ISSUES IN INTERDISCIPLINARY STUDIES
No. 35, pp. 200-220 (2017)

Facilitating Collaboration across Disciplinary and Sectoral Boundaries: Application of a Four-Step Strategic Intervention

by

Whitney G. Lash-Marshall
College of Environmental Science and Forestry
State University of New York

and

Christopher T. Nomura
College of Environmental Science and Forestry
State University of New York

and

Kimberly Eck
Office of Research and Engagement
University of Tennessee

and

Paul D. Hirsch
(corresponding author)
College of Environmental Science and Forestry
State University of New York

Abstract: This article describes a strategic intervention to empower interdisciplinary and transdisciplinary research groups to develop strategies for overcoming barriers to the collaborative process. We report on an application of the intervention with a team of researchers working on the development of "green materials" to reduce energy consumption in manufacturing processes. The intervention consisted of: 1) pairing team leaders with external facilitators; 2) identifying barriers to fruitful collaboration; 3) writing strategic operating agreements; and 4) developing collaborative visualizations of the research process. The results indicate that focusing

the collective intelligence of diverse researchers inwards, on the research process itself, can provide tangible benefits.

Keywords: collaboration, collaborative research, convergence, academic-industry partnerships, transdisciplinary, interdisciplinary, research policy, facilitative leadership, boundary objects, integrative thinking

Introduction

By working across disciplinary boundaries, researchers can share and cultivate ideas, knowledge, and other resources (Klein, 1990; Newell, et al., 2001; Repko et al., 2017; Frodeman, et al., 2017). By working across the boundaries of academia and other social sectors,[1] researchers can collaborate with those who possess relevant knowledge – and may have the most at stake – regarding the challenges and opportunities involved in applying research for social benefit and/or economic gain (Powell, 1996; Bozeman & Corley, 2004; Perkmann, et al., 2013). Over the past three decades, funders are placing an increasing focus on interdisciplinary and transdisciplinary engagement,[2] with some arguing that multi-partner, cross-boundary collaboration is now the pre-eminent model for research (Bozeman & Boardman, 2003; Corley, Boardman, & Bozeman, 2006; Wuchty, Jones, &Uzzi, 2007).

Collaborative efforts across the boundaries of discipline and sector are likely to entail barriers to success over and above more traditional modes of scientific research (Bauer, 1990; Fiore, 2008; Bruneel, et al., 2010; Falk-Krzesinski, 2011). Proceeding from this basic recognition, the proposition that motivates the activities discussed here is this: *Making the identification of barriers to collaboration – and the development of strategies to overcome them – an early part of the collaborative research process can facilitate the success of interdisciplinary and cross-sectoral transdisciplinary efforts.* This article reports on a unique opportunity to apply, test and increase the robustness of this idea in the context of work undertaken as part of a multi-year initiative called the "Networks of Excellence."

The goal of the Networks of Excellence Initiative, which was funded

[1] Menken and Keestra (2016) characterize research involving extra-academic stakeholders who bring their own (experiential) knowledge and values to the table as transdisciplinary research.

[2] For example, the recent National Science Foundation focus on Convergence Oriented Research (www.nsf.gov/pubs/2017/nsf17065/nsf17065.jsp) and the emphasis on cross-cutting research and development of interdisciplinary solutions by the EU's Horizon 2020 research funding scheme (https://ec.europa.eu/programmes/horizon2020/en/news/fet-living-interdisciplinarity).

by The State University of New York (SUNY) Research Foundation, was to spur statewide economic development by fostering interdisciplinary collaborations across the multi-institutional SUNY system, and by promoting collaborations between academic and industry-based researchers (Killeen, 2013). Our own interdisciplinary research team came together at an early meeting of SUNY faculty and administrators invited to help get the Networks of Excellence Initiative off the ground. Sensing the opportunity to take a system-wide view and to pilot specific strategies for improving research collaboration, we designed a project focused on understanding the barriers to interdisciplinary, cross-sectoral research collaboration and on developing strategies for overcoming them.

