Data Sharing from a Policy Perspective

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ABSTRACT

This paper addresses questions of data sharing from the perspective of a former NSF program officer. A brief comparison of policy and research perspectives is made to highlight different values in these two communities. Data sharing is framed as one means to support dialog between researchers and those involved in policy. Other uses of data sharing to those involved in policy are then outlined; it is seen that the role of data sharing is growing in a policy landscape in which program evaluation is becoming increasingly important. Despite the desire of Federal agencies to support data sharing there are legal, regulatory, and ethical constraints and tensions; these are briefly outlined. To help navigate these tensions data sharing is framed in terms of three value propositions: help tell stories, create usable ontologies, and support networks. Each of these value propositions is discussed and several heuristics are proposed that may help emerging data sharing efforts have more value for those who serve engineering education in a policy role. The paper concludes by exploring the larger question of data at scale, the need to connect data across scales, and the philosophical issues that underlie any future attempts to share data.

Key words: higher education policy, data sharing, program evaluation, heuristics, value proposition

INTRODUCTION

"...the America we have taken for granted for more than a generation is changing. Our society is changing: More people are old, fewer are young, more come from minority groups. Our industry is changing: We are not the world economic leader we were for so long, but a competitor with other industrial nations. Our education system is changing: Although our colleges and universities are the envy of the world, they are becoming more and more dependent on foreign students and faculty. Our precollege education system has reached a crisis state in which U.S.

students are no longer competitive with those in other industrialized countries. Our present scientific and engineering workforce-the foundation for U.S. technological, economic, and military leadership is eroding due to retirements and declining student interest."

The above quote is drawn from a national level report on engineering education. From the content can you determine how many years ago the report was published? While the answer to this question is obviously trivia, it is not irrelevant to the larger question of data sharing. Such quotes are often used justify requests for engineering education funding, and researchers often cite such reports to highlight the potential impact of their work. Such reports, however, are generally not written exclusively for engineering education researchers, but also for policy makers with the purpose of informing policy decisions.

Policy differs from research in important ways. While research frames and answers questions, policy is used to guide decisions to achieve "better" outcomes than might otherwise occur. Success in research comes from framing questions in a sufficiently narrow way such that they can be definitively answered using data. Policy decisions on the other hand, particularly those at upper levels of government, are used to make uncertain choices across very broad domains. Despite these differences, however, there are close relationships between research and policy. Research impacts policy since the understanding gained through research, particularly policy-focused research, can lead to better outcomes. Policy similarly impacts research through influencing agency budgets, which in turn impact research priorities. These relationships are not simple (Stephan 2012). Although the results of research can impact policy, policy makers' breadth of purview means that decisions are greatly affected by which sources of information policy makers access, how that information is framed, and how trusted the source of information is. Thus a purpose of reports like the one quoted above is to frame information in a way that is vital, trusted and accessible.

Bruner, building upon Vygotsky, identifies two modes of cognitive function, rational and narrative, and claims that we make sense of lived reality through stories as much as reason. Each mode has its own logic that implies causality but while rational modes require proof, narrative modes are based on likeliness, alignment with one's past experience, situatedness, and connection to others. Bruner argues that we construct stories about alternative realities in an ongoing, recursive process that leads to valid, generalized abstractions about the world (Bruner 1987). Policy decisions are uncertain and have human consequences, and thus are based on both rational and narrative modes of understanding. In other words, policy is informed by stories, particularly compelling human stories based on believable logic models that show an impact on issues important to policy makers such as jobs, economic growth, or security. Thus reports like the one quoted above often use a tone of crisis as a literary device to help make the story more compelling (Lucena 2005). Both rational and narrative modes are important; while stories can sway policy decisions, research and data help sus-

tain policies by proving or disproving their effectiveness. This paper explores interrelations between policy and research, the role of data sharing in data-driven evaluation of funding programs, and how data sharing can help the engineering education community tell compelling stories.

DATA SHARING FROM A PROGRAM OFFICER'S PERSPECTIVE

There are many possible perspectives on the relative value of data sharing. In this paper I share one viewpoint developed during the time I served as an NSF program officer responsible for funding engineering education research, from summer 2010 to winter 2012. The writing in this article will purposely adopt a first person perspective to make clear that I am expressing my own views, not those of NSF or other program officers.

The experience of being a program officer was in many ways transformative, and looking back it is clear I entered NSF with many misconceptions about what my job was to be. My naivety is not surprising since in hindsight there is not widespread understanding among many of those who apply to NSF for funding about the larger policy roles NSF plays. Like many others I viewed NSF primarily as an academic funding source whose main role was rating and funding proposals, and did not really appreciate the relationship between funding programs and larger policy goals. For this reason much of my time at NSF was spent learning the multi-dimensional role that program officers play in the larger research ecosystem. To frame the discussion of data sharing, it is first necessary to explain some of the day to day responsibilities of a program officer and my growing sense of the differences and similarities between my academic and policy lives. The goal of this section is to allow a reader to partially step into the role of a program officer to better understand how data sharing might impact how program officers manage their funding programs.

