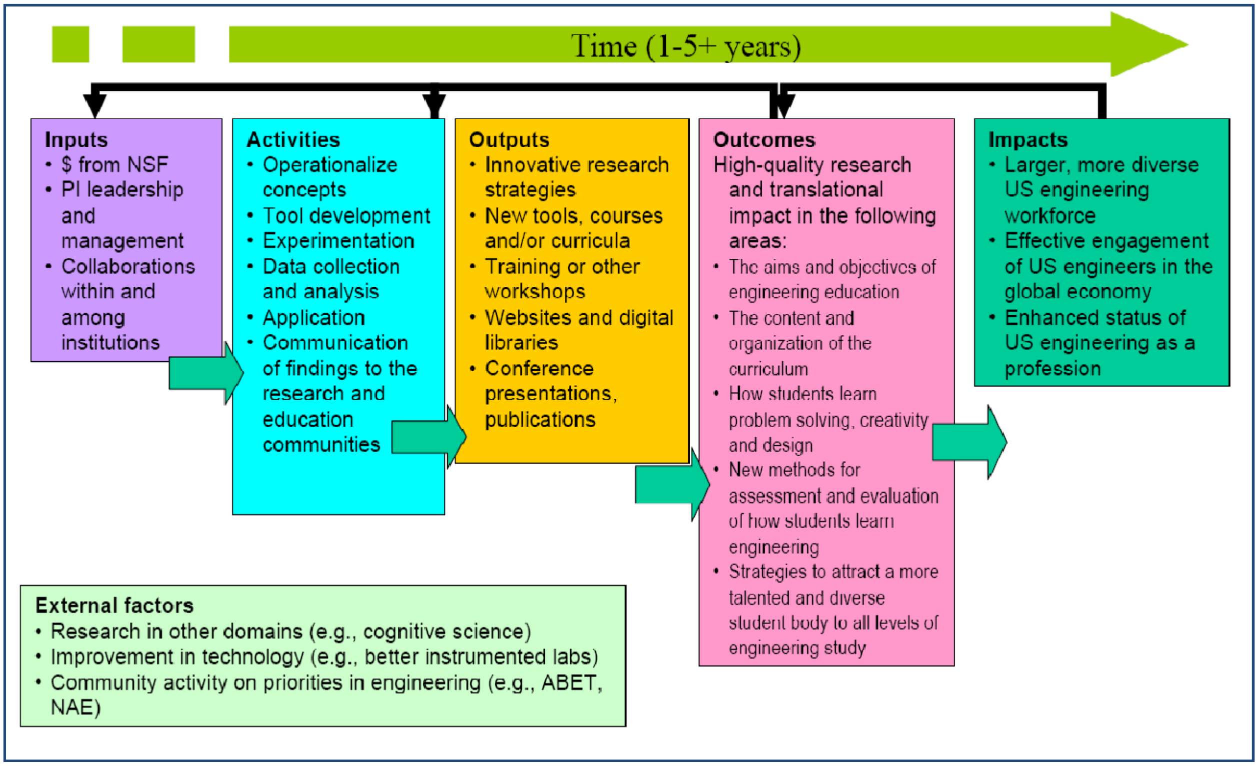

Figure 2: Explicating Theory of Change/Logic Model of the Program

SOURCE: P. Flattau, et al. *"Early Outcomes of the NSF Grants Program on How People Learning Engineering"* IDA STPI Report D-3725, January 2009. Available at: http://www.cpe.vt.edu/eensf/speakers.html

4. There are many types of evaluations that could be performed (see Figure 3 below). It is our belief, having worked with the Engineering Education and Centers Division for years, that the most valuable evaluation is often an outcome evaluation.

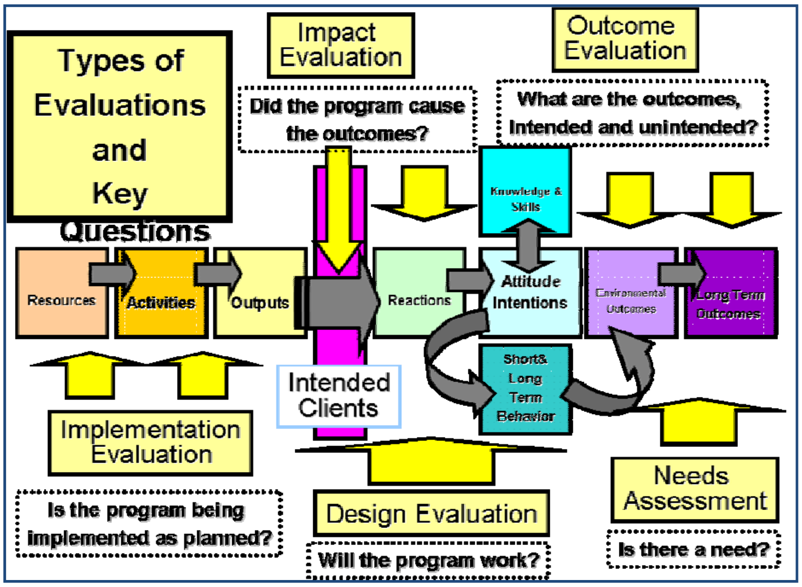

Figure 3: Types of Evaluations and Key Questions

SOURCE: Unknown

5. While the primary goal of research is knowledge generation[12] and this is certainly the mission of NSF, engineering education research must be viewed as "translational" research – with a strong applied component designed to bridge knowledge with practice[13].

6. The cost of an evaluation should be proportional to the size of the program. The ACC report did not merely make a recommendation that STEM programs be evaluated. It also made recommendations as to the approaches. While emphasizing experimental control group driven designs, the report recognized that "no single study design or evaluation methodology is appropriate for all education studies and [that] the appropriate methodology should be selected based on the maturity of the

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12 "The primary goal of research is knowledge, and the development of new knowledge depends on so many conditions that its efficiency must be evaluated in the context of quality, relevance, and effectiveness in addressing current priorities and anticipating future R&D questions." From *Evaluating Research Efficiency in the U.S. Environmental Protection Agency* Committee on Evaluating the Efficiency of Research and Development Programs at the U.S. Environmental Protection Agency, The National Academies. Available at: http://www.nap.edu/catalog/12150.html.

13 With the recognition, that it may take years before research is translated into practice. According to a 2003 paper by Burkhardt and Schenfeld [Improving Educational Research: Toward a More Useful, More Influential and Better Funded Enterprise, Educational Researchers Vol. 32 No 9, Dec 2003], the time scale for substantial research to practice impact could be 25 years.

activity, the intended use of the data, and the inferences to be drawn from the study results."[14] One input to the appropriateness of the evaluation methodology should be its relative cost to that of the program being evaluated - it makes no sense to develop random assignment experimental trials that cost millions of dollars to evaluate small programs.