This article touches briefly on the empirical dimension of our work, and then focuses on what we believe to be our most important result: *the development and application of a four-step process of strategic intervention for identifying and overcoming barriers to fruitful collaboration.* We piloted these steps with another research group – also funded by the Networks of Excellence – called the Green Composite Materials group, which organized around the challenge of developing "green" materials that can be manufactured at lower energy consumption levels (Gewin, 2015; McAdam, 2015). This latter research group consisted initially of researchers working across SUNY institutions and disciplines in the physical sciences, and ultimately included partners from relevant industries. As with any undertaking of this nature – and any scientific process more broadly – there were barriers between the group's collaborative efforts and the realization of their individual and collective intentions.

The four-step strategic intervention we developed and applied with the group entails:

1) Pairing team leaders with external facilitators;
2) Identifying barriers to fruitful collaboration;
3) Writing "strategic operating agreements";
4) Developing collaborative visualizations of the research process.

In this article, we first summarize the results of the survey we conducted with a cross-section of SUNY faculty on barriers to collaboration, which constituted the backdrop for the focused projects we worked on. Second, we discuss the institutional context of the SUNY Networks of Excellence Initiative and the specifics of the Green Composite Materials group, a research group funded by that Initiative. Third, we describe and report on our application of a four-step strategic intervention for overcoming barriers to research collaboration, developed based on the survey results and existing literature and piloted with the Green Composite Materials group.

This study took place in a unique context, one that allowed us to focus a lens on multiple scales from the entire research system down to a specific research group. However, our approach is applicable to other research systems and contexts. It would benefit, furthermore, from further testing and refinement. We therefore conclude with a discussion of lessons learned and additional needs for supporting effective research collaborations across the boundaries of discipline and sector.

Characterizing the System-Wide Barriers to Effective Research Collaboration

In order to develop a baseline understanding of barriers to collaboration within our system of study, we first conducted a literature review. From this review, in conjunction with conversations among team-members and other collaborators who had experience working on interdisciplinary and transdisciplinary teams, we developed a comprehensive list of barriers (for example: McEvoy, 1972; Bauer, 1990; Golde & Gallagher, 1999; Jakobsen, Hels, & McLaughlin, 2004; Lélé & Norgaard, 2005; Fiore, 2008; van Rijnsoever & Hessels, 2011; Roy, et al., 2013). In the process of developing the list, we developed an organizational structure for thinking about barriers in which we looked for interpersonal, intellectual, and institutional barriers. The three "I's" became a shorthand in our search for barriers, and representative of our intention to take a holistic approach to barrier identification. The list of interpersonal, intellectual, and institutional barriers then became the basis for the development of a survey to help us gain a more focused understanding of the kinds of barriers that researchers working in the SUNY system might be facing.

We conducted the survey online in the fall of 2014, distributing it to 2,356 faculty researchers at eight SUNY institutions. Four of the eight institutions were doctoral granting research institutions, and the other four were non-doctoral institutions whose faculty are encouraged to participate in research. We received 651 responses, for a response rate of 27.6%. Of these respondents, the majority were tenured (55%), and had been working at a SUNY institution for fewer than 21 years (24% between 1-10 years and 38% between 11-20 years).

The four top ranked barriers identified by respondents were: 1) lack of funding opportunities; 2) lack of adequate time to conduct collaborative research; 3) challenges of communicating with different audiences; and 4) different assumptions about what constitutes adequate scientific rigor. Table 1 shows the top 12 identified barriers to effective research collaboration.

Table 1: Barriers to effective research collaboration identified by SUNY faculty

Top 12 Barriers to Effective Research Collaboration
1. Lack of funding opportunities (42%)
2. Requires more time to conduct (41%)
3. Challenges of communicating with different audiences (38%)
4. Different assumptions about what constitutes adequate rigor (36%)
5. Travel required (35%)
6. Goals of academic research are not compatible with goals of practitioners (34%)
7. Scholarly research relevant to policy, education, or industry valued less (33%)
8. Lack of common terminology or language (33%)
9. Difficulties clarifying research problem and integrating objectives (31%)
10. Project organization or management structure inadequate (29%)
11. Issues of budget control or distribution (27%)
12. Lack of understanding of disciplinary differences (26%)

Our process and intention with the survey was to use empirically derived data about barriers experienced at the level of a large research community to empower specific groups of researchers *from* that community to identify barriers before they become a major issue, and to develop strategies for overcoming them. Below, we move from the larger multi-institutional research community to a specific group of researchers facing a unique set of barriers, and describe the interventions we applied to help them internalize their engagement with barriers to collaboration into the research process, and thereby work strategically to overcome them.