The interaction most researchers have with program officers (POs) is through the grant funding and management process. NSF, however, is a federally funded government agency with a congressionally defined mission: "*To promote the progress of science; to advance the national health, prosperity, and welfare; to secure the national defense....*" The legislation that authorizes and funds NSF supports other activities relevant to data sharing that include (National Science Foundation 2014):

- *Evaluate the status and needs of the various sciences and engineering and take into consideration the results of this evaluation in correlating our research and educational programs with other federal and non-federal programs,*
- *Provide a central clearinghouse for the collection, interpretation and analysis of data on scientific and technical resources in the United States, and provide a source of information for policy formulation by other federal agencies.*

- *Recommend and encourage the pursuit of national policies for the promotion of basic research and education in the sciences and engineering.*

While making funding decisions and managing awards remained a large part of my day-to-day activities, as time went on this role shrank as a relative fraction of my responsibilities. The growing role was to serve as an interface between national needs and a research community.

Information needs to flow in two directions across the policy-research interface. In communicating *to* potential PIs in the research community it was important to ensure my funding programs aligned with both emerging policy directions and the research being conducted in engineering education. Such alignment is most commonly articulated through program descriptions and program solicitations. Since NSF can only be as successful as the research it supports, an important aspect of my job was developing funding opportunities that both aligned with policy goals and attracted potentially transformative research ideas. To maintain program funding, however, information needs to flow *from* researchers to policy makers as well. In this role a program officer serves as a proxy who draws upon expertise from researchers to explain how federally funded research in their program contributes to larger national needs by reporting (usually indirectly) to the Office of Management and Budget (OMB) and Congress. Here "contribute" implies not just answering needs, but also helping to articulate them; this is an important point. Clearly articulating needs cannot be done by a program officer alone; it is a responsibility that must also be shared by a research community through, at a minimum, clearly expressing the broader impacts research can have. In my limited experience PIs who are successful over the span of a career seek to understand how to align their research, particularly the broad impacts that the research can have, with constantly shifting national priorities in ways that go beyond simply quoting *Rising Above the Gathering Storm* (Committee on Prospering in the Global Economy of the 21st Century 2006). Articulating national needs is neither simple to do nor is there consensus on what needs are. For this reason policy intersects with politics; while politics is beyond the scope of this paper it is a reality successful research communities must manage.

The role of a program officer is more than making and declining awards. It includes developing funding programs, marketing the program both within and external to NSF, collaborating across divisions and directorates by serving on interdisciplinary working groups, answering queries about the program from other government entities in the executive or legislative branches, and through these tasks assisting in making policy decisions.

DATA SHARING WILL BECOME MORE IMPORTANT AS ACCOUNTABILITY INCREASES

A good analogy for my former role as a program officer is an investment manager who is tasked with maximizing the return on investment to clients, in this case the American public. Of course

measuring the return on research investments is still challenging (Stephan 2012). Over the last decades there have been slow but steady changes in how the long-term payoffs of Federal investments are determined. Recently the shift has been from performance measurement—identifying outcomes and tracking progress towards those outcomes—to program evaluation that compares the outcomes of the program with similar alternatives or even taking no action (Office of Management and Budget 2014). The Office of Management and Budget increasingly asks Federal agencies to evaluate the effectiveness of their programs. As a recent White House memo stated (Zients 2012), "*Grant-making agencies should demonstrate that, between FY 2013 and FY 2014, they are increasing the use of evidence in formula and competitive programs.*" Such top-down pressure causes programs to increasingly assess and evaluate their effectiveness and develop theories of change or logic models that articulate recognizable benefits. These policy changes eventually find their way down to PIs who are asked to share data or better clarify the broad impacts of their research. Policy changes have impact outside of government as well, and affect many aspects of one's life. A controversial example, which has been criticized for lack of context, is the Department of Education's College Scorecard (Department of Education 2014) that tracks measures of university performance.