7. It may be more productive to further build on deep thinking around R&D assessment guidelines than to reinvent the wheel. There are several recognized efforts on evaluating R&D[15]. It would be worthwhile to use a combination of existing, well-vetted frameworks to examine EEC's research activities.

8. Any evaluation is incomplete unless it is fully integrated with the Division's strategic planning process. Evaluation results should feed into strategic planning efforts; in return planning should incorporate evaluation.

9. While the evaluation must by necessity be retrospective, it should also have a strong prospective orientation as well. The analogy of driving forward while looking through the rear view mirror is an apt one.

10. To maximize the impact of the evaluation, program leaders should communicate the results of their evaluations simply (and visually) to stakeholders including Congress and other decision-makers.

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14 The hierarchy describes three categories of evaluation design: experimental methods, primarily well-designed randomized controlled trials, which are the preferred trials; quasiexperimental methods, primarily well-matched comparison-group studies, which are preferred when randomized control is not feasible; and non-rigorous, preliminary reviews such as those based on pre- and post-tests or self-reported outcomes, which are the weakest evaluation alternatives but useful for other purposes.

15 The United States has dabbled in developing frameworks for evaluation for decades. The federal government has attempted several government-wide initiatives designed to better align spending decisions with expected performance. Examples include: Hoover Commission, Planning-Programming-Budgeting-System (PPBS), Management by Objectives, Zero-Based Budgeting (ZBB), Government Performance and Results Act of 1993 (GPRA), President's Management Agenda (2001), and the Performance Assessment and Rating Tool, 2001 (PART). A good resource is the NIST/ATP funded *Toolkit for R&D Evaluation*.

3.0 Proposed Questions for Evaluating Engineering Education Research

Based on discussions with NSF staff, the principles outlined above, as well as a review of the evaluation frameworks in the literature, we have developed a series of high level evaluation questions, and proposed approaches to collect the data that address these questions.

The evaluation framework, as laid out in Table 1, has two components.

- Investment Efficiency: The first set of questions revolves around **program rationale and design** emphasizing what purpose the program to be evaluated serves. It also relates to the program's **place and role in the landscape** of related programs.

- Process Efficiency: The second set of questions focuses on **program results.**

It is important to evaluate both aspects when evaluating a program or a portfolio. Sometimes, evaluators emphasize only the latter. As a result, government programs have trouble communicating to OMB and others about the basic purpose of their existence, and how they fit with other programs and activities in the broader domain.

Table 1: High-Level Evaluation Questions

Investment Efficiency - Program Rationale and Design (“Doing the Right Thing”)
1. What specific and existing problem, interest, or need does the program address?[16] How is this need relevant to NSF’s mission?
2. Is the program designed so that it is not redundant or duplicative of any other Federal, State, local or private effort?[17]
3. Is the program design effectively targeted so that resources will address the program’s purpose directly and will reach intended beneficiaries?[18]
Process Efficiency - Program Results and Outcomes (“Doing the Thing Right”)
4. In what way and to what extent does the program collaborate and coordinate effectively with related programs (to maximize its potential impact)?[19]
5. To what extent has the program demonstrated adequate progress in achieving its long-term performance goals?[20] In other words: is the program *effective*?
6. Does the performance of this program compare favorably to other programs, including government, private, etc., with similar purpose and goals?[21]
7. To what extent are program goals (and benefits) being achieved at the least incremental societal cost and to what extent does the program maximize net benefits?[22] In other words: is the program *efficient*?

16 Adapted from PART Guide OMB question 1.2, (Available at: http://www.whitehouse.gov/omb/part/fy2008/part_guid_2008.pdf)

17 Adapted from PART Guide OMB question 1.3

18 Adapted from PART Guide OMB question 1.5

19 Adapted from PART Guide OMB question 3.5

20 Adapted from PART Guide OMB question 4.1

21 Adapted from PART Guide OMB question 4.4

22 Adapted from PART Guide OMB question 4.RG1

4.0 Performance Measures

The high-level questions itemized above can be addressed in many different ways using a variety of performance measures and metrics. We propose a core set of eleven measures in this section. Table 2 relates each metric to the high level questions.

Table 2: Proxy Measures for Evaluation Questions

<table>
<tr><th></th><th>Evaluation Question
(from Exhibit 2 above)</th><th>Performance Measures
(Section in which discussed)</th></tr>
<tr><td rowspan="3">Investment Efficiency</td><td>Q1: What specific and existing problem, interest, or need does the program address? How is this need relevant to NSF's mission?</td><td>• Strategic planning at the <u>Division</u> level (section 4.1 below)</td></tr>
<tr><td>Q2: Is the program designed so that it is not redundant or duplicative of any other Federal, State, local or private effort?</td><td>• Strategic planning at the <u>Program</u> level (4.2)
• Extent and quality of collaborations and networks at the <u>Program</u> level (4.3)</td></tr>
<tr><td>Q3: Is the program design effectively targeted so that resources will address the program's purpose directly and will reach intended beneficiaries?</td><td rowspan="2">• Strategic planning at the <u>Program</u> level (Section 4.2 below)
• Extent and quality of collaborations and networks at the <u>Program</u> level (4.3)</td></tr>
<tr><td rowspan="4">Process Efficiency</td><td>Q4: In what way and to what extent does the program collaborate and coordinate effectively with related programs?</td></tr>
<tr><td>Q5: To what extent has the program demonstrated adequate progress in achieving its long-term performance goals?</td><td rowspan="2">• Meeting community needs *(4.4)
• Collaborative research (4.5)
• Interdisciplinary research (4.6)
• High quality research (4.7)
• Translational and use-inspired (4.8)
• Potentially transformative – high risk research **(4.9)
• User-oriented (4.10)
• Creating capacity and diversity (4.11)</td></tr>
<tr><td>Q6: Does the performance of this program compare favorably to other programs, including government, private, etc., with similar purpose and goals?</td></tr>
<tr><td>Q7: To what extent are program goals (and benefits) being achieved at the least incremental societal cost and to what extent does the program maximize net benefits?</td><td>• Researchers well-networked (and leverage other efforts) (4.5)
• Productive networks that grow richer with time (4.5)</td></tr>
<tr><td colspan="3">* Measures 4.4 – 4.12 are at the project level and are rolled up to the program level
** Not every project in the program can address all performance measures. A "portfolio" approach need be taken, especially for measures such as potentially transformative approaches and outcomes</td></tr>
</table>

4.1. Strategic Planning – Division Level

As Principle 2 outlines, an evaluation needs to begin with asking the question: is the program being evaluated "doing the right thing." One way to address this question is to examine the extent to which the goals of the program map on or feed into the strategic plans of the EEC Division (and that of the Engineering Directorate).