The SUNY Networks of Excellence and the Green Composite Materials Group

In 2013, the SUNY Research Foundation launched the Networks of Excellence Initiative with the intention of connecting and leveraging geographically dispersed assets in order to increase research and innovation activity (Killeen, 2013). Initially, there were four Sub-Networks of Excellence designed to leverage domain-specific assets: SUNY Health; SUNY Brain; SUNY Energy, Environment, Economics & Education (4E); and SUNY Materials & Advanced Manufacturing. The Networks were led

by two to four campus-based leaders in research development positions (e.g. Vice Presidents for Research), who were dubbed "Co-Champions." For each of the Networks, Co-Champions and a Steering Committee held planning meetings for one year leading up to launch.

The Health, Brain, and 4E Networks functioned similarly by providing funding based on proposals made by cross-campus groups. By contrast, the Materials & Advanced Manufacturing Network used a more targeted process in which funding was allotted to groups of core scientists with expertise in targeted research areas, who were then charged with inviting other researchers to co-formulate and implement specific research agendas.

The Green Composite Materials Group

The unique approach of the Materials & Advanced Manufacturing Network within the SUNY Networks of Excellence structure provided the opportunity for funding to be committed to a generalized call before defining a specific research problem, and before fully constituting the research group. The original focus for the Green Composite Materials group was therefore quite broad. The group, made up of eight research faculty from five SUNY Universities, included chemists, physical scientists, and engineers. Later, the group included members from a number of industries. The intention for these researchers coming together was to develop more eco- and energy-friendly strategies for manufacturing composites and other materials for commercial use. At initial meetings, the group focused in on responding to the grand societal challenge of achieving energy (and therefore cost) reductions in manufacturing processes, a challenge identified by a diversity of major funding organizations.[3]

The majority of group members had not worked together previously. In the first meetings of the collaboration, in which co-author Nomura played a lead role, all members of the team had undefined (and approximately equal) roles, and each individual had the potential to be a Principal Investigator on projects that emerged from the group's conversations and were selected through a group process. The initial charge for the group was to co-formulate a research problem (see Shockley, Lash-Marshall, Friedman, & Hirsch, 2016), and to decide how to allocate an initial pool of funding that had been

[3] Funding organizations that have directed calls for proposals to the societal grand challenge of achieving energy reductions in manufacturing processes have included the New York State Energy Research and Development Agency (NYSERDA), Department of Defense Air Force Research Lab, National Institute of Standards and Technologies (NIST), and National Science Foundation (NSF), among others.

committed by the Networks of Excellence.

Bringing together research participants across multiple institutions and between academia and industry provides significant opportunity for innovation, resource sharing, and the development of new synergies. At the same time, charging a newly formed research group with collectively deciding both on a research problem and on how (and where) to allocate group resources posed significant challenges. Exacerbating this challenge was the structural issue that, while the purpose of the Networks of Excellence Initiative was to facilitate collaboration across the SUNY system, the allocation of incentives and rewards was primarily to individual SUNY campuses.

At the early stages of the initiative, Nomura saw significant potential for inter-institutional competition and issues of trust to serve as barriers to authentic engagement by the various partners. One driver of his concern was the fact that intellectual property of potential economic significance could be at stake. Nomura was also a member of the "Understanding and Overcoming Barriers to Research Collaboration" research team, which was funded by the SUNY Networks of Excellence through the 4E Sub-Network. Hirsch served as Principal Investigator for the latter project, and Lash-Marshall was the post-doctoral researcher and project manager. After an initial consultation with Eck (also a co-author), in her collaborative research development role at the Research Foundation for SUNY, Nomura invited co-authors Hirsch and Lash-Marshall to help the Green Composite Materials team proactively understand and work to overcome the barriers they faced to effective research collaboration.

We saw this as an opportunity to develop and pilot an approach that is generalizable to a wide variety of collaborative research groups and challenges. Therefore, we focused not on specific barriers but on using the results of the survey as a catalyst in support of the group's capacity to identify barriers for themselves, and to develop strategies for overcoming them. Together, Hirsch, Lash-Marshall, and Nomura decided on our strategic interventions and a set of steps for applying them. These entailed, first, getting the right sort of facilitation; second, proactively identifying barriers to collaboration in a group setting; third, developing strategic operating agreements for overcoming those barriers; and fourth, using collaborative visualizations – or "boundary objects" – to better understand the collaborative process and foster creativity. We applied the interventions during meetings of the Green Composite Materials group. The interventions are described in detail below, along with their application in the context of the Green Composite Materials research initiative.