Clearly evaluating policies and programs can provide multiple benefits, from better allocation of scarce resources within agencies to answering questions such as "how does _____ create jobs in my district" in the political sphere. However there are some limitations to program evaluation. OMB is cognizant that good evaluation is resource intensive, so recent budgets provide resources for evaluation (Burwell et al. 2013) that must be reallocated from other sources. Additionally you can only evaluate what you look for, so too much focus on evaluation potentially limits innovation. Multi-tiered models that invest both in proven interventions as well as more speculative ideas are promoted by OMB (Office of Management and Budget 2014). A more subtle criticism is that evaluation often depends upon linear logic models or theories of change which may be inaccurate for nuanced and complex systems like education where small changes in context can make large differences in outcomes (Tough 2013). In agencies like NSF that are not as mission oriented as, for example, NASA or DoD, such models have significant limitations. For example, the return on investments in education is not isolated from other Federal programs. Academic opportunities increasingly depend on socio-economic status and experiences in early childhood, which in turn depend on programs such as Head Start and decades-old policy choices about social vs. military spending. Because no single evaluation program can provide the breadth of data needed for policy decisions, evidence framed so as to be widely understandable that is backed by a compelling story is highly valued.

It is a truism to state that political values and ideologies change over time. Over the last decade public dialog around higher education has increasingly been framed negatively, leading to a perception that

investments in higher education are ineffective[1]. One impact of such perceptions was that my time at NSF was increasingly spent evaluating my portfolio of awards (many of which were made by my predecessors) to accurately represent the overall impacts to higher level policy makers. Claiming impact is difficult. The standard of proof and the consequences of providing incorrect or misleading information are different in the government than in academia. Information is generally verified in a more hierarchical fashion than academic peer review. Similarly while academics have little incentive and few channels to publish negative results, the more procedural approaches in government seek to capture such data. At NSF, as in any organization, evaluation that confirms conventional wisdom is more easily accepted.

ISSUES AND TENSIONS OF DATA SHARING

The above discussion of the Federal research funding side of engineering education, based upon my admittedly limited experience as an NSF program officer, illustrates how access to data is useful to program officers. The extent to which a research community transparently shares data funded by research awards will impact a program director's ability to evaluate the impact of their program or enable other individuals or agencies to perform such evaluations.

Before discussing potential benefits and problems related to data sharing, it is important to clarify what is meant by data. Since a major function of government is to make laws, there is generally great care taken with the use of language so that data has, for the purposes of NSF, an operational definition:

"… the recorded factual material commonly accepted in the scientific community as necessary to validate research findings, but not any of the following: preliminary analyses, drafts of scientific papers, plans for future research, peer reviews, or communications with colleagues. This 'recorded' material excludes physical objects (e.g., laboratory samples). Research data also do not include:

(A) Trade secrets, commercial information, materials necessary to be held confidential by a researcher until they are published, or similar information which is protected under law; and

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1 Ideologies span the political spectrum and values are often influenced by ideas in circulation at any moment. A historical example is the Powell memo (Powell 1971) which influenced efforts to bring more free market ideologies into higher education (Demarrais 2006). More recent examples focus on rising costs (Kirshstein and Wellman 2012) and the idea of "disruption" which has entered higher education from business (Christensen et al. 2011) and is widely quoted despite recent critiques (LePore 2014). See also Peter Brooks' commentary on, and review of, recent books painting higher education in crisis. (Brooks 2011)

(B) Personnel and medical information and similar information the disclosure of which would
constitute a clearly unwarranted invasion of personal privacy, such that could be used to
identify a particular person in a research study." (Office of Management and Budget 1999)

While OMB provides the broad definition above, for this paper data can be succinctly defined as the information that emerges from a research study which is deemed to be true, important, and that has no legitimate reason for not being shared. The term "data" includes metadata that explains how the data was collected since the value of data itself depends upon an understanding of the context in which the data was generated. In engineering education this context is critical yet difficult to characterize.

While NSF began to require a plan for data sharing as a two page addendum to proposals that would be rated as part of the intellectual merit in January 2011, various constraints make this policy difficult to implement. Since Federal agencies are required to follow the Government Performance Results Act (GPRA) which mandates efficient operation, NSF's Grant Proposal Guide indicates that data sharing should not incur "...more than incremental cost...". The question of how meaningful data sharing can be managed with only incremental cost remains unanswered. There remain ontological uncertainties with what constitutes data and metadata—notwithstanding OMB definitions—that need to be resolved within each discipline; recent work on ontologies by Cynthia Finelli (Finelli and Borrego 2014) and others may help in engineering education. There are additionally important ethical questions that arise at the interface of technology and privacy, regulatory and legal issues such as the Family Educational Rights and Privacy Act, the fact that IRB processes vary between institutions, and issues of the potential liability of researchers and institutions who share data that is used for unintended purposes. What "data" is varies greatly across the disciplines supported by NSF. Practices that work in particle physics—where sharing raw data can allow external validation and review of results or even new discoveries—may not work in engineering education.