The evaluation should also look for evidence that the program genesis and design is based on a clearly articulated *theory of change* (which is essentially an expression of *how* the program, if it were to work, over some length of time, would bring change in learning and teaching in the classroom, and ultimately meet the goals laid out in the Division strategic plan). The evaluation should build a "logic model" based on the program's theory of change (as Exhibit 1b does above) which will allow each element of the rationale for program design and implementation plan to be closely examined. For example, the theory of change needs to show how improving of the teaching and learning of engineering could lead to increases in degree production in engineering fields.[23] The logic model should also incorporate other programs (e.g., NSF's Science of Learning Centers program, EEC's Engineering Research Centers programs, university-based efforts, and foundations such as the Whitaker Foundation that fund engineering education reform) and other contextual factors (e.g., markets, trends in offshoring of engineering jobs) that are likely to influence activities of the program and its grantees.

The evaluation should also probe if there are institutionalized ways in which its findings would feed into the ongoing strategic planning process.

All of the above evaluation activities are qualitative assessments to be made by external experts with experience in examining and evaluating logic models and strategic plans.

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[23] The logic modeling exercise may reveal flaws in the theory of change for the program itself. For example, the current EEC strategic plan implicitly implies that EEC activities (that encompass improvements in engineering education and research) would lead to greater enrollments. NSF's own data show however that this link has not been particularly strong in the past – improving engineering education alone may not lead to increased enrollment:

"*While the past 15 years have witnessed many successful advances in engineering education (for example, more student-centered pedagogies, the integration of research and engineering education), the introduction of design and other engineering concepts and experiences earlier in the curriculum, better understanding of the role of assessment, and new ideas on how to recruit, retain and graduate underrepresented groups (women and minorities). However, these changes have been piecemeal and have not resulted in major systemic change within engineering education. For example, in 1983 about 1.9 percent of all four-year baccalaureate degrees received by women were in engineering. Twenty years later, this percentage not only did not increase, but declined to 1.7 percent.*"

(As quoted in the ICCEI RFA, from NSB S&E Indicators 2008, Appendix Table 2-27).

EEC may need to do more than fund research in improving pedagogy and curricular reform (or be more precise about targeting it) if it truly wants to address the current division goals of increasing enrollments in engineering.

4.2. Strategic Planning – Program Level

In order to understand if the program is designed such that it is not redundant or duplicative of any other Federal, State, local or private effort, the logic modeling exercise is critical. The model identifies all internal and external stakeholders, discussions with whom would reveal the distinctions between the goals and approaches of EEC vs. these other programs.

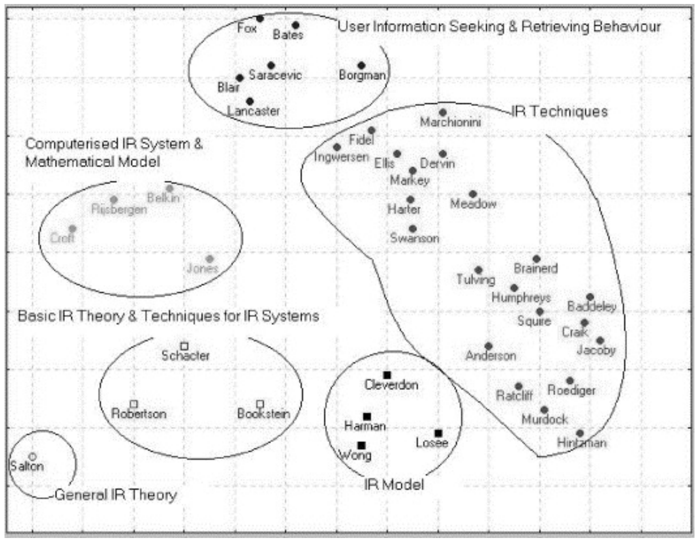
It is important for the evaluator to look at the activities of universities, many of whom experiment with new criteria and curricula. An example is that of MIT, where in the 1980s, the curriculum (not to mention physical space) of the aeronautics and astronautics department was completely overhauled in light of changing industry needs and new theories in the areas of experiential and collaborative learning and teaching methods. In the late 1990s, MIT also introduced the concept of engineering systems – and created a whole new cross-disciplinary division that brought together schools of Engineering and social sciences. Similarly, Olin College in Boston, MA, redefined the teaching of engineering, and is an important component of the ecosystem in which the EEC program operates.

Other reforms (not just in engineering education) have been undertaken by Foundations such as Sloan and Whitaker Foundations, and it would be worthwhile to examine NSF efforts in light of these other activities. Again, these are qualitative assessments to be made by external experts.

4.3. Program-Level Collaborations

In order to understand the ways in which the program collaborates and coordinates effectively with related programs, an evaluation should examine how well the program fits and is recognized within the community (i.e., other entities that fund education research or education implementation activities). Inter-entity synergism, collaboration and coordination can help ensure that NSF maintains its unique niche, and is not replicating unnecessarily other efforts.

Again, examples of these organizations include Sloan and Spencer Foundations, universities that create new experiments in engineering education reforms, as well as other NSF programs such as ERCs that are themselves involved in reform in engineering education. The intent is not just to examine the placement of the NSF program in the larger community, but the effort NSF makes to collaborate and coordinate within this community. Indicators of this effort are the presence of joint workshops, symposia, and formal and informal meetings between EEC leaders and those of other programs. Network analyses are a good means to examine the presence and evolution of these collaborations and networks. Figure 4 provides two illustrations of how EEC can identify its role/niche within the education research ecosystem.



