Ecosystems as Analogies for Engineering Education

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Abstract
This poster is based on the results of a 2015 workshop for engineering educators, policy makers, engineering industry representatives, and funders of engineering education. In this workshop participants sought to develop a preliminary map of an engineering education ecosystem to better foster communication of needs and goals across "ecological niches" within the larger sphere of engineering education. Participants jointly developed a map of the ecosystem based on first, second, and (indirectly) third order interdependencies of themselves with other niches in the imagined ecosystem as well as identified "keystone species" that transcend different ecological niches.

This poster will present the overall ecosystem map as derived from participant feedback as well as discuss findings that highlight how to maintain the overall health and resilience of the ecosystem. Particular strengths and weaknesses of the ecosystem analogy will be presented along with heuristics for engineering educator who wish to better communicate with those elsewhere in the larger sphere of engineering education.

Background

> *"And while innovation takes many forms, a series of economic studies over the years has shown that between 50 and 85 percent of the growth in U.S. GDP is attributable to advancements in science and technology. This despite the fact that less than 5 percent of the U.S. workforce is composed of scientists and engineers, thereby suggesting that each one percent of the workforce engaged in those professions accounts for something like 15 percent of the growth in GDP. A truly remarkable multiplier."*
> - Norm Augustine (Augustine, 2013)

In Spring 2015 a workshop was held at the National Academy of Engineering designed to build capacity for the engineering education research community to better communicate with a broad spectrum of policy makers. The underlying hypothesis is that despite the impact how engineers are educated has on national priorities, researchers in engineering education do not always often effectively communicate the larger contexts and multiplying effects of their work to policy makers. The two-day workshop involved current and emerging leaders in engineering education, some individuals in the community with prior policy experience and representatives from industry, professional societies, foundations, and government. An *a-priori* assumption that underlay the workshop was that given the relative newness of engineering education as a field relatively few researchers have been trained or been able to acquire the needed experience to effectively communicate how the community's work impacts the economy and society to policy makers. It was hypothesized that by explicitly addressing the need for such communication upfront with selected community leaders, it would help build capacity within the community for more effective communication.

The relevance of this workshop was due to the growth trajectory of the engineering education research community. Over the last two decades, following NSF funding of the engineering education coalitions and the research networks these awards created, there has been substantial growth of research that supports a scholarly approach to engineering education. As engineering education research has moved from a side-pursuit of a few pioneers to a more mainstream research activity, PhD programs have been founded whose newly-minted graduates are finding academic positions in universities across the country. These graduates are pursuing their own research in engineering education thanks in part to NSF's support of CAREER awards that work to further the ambitions and success of new researchers. Clearly the relatively small investments made by NSF in engineering education have given birth to what is becoming a well-established research community.

Although the engineering education research (**EER**) community is growing and becoming more established, it still relies heavily on Federal sources, primarily NSF, to support much of its activities. Thus like all other disciplines, EER is affected by the relatively flat Federal funding for research in recent years. Since policy makers are continually making choices between how to balance funding between competing needs, it is important for this emerging field to build the capacity to clearly articulate how their work impacts the creation of new engineers and how engineering education research improves the education of those who pursue engineering degrees. As the above quote from Norm Augustine illustrates, scientists and engineers play a remarkably important role in the economy and thus job growth. The arguments for investing in improvements in how we educate engineers are more than merely economic, however. Although STEM education is most often framed around its extrinsic benefits—e.g. for the economy, security, or technology—being educated as an engineer benefits both the individual and society *regardless* of later career choice. For example, data shows that individual accrue a lifetime financial return on their investment in engineering education (Carnevale, Smith, & Melton, 2011; Taylor et al., 2011). Beyond economic benefits, as recent events have shown there is a need for technically literate citizens which can provide *intrinsic* value to the individual, community, and society. For example there is evidence that people see intrinsic value in their own college education (Taylor et al., 2011) and students value their engineering identity (Atman et al., 2010). The intrinsic value of an engineering education is also based on the fact that the systemic thinking of engineers helps one be a better citizen in a society that relies on complex technologies.