USING VALUE PROPOSITIONS AND HEURISTICS TO NAVIGATE ISSUES

In my opinion, these real constraints mean that data sharing will not occur in a meaningful way if viewed by a research community as a Federal mandate. Furthermore, I consider it unlikely that a widely-accepted model that is effective for engineering education will be developed by NSF or another government agency. Given the need to develop best practices in data sharing that cover the wide spectrum of engineering education research approaches it will further be difficult, if not impossible, to frame data sharing in a rigorous or deontological way. For these reasons I adopt a value framework in exploring data sharing (Carlson and Wilmot 2006). Value can be roughly defined as the ratio of

the benefit to the cost, so from the value perspective the benefits of data sharing must be greater than the cost for multiple stakeholders including researchers, universities, and funding agencies. The intent of defining value is not to propose an exact economic calculus; both "benefit" and "cost" include intangibles. Rather it is to identify ways in which data sharing could create value and develop particular value propositions for data sharing guided, where possible, by actionable heuristics.

The value of data sharing means different things to different organizations. Different sectors of the engineering education ecosystem—Federal agencies, large schools with significant resources, and small schools with more limited resources—will have different value propositions. Furthermore given the breadth of research approaches in the engineering education community, data sharing likely has very different connotations to researchers from different traditions. Since it is not possible to represent all viewpoints I take the stance of an NSF program officer; my stance might be different in my role as a researcher, as department chair, or even had I served in the Education and Human Resources rather than the Engineering Directorate within NSF. In the remainder of the paper I discuss three ways that data sharing could potentially have created value to me as an NSF program officer. From this perspective I will try to identify both benefits—e.g. understanding how NSF funding has increased the connectivity of PI networks—as well as costs such as program funds, time, or bureaucratic red tape. I will skip over the obvious ways shared data can improve the proposal review process such as finding panelists or judging the merits of a proposal since while these are important, they are lesser concerns in the larger realms of policy.

Value Proposition #1: Help Tell Stories

The first value proposition is that data sharing can better enable a program officer to tell sequential, ideally causal, stories about the impact of their program on the larger engineering education system. Here the word "system" is used in the integrative, rather than reductionist, sense to capture the combination of people, programs, and institutions that support and credential engineering learning. Such stories, where small investments lay the groundwork for long-term changes, are critical to explain the impact of research programs given the relatively small role NSF funding plays in the education system. In 2013 state funding for higher education varied from about $360M in Vermont to $14B in California with a median of about $1.8B (Staff of the State Higher Education Executive Officers 2013). Amounts are given in US Dollars with M = million, B = billion, and T = trillion. Funding from all states totaled about $130B. Additionally the top 800+ universities managed endowments of approximately $400B in 2013 (Finance: Almanac 2013 2013). If one calculates the annual revenue from tuition of engineering undergraduate students in the US, the total comes to about $10B (Cheville 2012). In comparison NSF's EHR Directorate was funded at about $830M in FY2013 with the Engineering Education & Centers Division in the ENG Directorate at about $115M, of which a large part went

to Engineering Research Centers. The 2011 Committee on STEM report found that in 2010 $1.1T or about 8% of GDP went to education overall. About 40% of this education spending was in the post-secondary sector of which agencies such as NSF contributed 0.2% (Committee on STEM Education 2011). Given these dollar values any one award can have miniscule direct impact on measures that policy makers care about—jobs, competitiveness, economic growth, or the number of engineering graduates. For this reason funding programs attempt to create synergy between awards such that incremental advances build upon each other. NSF funding is the seed which must be nourished by other funding sources to grow to a level that can impact policy decisions.

The costs of data sharing are in setting up a system to turn data into knowledge, researchers' time, and creating a culture within the community that values building a coherent body of knowledge. The way the system was set up would dictate to a large extent the cost of creating actionable insights from the data. The benefits if data sharing were widely adopted in a way that data provenance was meaningfully addressed *and* resources were available to draw stories from this data would be to help program officers tell the story of how awards in their portfolio seeded larger efforts. While annual progress reports and PI-submitted highlights are intended to capture such impacts, generally reporting ends with the award period before results can achieve wide impact (Stephan 2012). Furthermore award-centric stories may fail to capture connections between investments. Bibliometric research techniques primarily capture publications and miss other impacts that are important to policy makers. Newer techniques such as *altimetrics* (Priem, Groth, and Taraborelli) are seeking to capture other measures such as mentions in social media, but their limits and veracity are still being tested (c.f. *Information Science Quarterly*, vol. 25, issue 2). It is worth mentioning that much knowledge of how the findings of many small projects compound over time currently resides in the institutional memory of career program officers who often have strong social networks in policy circles. When such career program officers retire or move to other research programs it can have a long-term effect on a field. Should the institutional culture at NSF change in a way that impacts the long term retention of program officers, the effects could be far reaching.