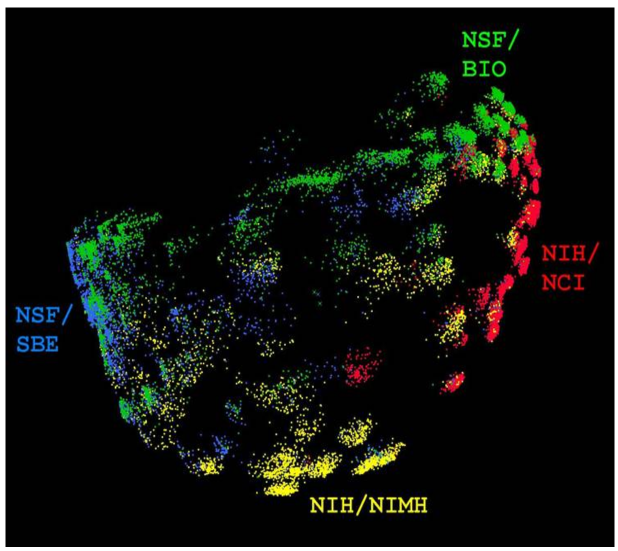


Figure 4: Illustrations of How EEC's Activities Can Be Viewed within the Landscape of Education Research

SOURCE: *Science Direct Portal* and prior STPI analysis

4.4. Meeting Community Needs

In order to understand the extent to which the engineering education division and its research funding program has demonstrated adequate progress in achieving its long-term performance goals, and how this performance compares to other programs with similar purpose and goals, we propose eight metrics (discussed in Sections 4.4 – 4.11), each to be examined at the project level and meant to be aggregated up to the program/portfolio level. These measures are: meeting community needs; collaborations; interdisciplinarity; high quality research; translational and use-inspired research; transformational – high risk research; User-oriented research; and creation of capacity and diversity.

Starting with community needs, the evaluation must examine if the goals and activities of funded research map onto the goals set by the engineering education research community. The evaluation could, for example, assess the degree of overlap of EEC-funded research with the priority areas set by the *National Engineering Education Research Colloquies*, and other priorities articulated at regular intervals by the *National Academy of Engineering* and other members of the community (e.g., ABET). These mappings would be qualitative though highly structured assessments, made by experts. Table 3 provides a template to organize such a mapping.

Table 3: Template for Mapping Community Goals on to EEC-Funded Research

<table>
<tr><th></th><th>Community Goal 1</th><th>Community Goal 2</th><th>Etc</th></tr>
<tr><td>Project 1Goals</td><td colspan="3" rowspan="3">Strength of the alignment (+, ++, -, etc)</td></tr>
<tr><td>Project 2Goals</td></tr>
<tr><td>Etc</td></tr>
</table>

4.5. Collaborative Research

Building on the assumption that cutting-edge and/or potentially transformative research is often collaborative, the evaluation should explore the extent to which program-funded researchers are working collaboratively with other education researchers, and how well-integrated they are (and getting better networked with time) within the education and learning communities.

There are several ways of examining these collaborations, although the specific networks may vary from grant to grant. One is to use annual reports (or *Fastlane* submissions) to document if EEC-funded researchers are collaborating with not only researchers in the domain of engineering education, but also researchers within the broader education and learning communities (education-oriented researchers at NSF-funded Centers – Science of Learning Centers (SLCs), Engineering Research Centers

(ERCs), etc.). The evaluation should also use annual and progress reviews to document if grantees are attending and presenting joint papers, again, not only at core engineering education research conferences (e.g., ASEE) but also other learning-oriented gatherings (e.g., American Educational Research Association (AERA)). One of the finding that emerged from the STPI review of EECs HPLE program was that EEC funded research are not integrated well with the general education and learning research communities. While engineering education research is quite different from general education research, it may be important for engineering education researchers to build on research done by these older communities. Indeed, given that the field is still emerging, it is important to see it *both* be part of and distinguish itself from the broader fields of education and learning research.

If good data on collaborations is available through routine extraction from progress reports or surveys, they are easy to analyze and represent using many freely-available commercial tools (e.g., UCNET). Figure 5 below illustrates a network diagram where researchers from multiple projects collaborate together. Figure 6 on the following page illustrates how these networks have evolved and deepened over the course of three years.

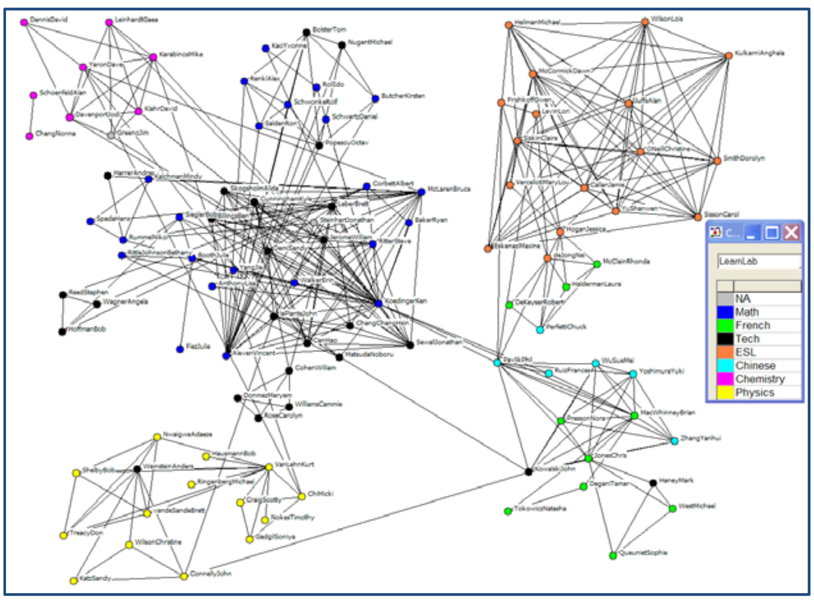


Figure 5: Use of Network Methods to Examine Collaborations

SOURCE: STPI Analysis of NSF Data

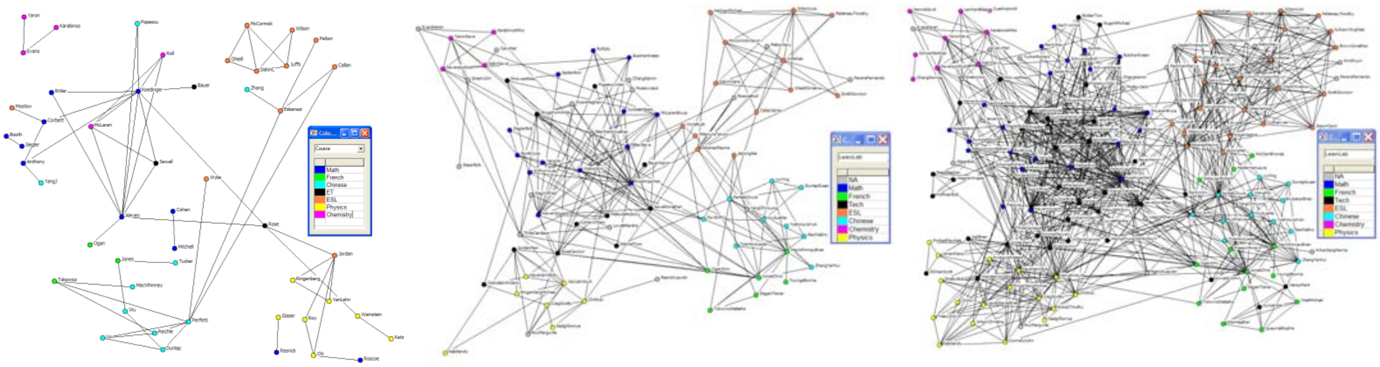


Figure 6: Use of Network Methods to Track Growth/Deepening of Collaborations
SOURCE: STPI Analysis of NSF Data