There have been notable successes and milestones in the emergence of the engineering education research community. The community has worked aggressively to create a scholarly venue for publication that emphasizes research in the *Journal of Engineering Education*, held high profile workshops to identify research areas through the NSF funded colloquies in 2005 (Radcliffe, 2006), and has recently begun to focus on understanding how to better impact practice through transitioning research-supported instructional strategies into university classrooms. Despite these necessary steps in creating a sustainable research community, engineering education researchers have not been as organized or cognizant about the need to make the world at large aware of the systemic impact of their work. The community does not always communicate the pivotal role that

they play in the larger social-economic system in which they are embedded and upon which they depend.

The impact of engineering education on the larger system is significant if Dr. Augustine's figures quoted above are correct, as the following back-of-the-envelope calculation illustrates. One can estimate the investment in engineering education by all stakeholders at somewhere around $20B annually based on public and private university tuitions (Cheville, 2012). Given that approximately 100,000 new engineers are created each year (National Science Board, 2012), this is an initial investment of about $200,000 per engineer split between public and private funds. To estimate the economic return of these engineers, one can make a conservative estimate that growth in the $15T US GDP is about 2% annual which means that the US economy is growing by about $300B per year. Using Dr. Augustine's estimate that 50% of growth comes from scientists and engineers and further assuming engineers contribute half of this amount, engineers are then responsible for $75B per year of economic growth. Given that there are approximately 1 million engineers in the workforce (Bureau of Labor Statistics, 2010), each engineer contributes $75,000 annually to economic *growth* over and above the amount they contribute to the economy. Looking at this a different way, each engineer that graduates contributes to creating approximately one new job *every year* over the span of that engineer's career. While this calculation is at best a rough estimate, it does illustrate that relatively small investments in educating engineers may have substantial policy implications.

Despite the likely importance of engineering education on larger issues of national policy, there is much we still don't know about the impact engineering education has on issues like economic growth, security, and human thriving. For example we don't fully understand how the quality or form of engineering education impacts the success of engineers later in their careers. We don't understand how to most effectively target investments within the larger educational system to achieve a given outcome. Nor do we understand how educational environment and pedagogy affect long-term outcomes. Such research and the knowledge it generates should inform policy decisions since these questions are relevant not only to the engineering education research community, but also to universities, Federal agencies, private foundations, and industry.

Given the potential importance of engineering education research on issues of prosperity and security and the current research funding climate, it is important that the EER community realize the impact of their work and inform policy makers of its implications. Rather the dialog is predominately one way, from policy makers to engineering educators through high level policy reports such as *Rising Above the Gathering Storm*. While there have been a significant number of reports from prestigious agencies and organizations over the last century declaring what should be done by engineering educators and how these goals should be accomplished, there has been little visible or organized response from the engineering education community that explains how the recommendations from these reports have been addressed through sustained research. Without such two-way dialog the EER community runs the risk of endlessly repeating the same stale mantras and being steered into addressing problems that may not create meaningful impact.

Workshop Objectives and Process

The first objective of the *Engineering Education and Policy Workshop* was to identify what issues across the engineering education ecosystem inhibit effective communication with policy makers at local, state, and national levels. Since policy decisions and funding for the engineering education ecosystem originates from a variety of public and private entities, individuals from these organizations were represented at the workshop. To allow discussion between representatives of diverse organizations, the workshop adopted the framework of an ecosystem in order to provide a coherent method to discuss/compare different goals. A second objective was to provide training and tools to leaders and emerging leaders in the EER community that increase the capacity to communicate the aims, goals, and needs of the engineering education ecosystem to policy makers at all levels. Expertise was drawn from an individual who had experience in agricultural lobbying to lead a messaging workshop. The third objective was for participants to strategically develop messages, test them on other participants for effectiveness, and refine them to appeal a range of audiences. The workshop provided a venue to test the effectiveness of ecosystem analogies. Only the first goal is substantively discussed here.