In summary the first value proposition for data sharing is to be able to better connect how what was learned in one NSF project influenced other efforts—publications, proposals, internally funded reform initiatives—over a period of decades. Heuristics for a data sharing effort that would support story telling include capturing NSF award numbers, capturing why data was collected, and developing capacity for users of data to explain how drawing on previous results led to new insights or collaborations. Policy is driven in part by data and the stories that emerge from analyzing that data[2]. If

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2 This paper does not assert that data and stories are the only influence on policy decisions. Policy is driven by factors such as public opinion, economic conditions, and interest groups as well as networks and relationships (Marsh and Smith 2000). Data plays a role in supporting these factors however, and can influence policy either for good—e.g. data on highway fatalities influencing transportation safety—or for ill as Robert McNamara's emphasis on body counts in the Vietnam War shows.

engineering education is to meaningfully share data, it is worth considering up front ways that make it easier for such stories to be written. A related effort is developing new ways of representing data that can help brand engineering education in a way the goals of the research community can be consistently messaged to policy makers.

Value Proposition #2: Ontologies and Grand Challenges

The second value proposition is that by learning how to share data and debating what constitutes "data", engineering educators will become better at developing more consistent terminology and begin to self-organize around a set of important problems. This is clearly a second order effect, and I am admittedly optimistic to believe data sharing will result in this outcome. However my experience in managing a relatively small funding program is that developing a consistent vocabulary, precision in underlying concepts, and clear goals are becoming increasingly important to sustain Federal invest-ments. In the current political climate of trimming government spending it is important for programs to clearly articulate both how they align with national priorities and differ from similar efforts. Re-member that policy is a process used to guide decisions to achieve "better" (from some perspective) outcomes than would otherwise occur , and the appearance of redundancy is carefully scrutinized. The costs arise from the effort needed to develop more conceptually precise definitions and terminology.

A recent example of how high level policy decisions can affect funding programs and the re-search communities they support is the Committee on STEM (CoSTEM) report from the Office of Science and Technology Policy (OSTP) in the White House (Committee on STEM Education 2011). The report was the result of a cross-agency survey of STEM education funding and led to the re-lease of a strategic plan in 2012 (Federal Coordination in STEM Education Task Force- Committee on STEM Education 2012). The plan is too comprehensive to discuss in detail, but a major theme is coordinating STEM education investments across the government. The strategic plan focuses heav-ily on evaluation, common metrics, milestones, and synthesizing practices. Four "Strategic Federal Coordination Objectives" were developed:

- Use evidence-based approaches.
- Identify and share evidence-based approaches.
- Increase efficiency and coherence.
- Identify and focus on priority areas.

To achieve these objectives agencies are expected to develop roadmaps—hopefully in conjunction with research communities—to address the priority areas. Note that the espoused values of such reports do not always align with what is enacted in the policy realm.

The process of implementing data sharing and the discussions exemplified by this special edi-tion can enhance the ability of engineering education to share ideas. In considering the merits and

disadvantages of data sharing it is important to ask what distinguishes engineering education from the rest of the STEM ecosystem, and what priority goals can our community agree upon? These are contentious questions, but the needs identified by policymakers are only as good as the information they receive. As an example relevant to engineering education one of the priority areas stemming from the fourth coordination objective is improving retention of students in the first two years in undergraduate STEM education. There is some evidence that in engineering getting students to transfer in to the major is a larger issue than retention (Atman et al. 2010); this is an example of how research might be used to inform changes to existing policies.

The second value proposition is that the act of creating meaningful ways to share data in itself creates value. One heuristic for data sharing is to develop a clear and simple language and a set of organizing ideas. A second heuristic is to support discussions on what constitutes valid data in engineering education, how data is tagged, and what minimal set of metadata is needed for context. There is increasing use of data mining tools within NSF to understand investments within a program, across divisions, directorates, and all of NSF. It is easier for a program officer, or their proxy, to use these tools to extract meaningful insights when a research community agrees on what constitutes data and uses consistent terminology. Thus a third heuristic is to design data sharing in a way that users are able to easily perform queries that can inform policy-relevant questions.

Value Proposition #3: Creating Networks of Researchers

The author Parker Palmer shares a story about a government employee at the Bureau of Land Management who came to one of his retreats conflicted about his career (Palmer 2004). A new political appointee was pushing policies that the man believed undermined BLM's mission, and this created stress. In the silent space created at the retreat the man realized his conflicted state arose because he was not sure who he served. When he realized that regardless of whom he worked for he ultimately served the land, the conflict evaporated. This question of who I served was one that was much on my mind as a program officer, and one that I never fully resolved. Clearly while improving engineering education serves national policy needs, the field cannot advance without the efforts of many individuals whose careers are greatly impacted by NSF funding decisions. With the increasing emphasis on evaluating the products produced by funding programs, it is important not to overlook the role that such programs play in the development of new, and support of established, researchers. The impact of grants includes people, particularly graduate students and young faculty, as well as publications and insights. There is a clear long-term benefit that arises from a networked, cooperative community of PIs focused on a set of problems that is diverse enough to generate new insights yet coherent enough to articulate the impact it is having on national needs. Engineering education draws from at least two disciplines—engineering and education—that have

different cultures; the community is developing its own theories, norms, and values and needs to be supported in these efforts.