4.6. Interdisciplinary Research

Interdisciplinarity[24] is viewed as a vital constituent of cutting-edge research (Porter et al). To examine the extent to which program-funded research is inter- and multi-disciplinary and brings together a broad range of people and topics, again, use of publications and conference presentation data is the least burdensome method (there are other methods as well, for example, tracking of email traffic or participation in online virtual communities, etc).

Analyses of co-authorship patters would reveal if researchers are including authors from multiple departments and schools, publishing in non traditional journals, and attending a broad range of conferences (e.g., AERA). Figure 7 below (as well as Figures 5 and 6 above) illustrates how networking and data mining and visualization tools can be used to assess interdisciplinarity in a portfolio of research.

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24 Some experts distinguish interdisciplinary research from multidisciplinary research. “Interdisciplinary research is a mode of research by teams or individuals that integrates: perspectives/concepts/theories and/or tools/techniques and/or information/data from two or more bodies of specialized knowledge or research practice. Its purpose is to advance fundamental understanding or to solve problems whose solutions are beyond the scope of a single field of research practice. … ‘multidisciplinarity’ as a basic situation in which elements from different disciplines are present, whilst ‘interdisciplinarity’ is a more advanced stage of the relationship between disciplines in which integration between them is attained.” (From http://www.tpac.gatech.edu/papers/Researcher_Interdisciplinarity_2007.pdf)

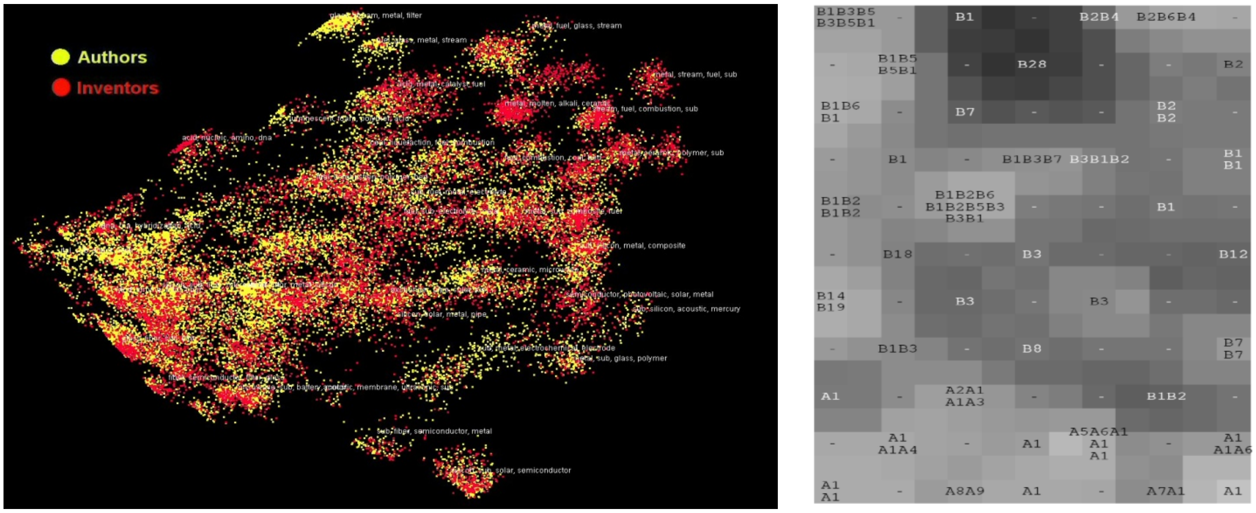

Figure 7: Illustration of Ways of Examining the Extent to Which EEC Funded Research is Interdisciplinary

SOURCE: US Department of Energy, and Pölla et al. 2006

4.7. High Quality Research

To examine the extent to which EEC-funded research is of high quality and highly respected by peers, the evaluation can take both the peer review route[25], and a more scientometric oriented route which involves citation analysis. Typically both may be needed, as both methods have inherent weaknesses that are difficult to overcome.

Over the years citation analysis has become more sophisticated and inexpensive. For example, *Publish or Perish* is a citation analysis software program, designed to help individual academics to present their case for research impact to its best advantage; Exhibit 9 below lists some of the metrics used in *Publish or Perish*.

For research that may lead to patenting and/or licensing activities, these outputs can easily be extracted from USPTO and other public sources and analyzed. For example, Exhibit 10 on the following page shows how patent-paper links can be used to identify seminal research in a field using scientometrics tools). While patents are not the currency of research in engineering education, the method (which can also be used with published papers) is nonetheless valid to trace high-quality research that may lead to downstream benefits.

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[25] For example, assemble a panel of experts (e.g., Committee of Visitors) to review a representative sample of the research.

Table 4: Some Common Measures of Research Quality

h-index	Aims to measure the cumulative impact of a researcher's output by looking at the amount of citation his/her work has received.
g-index	Aims to improve on the h-index by giving more weight to highly-cited articles
hc-index	Adds an age-related weighting to each cited article, giving less weight to older articles
hi-index	Divides the standard h-index by the average number of authors in the articles that contribute to the h-index, in order to reduce the effects of co-authorship
hi-norm	Instead of dividing the total h-index, it first normalizes the number of citations for each paper by dividing the number of citations by the number of authors for that paper
AWCR	Measures the number of citations to an entire body of work, adjusted for the age of each individual paper.
AWCR-index	sqrt (AWCR) (compares to h-index)

SOURCE: Summarized by STPI from *Publish or Perish,* August 2008.

Conference presentation data can also be used for informal analysis of research quality. In our experience, in some cases, journal articles may not be the coin of the realm; there are many journals in which EEC-funded researchers publish that are not ISI indexed, and many of the most important venues for dissemination are conferences rather than journals, which makes the more quantitative indicators from traditional bibliometrics sources hard to use. Since many of the key education conferences are small, integration of the specialized ones (e.g., percentage of researchers presenting who are program-affiliated, memberships on conference steering committees; winning awards for best paper) should be considered as a supplementary success metric.