Table 1: Biological vs. Organizational Ecosystems

Ecosystem Property	Biological Ecosystems	Organizational Ecosystems
Exhibits properties of emergence	✓	✓
Existence does not imply health, function, and persistence.	✓	✓
Stability dependent on keystone species or actors.	✓	✓
Interaction linked by flows of resources and information	✓	✓
Interactions range widely in outcome (mutualism, commensalism, predation).	✓	✓
Nestedness confers more resiliency.	✓	✓
Specialized and generalized actors or species interact frequently.	✓	✓
Bottom-up interactions drive system.	✓	✓
Top-down interactions drive system.	✗	✓
Planning for the future.	✗	✓
Competition is always harmful.	✓	✗
System structures/innovations can propagate broadly.	✗	✓

Ecosystems are a useful but imperfect analogy for complex social systems as indicated in Table 1. In other words, some elements that describe natural ecosystems are not found in organizational ecosystem and vice versa. During the workshop participants were provided information to better understand the ecosystem analogies used as well as given a basic grounding a grounding in systems thinking. Participants then broke up into small groups to map the engineering education ecosystem then used their maps of the ecosystem to develop messages targeted at particular audiences or

groups. The jigsaw technique was used to separate participants from various organizations so there would be a diversity of perspectives on each working group. Groups were then tasked with determining the inputs and outputs of their portion of the overall ecosystem using the framework shown in Figure 1.
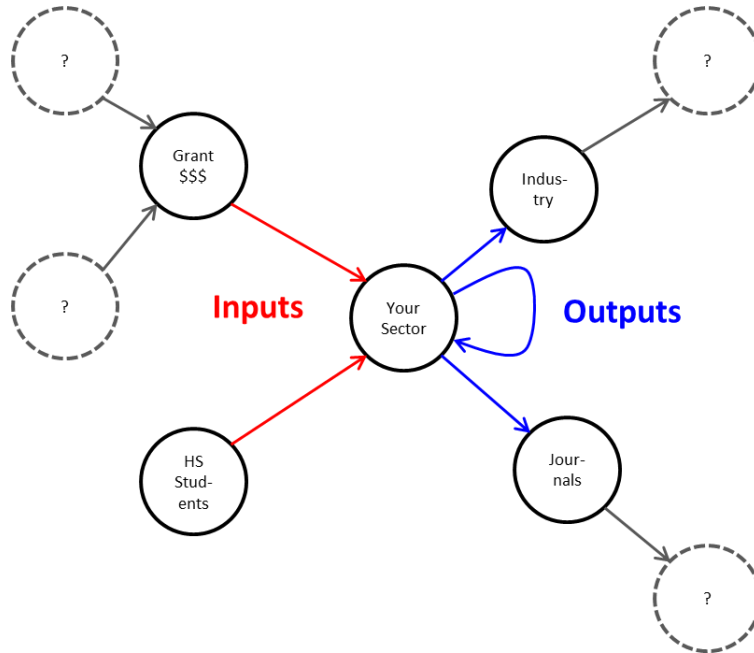
Figure 1: Mapping inputs and outputs of a node of the larger engineering education ecosystem.

In order to capture this data from all participants, each individual filled out the worksheet shown in Figure 2 which was based on elements of Carlson's Need-Approach-Benefit/Cost-Competition (NABC) value proposition framework (Carlson & Wilmot, 2006). Each participant, representing a range of organizations in the larger ecosystem, identified first order (solid lines in Figure 2) and second order (dashed lines in Figure 2) inputs and outputs to their role in the ecosystem. For each input and output they were asked to use the NABC framework to hypothesize the needs of, their approach to working with, and competition for resources for both first and second order connections. Given time constraints these descriptions were somewhat cursory. The NABC framework was used to encourage participants to think not only about the approach they use in their work but how their work addresses another's need and competing approaches, i.e. creates value for others. Participants also identified what resources they needed in order to be effective in their perceived role. The goal of this section of the workshop was to get participants to begin to think directly about their relationships to the other parts of the engineering education ecosystem and recognize alignments or differences between the different sectors of the ecosystem represented at their table.