Thus the third value proposition is that data sharing can create a better networked engineering education community. Depending on how data sharing systems are implemented, it is not just the results of research that are shared, but also knowledge of who knows what and how they came to develop that expertise. Given the breadth of a program officer's purview, this information is of great value to determine emerging areas, whether a community is sizable enough that a new funding program is needed, or simply to suggest collaborations to visiting PIs.

A heuristic in designing data sharing is to make any system people- as well as data-centered. While privacy concerns limit adoption in the US, research reporting systems in some countries specifically have adopted a researcher-based focus. An example is the LATTES system in Brazil (Pacheco 2012). LATTES is managed by the Brazilian science funding agency, the Brazilian National Council for Scientific and Technological Development (CNPq). Anyone who receives funding from CNPq, including students funded by an award, must have a CV on file in the LATTES system and update their CV annually. Once CVs are integrated into the LATTES database, they can be widely accessed and searched which provides value to researchers seeking to establish collaborations. Since LATTES was designed with the intent of supporting research collaborations, it also supports a database of research groups. While it is still an open question of how best to evaluate the impacts of investments in research, there are significant efforts underway in many countries to improve the science of science policy (Lane 2009). LATTES is one model that collects data from CVs and thus is organized around individuals in the research community. The similar effort in the US, STAR METRICS (U. S. Department of Health and Human Services 2014), uses research awards as the central unit of analysis. It will be interesting to see how each system evolves.

FUTURE WORK ON METHODOLOGICAL APPROACHES

One of the questions that frame the issue of data sharing in engineering education is whether new methodological approaches are needed for handling data at scale. The question as it is phrased implies that there is need to handle data at large scales and that if new methods were to be developed some value would emerge from them. I would like to reframe this question by challenging the concept of scale. In engineering education "large scale" might be defined in terms of understanding the system that educates future engineers. The number of engineering undergraduates entering and leaving US universities in any given year is on the order of 10^5 at roughly 10^3 institutions. Including

technical programs at 2 year colleges adds a similar amount (Cheville 2012). In terms of research, the annual number of engineering education publications is likely on the order of 10^2–10^4, depending on how one defines research. In terms of actual numbers these are not particularly large compared to the 3×10^9 human DNA base pairs or 10^9 Tweets per week generated by Twitter users.

The issue in engineering education is not the scale of data but that making sense from the data depends on local contexts and environments that are best understood through more qualitative techniques. Because creating large scale data generally requires some form of aggregation which removes these critical local variations, the problem I saw as a program officer was not the size of the dataset, but rather how to meaningfully connect data *across scales* of the education system. This is roughly illustrated in Figure 1. At the finest granularity, i.e. most central level, are individual students that can be aggregated to provide data on retention or graduation rate. As discussed previously, Federal funding is not sufficient to affect a sufficient number of students to significantly impact these numbers. However, students are affected by more coarse grained elements of the system such as what is taught (content), how it is taught (pedagogy), and the overall learning environment (education system) where ideas from research can ideally impact practice. The arrow illustrates that one further has to choose between certainty of impact or investing at scale. In other words investing in people, for example by providing scholarships or supporting REU programs, has high probability of impact but is not scalable to the entire education system. That is not to say these programs are ineffective; people are not ants and individuals can do great good in the world. More systemic investments, e.g. researching learning, have the potential to impact the system as a