There may be other ways to capture quality (or “pioneeringness” if that is important to assess) as well. For example, in recent years the idea of a *virtual congress* has gained a foothold. In this technique, a small panel of experts is assembled and panelists ask other experts (round the world, if desired) to identify the “best of the best” researchers for particular subfields. The pollees are asked to imagine themselves as organizers of a session in their particular subfield, and to furnish a list of 5–10 desirable speakers. Even if a large number of experts are polled, soon a small number of researchers rise to the top as leading the “forefront” or among “world leaders.” NSF can then document the extent to which this subset of researchers is part of its funding portfolio.

Both are qualitative data sources, but may be richer and more useful than some scientometric analysis. The challenge may also be that PIs sometimes do not provide NSF with a listing of publications (there is also evidence that final progress reports are not always turned in, which may mean that NSF does not always get a full listing of the publications it funds). Unlike NIH, which requires all NIH-funded publications to be turned into PubMed, there is not counterpart to PubMed, and EEC-funded publications may not be easily captured in automated ways, making scientometric tools more difficult to use in evaluations.

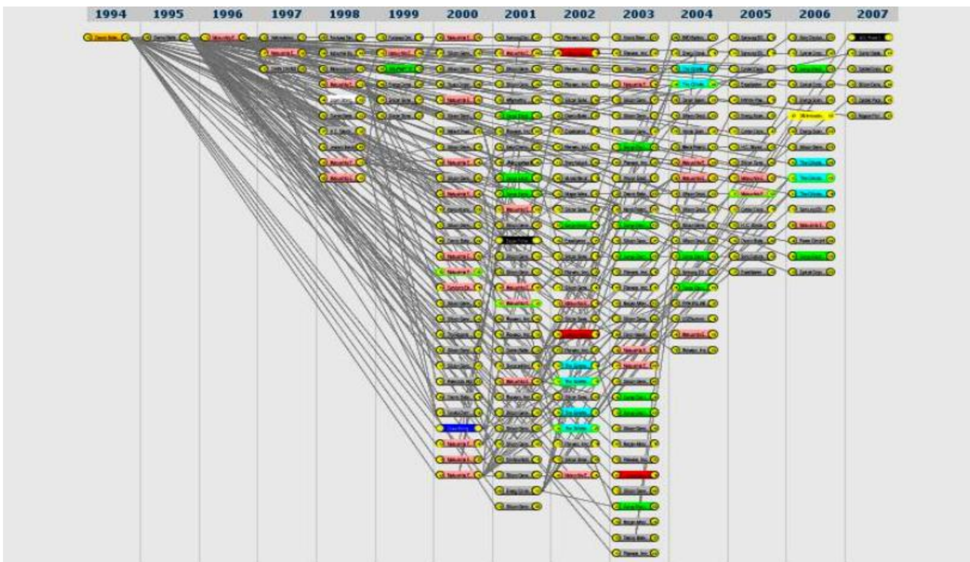

Figure 8: Illustration of a Way to Examine If/How Research is Seminal
SOURCE: NIST Advanced Technology Program[26]

[26] The diagram above represents what is called "innovation tracing" and shows that "Seventy patents have cited Lockheed Martin's Patent #5,314,765, Issued in 1994, Titled "Protective lithium ion conducting ceramic coating for lithium metal anodes and associate method"

4.8. Translational and Use-Inspired Research

Education research is unique in that it aims not only to produce new knowledge but also to build bridges to practice. An evaluation should explore the extent to which a subset of the EEC-funded research portfolio is translational in nature – i.e., focuses on translating theories and frameworks into classroom interventions (the educational equivalent of "bench to bedside" in the biomedical community). "Translationalness" is a qualitative measure though it has been possible to measure it quantitatively in other domains (e.g., paper-patent-product links of research funded by DOE, see Figure 8 above). In the engineering education research domain, we expect it will be explored qualitatively through case studies that are subsequently reviewed by an expert panel. Visual representations such as shown in Figure 9 illustrate how a set of research findings could bridge research and practitioner communities.

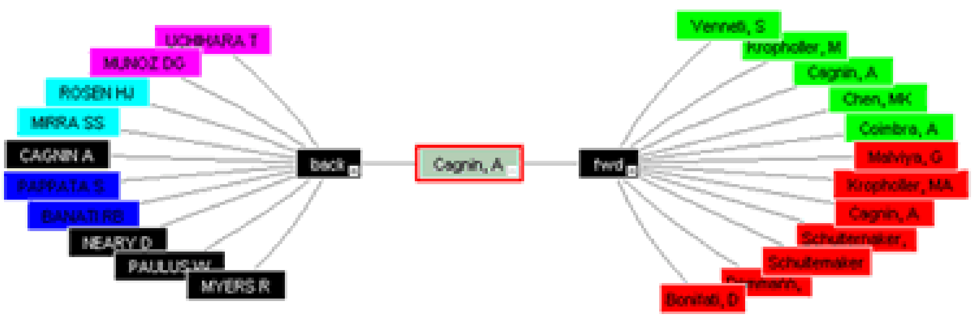

Figure 9: Illustration of a Way to Examine Translational Research
SOURCE: ISI Web of Science

4.9. User-oriented Research

Engineering education research should not only be translational (i.e., intended to move theories, frameworks, tools etc into practice) but also produce outputs that may be useful in classroom situations (as the cartoon on the right shows, it is not trivial to move R&D to the marketplace). Again, this measure should not be sought in every grant, but rather in the portfolio as an aggregate. An evaluation should document the extent to which some fraction of EEC-funded research leads to (or, in the short-term, is intended to lead to) changes in learning, teaching or classroom practices.

Research outputs are not only presentations and publications but also products such as digital libraries, algorithms, websites, games, CD-ROMS, and other use-oriented materials. The evaluation should examine, through reviews of progress reports, the production of these outputs, and through tracing methods, use and utility of these outputs in classroom settings.

4.10. High Risk/Potentially Transformative Research

While engineering education research is a nascent field, with substantial "low hanging fruit" to be had, it is worth identifying and funding exceptionally creative ideas that have the potential to transform engineering education. The evaluation should therefore explore if at least a fraction of program-funded research has been high risk and potentially transformational.