Following individual work each subgroup collected the results and used individual perspectives to create a map of the engineering education from their groups' perspective. A short report-out allowed each group to present their view of the ecosystem to the entire workshop. Both the individual and group artifacts were collected then captured electronically.
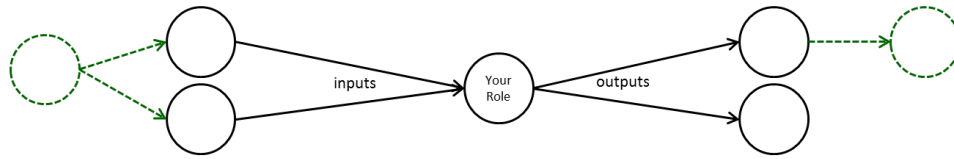
Inputs	Role	Outputs
Needs	Resources needed to be Effective	Needs
Approach		Approach
Competition		Competition

Figure 2: The form shown above was used to collect individual participant's first and second order connections and interactions in the engineering education ecosystem.

Following the development of a larger view of the ecosystem from the report-out which enabled a richer view of the various inter-relationships between areas of the ecosystem, participants were asked to reflect on their relationships with other parts of the ecosystem. The goal of this exercise was to begin to elicit both the types of resources participants needed from others to thrive (inputs) as well how the results of their efforts were utilized by other sectors (outputs). This elicitation was scaffolded using the framework shown in Figure 3. This framework drew from the Crucial Conversations framework (Patterson, Grenny, McMIllan, Switzler, & Roppe, 2012) to identify areas where participants had, and were lacking, resources they might draw from or contribute to other parts of the ecosystem. Messages were then developed for different audiences that were one or two steps removed in the ecosystem that explicitly identified both the message and the channel of communication that was seen to be most effective.

Figure 3: Framework to determine participant roles in the ecosystem.

Participants then worked on refining their messages and comparing and contrasting with other groups by posting them to a sticky wall. To help guide participants towards interactions with policymakers, participants were asked to address a sector of the ecosystem they did not interact with often. The final exercise was to regroup posters to synthesize individual results into a common set of messages that participants could use in messaging policy makers. Each participant was also asked to individually write down messages and reflect on actions they could engage in over the six months following conclusion of the workshop.

Results

Four key messages for policy makers emerged from the workshop:
1. There is increasing inequity in the K-12 system with the growing re-segregation of schools. This poses a threat to engineering education efforts focused on diversity, access, and inclusion. Moreover, there is a need to remove bias that exists in higher education admissions criteria.
2. There is a need for clear and consistent funding for engineering education research.
3. Current engineering education research does not have the impact that we, as a community, believe is possible. Work is needed to understand systemic barriers.
4. Engineering students need opportunities to innovate their careers. This will contribute to a global workforce that is ready to create value.

In messaging others in the ecosystem every key message should answer three questions: What is the problem that needs to be addressed, what can be done about the problem, and what are specific actions I can take to solve the problem? It was also noted that engineering education researchers should deliver messages via the appropriate channel, precede each message by a relevant personal story, and follow up each message with a specific "ask".

The participants saw the framework of ecosystems as a valuable analogy to improve thinking about messaging. Particularly related to the topic of ecosystems as a valuable analogy were the following findings:
1. Embrace the imperfect, but powerful, ecosystem metaphor.
    a. Develop an appreciation for entire engineering education ecosystem— including, but not limited to, student advisors, residence life, higher education personnel outside of engineering, etc.
    b. Discover new partners in the ecosystem (e.g. admissions officers).
    c. Develop the ecosystem framework and our understanding of keystone species to be able to make better investments.
2. Share the ecosystem metaphor with students and colleagues to facilitate a more comprehensive perspective.
3. Better understand the needs of the different actors in the engineering education ecosystem.
4. Inculcate the idea of an ecosystem into the engineering education culture (Davis, 2009).

Another finding was to work on improving the engineering education ecosystem itself. The could be done by seeking to change the ecosystem in ways that benefit all sectors; deepening our understanding of the growing re-segregation of K-12 schools; organize a distinguished lecturer at

an upcoming ASEE annual conference on what this means for the next generations of engineers; finding more students to pursue doctoral degrees in engineering education; and identifying people to have conversations with about funding issues surrounding federal investments in engineering education research.

Finally the results of the overall individual ecosystems developed by working groups were analyzed by the project evaluators to produce an initial engineering education ecosystem map, Figure 4.

Figure 4: Engineering education ecosystem map.

Citations

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