Figure 1. Illustration of different scales of the education system.
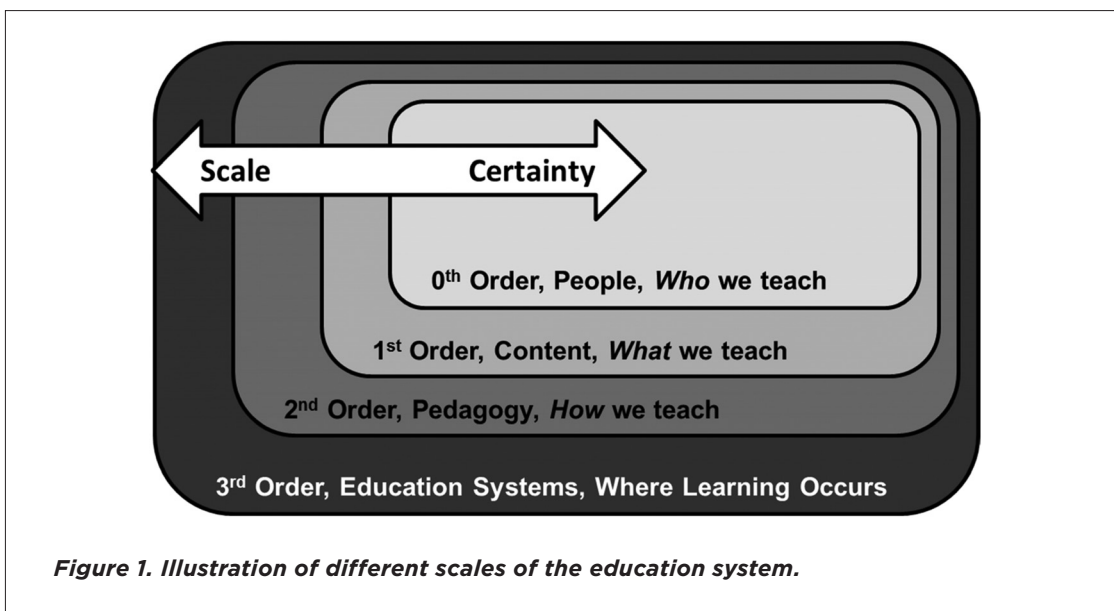
whole, but impact is not as certain and thus much more difficult to evaluate. There is a critical need in engineering education to develop techniques that help understand the system as a whole, i.e. connect rich, local qualitative data with large scale quantitative data. While some initial efforts are underway (Lemke and Sabelli 2008) more work is needed.

There are other, more subtle issues related to large scale data. One is that heavily investing in capabilities to explore large scale data may trigger an inverse form of the "law of small numbers" fallacy and lead to a belief that large population trends are representative of individuals. While questions of overall number are important to policy makers, the benefits of education accrue both to society and to individuals. These benefits are inextricably linked and not easily separable. One cannot lose sight of the individual because ultimately it is individuals who are educated and who collectively make up society. Furthermore because a few individuals can have a collective effect on the education system focusing only on large scales makes it is possible to overlook important impacts of investments.

A second issue that arises from such individual-collective tensions is related to what student data informs policy decisions. In other words, if researchers are not extremely careful about clarifying which groups of students give rise to trends in large scale data sets then some groups may be adversely affected by policy decisions. Jaron Lanier in *Who Owns the Future* explored issues of who owns the rights to data drawn from an ensemble of individuals and suggested an economic model of micropayments when data is used (Lanier 2013). A micropayment model is likely not feasible for engineering education but the questions Lanier raises are relevant to metadata, privacy, and the importance of maintaining sight of one individual in large data sets.

PARTING THOUGHTS

It is important to realize that data sharing is not an end in itself, but a means to an end. Much data is already shared; the current reality is that all entities in the public and private sectors are increasingly using sophisticated tools to analyze large data sets to further their missions. Thus I believe the question is not whether we should or should not share data, or how such data sharing should occur, but how data sharing can best serve the greater good or what end shared data should advance? The question of the greater good is clearly a philosophical one, but one that I maintain is becoming increasingly important for engineering education.

To close the loose end that began this paper, the quote at the beginning of this article came from a report given to me by an NSF colleague entitled "*Changing America: The New Face of Science and Engineering*" published about a quarter century ago, in 1988 (The Task Force on

Women 1989). If the quote seems relevant today, if we are addressing the same policy issues as we were a quarter century ago, then a conversation about ends, about what greater good we are working towards, is likely in order. Obtaining one's own definition of the greater good is not something borrowed from policy reports but rather developed by a lifetime of questioning our underlying assumptions and schemas. Data sharing is one way to help us, as a community, learn to ask the right questions. The questions we ask and the answers we obtain can inform the policy decisions that affect our community. But these insights need to be supported by data that also gives us insights into the complex workings of the education system in a way that does not lose sight of the individual.

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REFERENCES

Atman, C. J., S. D. Sheppard, J. Turns, R. S. Adams, L. N. Fleming, R Stevens, R. A. Streveler, K. A. Smith, R. L. Miller, L. J. Leifer, K. Yasuhara, and D. Lund 2010. Enabling Engineering Student Success: The Final Report for the Center for the Advancement of Engineering Education. San Rafael, CA.

Brooks, Peter. 2011. Our Universities: How Bad? How Good? *The New York Review of Books*.

Bruner, J. 1987. *Actual Minds, Possible Worlds*. Cambridge, MA: Harvard University Press.

Burwell, S. M., C. Munoz, J. Holdren, and A. Krueger. 2013. Next Steps in the Evidence and Innovation Agenda. edited by Office of Management and Budget. Washington, DC.

Carlson, C. R., and W. W. Wilmot. 2006. *Innovation: The Five Disciplines for Creating What Customers Want*. New York: Crown Business.