Proposing indicators for high risk research is not trivial – high risk research may defy all prior characteristics. For example, it may not fit with the community vision of required research in engineering education, or be highly cited – at least in the short term. The portfolio is best assessed qualitatively through reviews by experts known for being pioneering themselves. It may also be appropriate to track the networks into which EEC funded research is conducted, its degree of interdisciplinarity, among others, as there is some evidence of their correlation with riskiness of research. The National Institutes of Health (NIH) is conducting research on identifying metrics for transformative research that may be relevant for NSF as well (contact Dr. Stephane Philogene, philogeS@OD.NIH.GOV, for details).

4.11. Creating Capacity and Diversity

Given concerns about declining interest in engineering as a field of study (and low enrollments in engineering education research as a field of study), the evaluation should explore the extent to which the program (as the sum of individual projects) focuses on creating a pipeline of the next generation of engineering education researchers.

There are several ways to explore this facet of the program. One could examine the roles of graduate students and postdoctorates in the research, what they do after they complete their training, if they stay in engineering education research, and the departments do they go into (psychology, cognitive science/neuroscience, education, etc.). Curriculum vitae (CV) analysis is a complementary technique to the more traditional method of surveys or bibliometrics, and one becoming increasingly automated in recent years.

5.0 Data Collection and Analysis

The sections above identify measures that could be used to evaluate the portfolio of EEC-funded research. Table 5 below links these measures with sources from which data to examine a particular facet of the program, and data collection and analytic methods.

Table 5: Summary of Data Collection and Analytic Methods

Metrics / Performance Measures	**Data Source**	**Data Collection / Analytic Method**
• Strategic planning at the Division level	- EEC Strategic Planning Documents - Program Staff	- Interviews with NSF/ENG/EEC program staff
• Strategic planning at the Program level • Extent and quality of collaborations and networks at the program level	- EEC Strategic Planning Documents - Other programs - Program Staff	- Interviews with NSF/ENG/EEC program staff - Interviews with leaders of comparable programs and other experts
• Strategic planning at the program level	- EEC Strategic Planning Documents - Program Staff	- Interviews with EEC program staff and grantees
• Meeting community needs • Collaborative research • Interdisciplinary research • High-quality research • Translational and use-inspired research • Potentially transformative – high risk research • User-oriented research • Creating capacity and diversity	- Literature (e.g., ASEE, ABET) - EEC funded publications, presentations, and other outputs (e.g., digital libraries) - Select PIs - Users - Experts - Program Staff	- Interviews with EEC program staff, grantees, and other experts - Analysis of literature, survey data and interviews - Network analysis - Data mining - Historical mapping - Citation analysis - CV analysis
• Researchers well-networked (and leverage other efforts) • Productive networks that grow richer with time	- EEC funded publications, presentations, and other outputs (e.g., digital libraries) - Users - Experts	- Analysis of survey data and interviews with grantees - Network analysis - Data mining - CV analysis

There are two main challenges to this data collection.

The burden on the Principal Investigators (PIs): A recent *Science* magazine editorial pronounces that 'the administrative burden on practicing scientists has grown tremendously over the past decades and is limiting their ability to get important scientific work done," noting that of the total time that faculty devote to research, 42% is spent on pre- and post-award administrative activities. NSF should be especially mindful of further burdening its grantees[27]. Data collection for the evaluation should be orchestrated such that it minimizes burden on grantees; grantees should incorporate evaluation measures in their reporting, and the reports should be planned such that data extraction from them is largely automated. Progress reports could be made more survey-oriented rather than free-form text, for example, to ensure that NSF receives all the information it needs and in the format it needs them, to make informed decisions for the future.

The effort NSF must expend in gathering and analyzing the data: Reducing burden on the PIs likely increases the burden on NSF program officers – in terms of the resources expended extracting and synthesizing the data.

In order to balance the burden on either party, we propose that the annual and end-of-grant reports be more survey-oriented than free text (as they are now). While free-text is getting easier to manipulate using text mining tools such as *nvivo*, PIs responses to precise questions regarding project outcomes would go a longer distance. There is much precedence at NSF for such data collection. Both the ERC and STC programs have templates that program leaders can use as a point of departure for its efforts.

Last, but not least, we recommend that evaluation findings be presented in visually relevant ways to ensure stakeholders understand the contribution of EEC funded research programs. Visualization methods have become increasingly easy to use and important in recent years to communicate data-driven findings, and we recommend that they be used to the extent possible not only for analytical purposes (as evident in the graphics in the sections above) but also to communicate the findings of evaluation of EEC programs. Many of the illustrations in the sections above were intended to give EEC leaders a glimpse of these tools. Figure 10 below shows that many Directorates at NSF have already been using visualization techniques to communicate their accomplishments and activities, and EEC should build on this work.

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[27] Science 12 December 2008: Vol. 322. no. 5908, p. 1609 DOI: 10.1126/science.1168345 Editorial *Reduce Administrative Burden* by Alan I. Leshner.

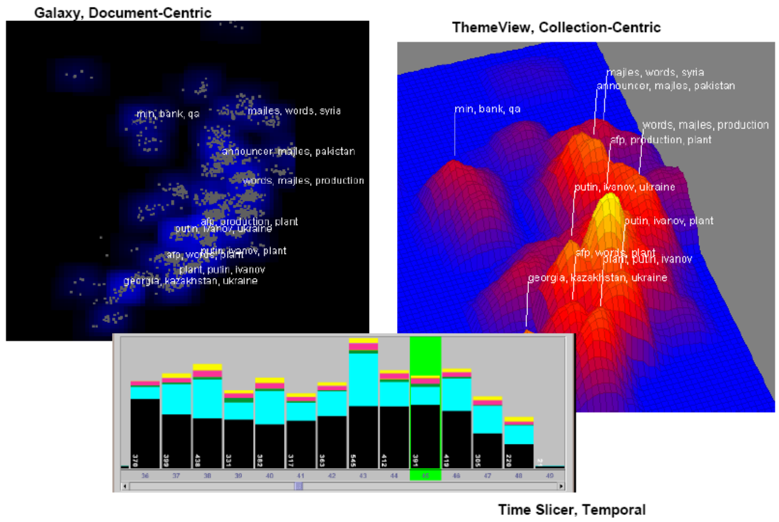

Figure 10: A Medley of Visualization Tools Can be Used to Present Evaluation Findings
SOURCE: National Science Foundation

6.0 Summary and Next Steps

An evaluation of a portfolio or program of research funded by EEC should be based on a series of principles that sharpen and focus the study questions, data collection approach, and analytical techniques. At the beginning of this brief report, we itemized ten of these principles. Based on these principles, we proposed a set of study questions and measures for evaluating EEC's research program.

- To what extent does the program's existence and its goals fit with the strategic direction of the EEC Division and NSF, and is based on a clearly articulated *theory of change* (how the program, if it works, over some length of time, will bring change in learning and teaching in the classroom)? [review of Division strategic planning]

- To what extent does the program design and activities fit with the Division's strategic direction, and are they likely to lead to the outcomes outlined in the theory of change? [review of Division strategic planning]

- To what extent does the program fit and is recognized within the community (other entities that fund education research or education implementation activities)? [network analysis, interviews with experts and members of the community]

- To what extent are program-funded researchers integrated (and getting better networked) within the education and learning communities? [network analysis, co-authorship patterns analysis, interviews with experts and members of the community, publication/presentation analysis, surveys to explore collaborative activity]

- To what extent is some fraction of the research portfolio translational in nature – i.e. focuses on translating theoretical ideas into classroom interventions (the educational equivalent of "bench to bedside" in the biomedical community)? [expert assessment, historical tracing]

- To what extent does program-funded research fit with the goals the engineering education research community has set for engineering education research? [interviews with experts and members of the community]

- To what extent is program-funded research inter- and multi-disciplinary, and brings together a broad range of people and topics? [publication/presentation analysis, surveys]

- To what extent does program-funded research lead to (or, in the short-term, intend to lead to) changes in learning, teaching or classroom practices? [interviews with members of the user community - educators]

- To what extent is some fraction of program-funded research high quality and highly respected by peers? [publication/presentation analysis, expert interviews]

- To what extent is some fraction of program-funded research high-risk and potentially transformative? [interviews with pioneering researchers within and outside community]

- How is the program building the next generation of leaders in the engineering education research community? [CV analysis]

In parallel with requesting the memo that preceded this brief report, NSF has begun the effort of characterizing its portfolio. Three next steps are recommended:

1. NSF leadership should assess the extent to which a review of the current portfolio reveals that evaluation of ENG education research would be worthwhile. In other words, is there sufficient depth to the engineering education research portfolio that there is beginning to be evidence of the accomplishments discussed above; the scale of the evaluation should be proportional to the size of the program.

2. If the basics of this report are acceptable, NSF staff should conduct internal activities to explicate the Division's Theory of Change and how it maps on to the Division's, Directorate's and Foundation's strategic plans (a program driven by a theory of change will ensure that the program is "doing the right thing"). Further, the evaluation should indeed examine inputs and activities at the program and grantee levels, but through a results-oriented lens (measuring if the program is "doing the thing right").

3. NSF staff should also identify questions and measures from this report that are of interest and begin to develop data collection templates and procedures to collect the data required. It is important to note that collection for the evaluation should be orchestrated such that it minimizes burden on grantees; grantees should incorporate evaluation measures in their reporting, and the reports should be planned such that data extraction from them is largely automated. Progress reports could be made more survey-oriented rather than free-form text, for example, to ensure that NSF receives all the information it needs and in the format it needs them, to make informed decisions for the future.

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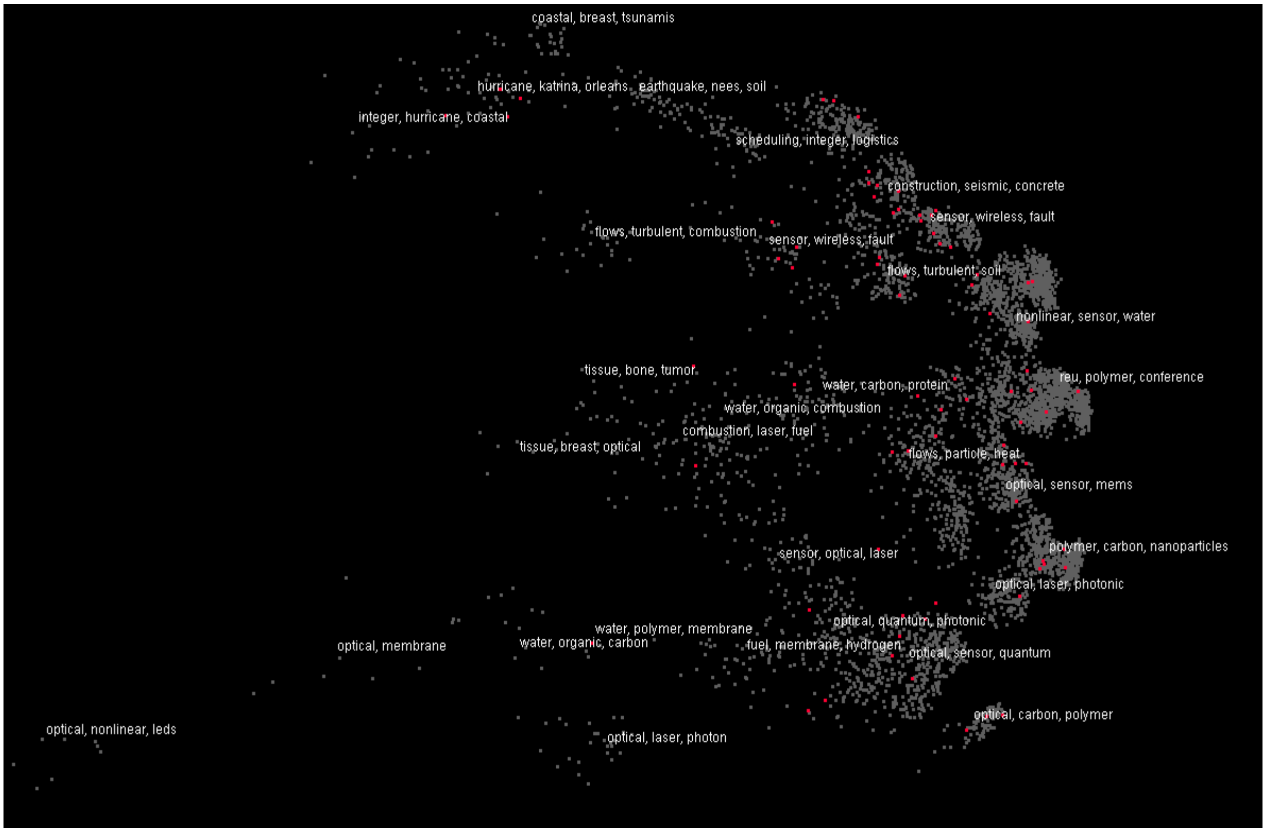

Figure 11: The ENG Directorate's Portfolio in 2006

SOURCE: STPI Analysis

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14. ABSTRACT

An evaluation of a portfolio or program of research funded by NSF's Engineering Education Division should be based on a series of principles that sharpen and focus the study questions, data collection approach, and analytical techniques.

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