Cheville, R. A. 2012. "Engineering Education Today: Capturing the Afterlife of Sisyphus in Five Snapshots " *Proceedings of the IEEE* no. 100:1361–1375.

Christensen, C. M, M. B. Horn, L. Caldera, and L. Soares. 2011. Disrupting College: How Disruptive Innovation Can Deliver Quality and Affordability to Postsecondary Education. Center for American Progress and Innosight Institute.

Committee on Prospering in the Global Economy of the 21st Century. 2006. Rising Above The Gathering Storm: Energizing and Employing America for a Brighter Economic Future. Washington, DC: National Academy of Sciences, National Academy of Engineering, Institute of Medicine.

Committee on STEM Education. 2011. The Federal Science, Technology, Engineering, and Mathematics (STEM) Education Portfolio: A Report from the Federal Inventory of STEM Education Fast-Track Action Committee Committee on STEM Education. edited by National Science and Technology Council. Washington, DC.

Demarrais, K. 2006. ""The Haves and the Have Mores": Fueling a Conservative Ideological War on Public Education (or Tracking the Money)." *Educational Studies* no. 39:201–240.

Department of Education. 2014. College Scorecard. edited by Department of Education. Washington, DC.

Federal Coordination in STEM Education Task Force- Committee on STEM Education. 2012. Coordinating Federal Science, Technology, Engineering, and Mathematics (STEM) Education Investments: Progress Report. edited by National Science and Technology Council. Washington, DC.

Finance: Almanac 2013. 2013. Almanac of Higher Education 2013 Washington, DC: The Chronicle of Higher Education.

Finelli, C. J., and M. Borrego. 2014. An inclusive process for developing a taxonomy of keywords for engineering education research. Paper read at American Society for Engineering Education Annual Conference and Exhibition, at Indianapolis, IN.

Kirshstein, Rita J., and Jane V. Wellman. 2012. Technology and the broken higher education cost model- insights from the Delta Cost Project. *EDUCAUSE Review*.

Lane, J. 2009. "Assessing the Impact of Science Funding." *Science* no. 324 (5932):1273–1275.

Lanier, J. 2013. *Who Owns the Future?* New York: Simon & Schuster.

Lemke, J. L., and Sabelli N. J. 2008. "Complex Systems and Educational Change: Towards a new research agenda." *Educational Philosophy and Theory* no. 40 (1):118–129.

LePore, J. 2014. The Disruption Machine. *The New Yorker*, June 23.

Lewis F. Powell, Jr. 2015. *The Powell Memo (also known as the Powell Manifesto)* 1971 [cited April 2015]. Available from http://reclaimdemocracy.org/powell_memo_lewis/.

Lucena, J. C. 2005. *Defending the Nation- US Policymaking to create scientists and engineers from Sputnik to the 'war against terrorism'*. Lanham, MC: University Press of America.

Marsh, D., and M. Smith. 2000. "Understanding Policy Networks: towards a Dialectical Approach." *Political Studies* no. 48:4–21.

National Science Foundation. 2014. *NSF at a Glance* [cited June 2014]. Available from http://www.nsf.gov/about/glance.jsp.

Office of Management and Budget. 1999. OMB Circular A110. edited by Office of Management and Budget. Washington, DC.

Office of Management and Budget. 2014. Analytical Perspectives, Fiscal Year 2014 Budget of the U.S. Government. Washington, DC: Office of Management and Budget.

Pacheco, R. C. S. 2012. The role of Lattes Platform in the Brazilian Innovation System. Available from: http://nano.gov/sites/default/files/cavalheiro.pdf

Palmer, P. J. 2004. *A Hidden Wholeness: The Journey Toward an Undivided Life*. San Francisco: Jossey-Bass.

Priem, J., P. Groth, and D. Taraborelli. "The Altmetrics Collection." *PLOS One* no. 7 (11):e48753.

Staff of the State Higher Education Executive Officers. 2013. State Higher Education Finance 2013. Boulder, CO: State Higher Education Executive Officers Association.

Stephan, P. 2012. *How Economics Shapes Science*. Boston, MA: Harvard University Press.

The Task Force on Women, Minorities, and the Handicapped in Science and Technology,. 1989. Changing America: The New Face of Science and Engineering Washington, DC.

Tough, P. 2013. *How Children Succeed: Grit, Curiosity, and the Hidden Power of Character*. New York: Houghton Mifflin Harcourt.

U.S. Department of Health and Human Services. 2014. *Science and Technology for America's Reinvestment: Measuring the Effect of Research on Innovation, Competitiveness and Science*. National Institutes of Health 2014 [cited June, 1 2014]. Available from https://www.starmetrics.nih.gov/.

Zients, J. D. 2012. Use of Evidence and Evaluation in the 2014 Budget,. edited by Executive Office of the President. Washington, DC.

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