Applying the Four-Step Strategic Intervention

Step *1: Partnering Team Leaders with External Facilitators*

Even the strongest of leaders may have trouble providing effective facilitation in the context of a group of researchers coming from different disciplinary or institutional perspectives, particularly when they themselves may have a disciplinary or institutional bias and/or have a personal stake in decisions. While not always necessary, inviting to a meeting a facilitator who has no stake in the outcome can play an important role in stimulating group conversation, and in making the discussion of potential barriers and how to overcome them a collaborative activity. Group members may be more willing to participate in a facilitated discussion, and it allows the leadership to participate more fully in the discussion. In addition, working with a facilitator to structure key discussions about research processes provides training in facilitation to the group members and reinforces the effort required to protect and maintain collaborative function.

It is important to point out here that facilitation in an interdisciplinary context may call for skill-sets additional to those required for facilitation in other contexts. At a minimum, an interdisciplinary facilitator must "speak" multiple disciplinary languages at a high enough level to appreciate the diversity of conceptual apparatus brought to bear in a given collaborative setting (Repko, et al., 2017). He or she must also be intellectually open-minded and adept enough to avoid ongoing temptations to simplify problems seen from one perspective in the terms of another (Hirsch, et al., 2013).

External facilitation, nevertheless, has its limits. An external facilitator will never understand the nuances of a specialized set of research problems; furthermore, the need for effective group facilitation does not end after a given meeting or workshop. There is an ongoing need for group leaders – and other group members – to exercise facilitative skills in order to help groups navigate the complex processes of interdisciplinary research. This model – sometimes termed "facilitative leadership" – has been utilized in fields of education (Hord, 1992), medicine (Gray, 2009), and community planning (Forester, 2009) but has received less attention for interdisciplinary research (Schwarz, 2006).

In an interdisciplinary setting, a facilitative leader – who may be the Principal Investigator but does not have to be – is a member of an interdisciplinary team who can play a major role in establishing an environment within which effective collaboration can take place. As discussed by Keestra (2017, this volume), facilitative leaders should be able to lead the team in a process of

"metacognition." This entails becoming aware of complex processes by which team members develop representations, or mental models, of their individual tasks and contributions to the team project, and the extent to which different group members' understandings are or are not aligned with those of others which might impede the team's creation of novel insights and ideas. When appropriate, the process of meta-cognition sets the stage for the development of practical working agreements that satisfy diverse parties' interests (Forester, 2009). In addition, a facilitative leader can guide the development of short-term, mid-term, and long-term goals for the group to be addressing, and can highlight links between those goals and incentives to promote collaborative work. This person(s) must have an interest in the positive outcome of the collaborative project as well as the vision to identify real and perceived barriers to the collaborative process.

In our work with the Green Composite Materials group, the pairing of external facilitators and internal facilitative leaders took the following form. Nomura, a member of the leadership team for the Green Composite Materials group, invited non-group members Hirsch and Lash-Marshall, both of whom have extensive experience facilitating interdisciplinary groups, to help co-design, mediate, and provide training in facilitative leadership and critical reflection on the collaborative process. In order to prepare materials and frame the initial interaction in the context of collaboration, this partnership began prior to the first meeting of the Green Composite Materials team. Aided by the results of the survey and the adaptation of previous work, this partnership then supported a series of conversations in which – as explained in the next sections – the entire team identified barriers that might hinder collaboration and developed and implemented strategies for overcoming them.

Step 2: Identifying Barriers to Fruitful Collaboration

In order to develop productive collaborations between researchers with different academic backgrounds and different levels of experience with interdisciplinary collaboration, and between academic and non-academic partners, it is important to define and overcome potential impediments. Our survey research had built on the work of others to identify obstacles to collaborative efforts between disciplines (Bauer, 1990; Lélé & Norgaard, 2005; Fox et al., 2006; Hicks, Fitzsimmons, & Polunin, 2010; Roy, et al., 2013) and between academia and industry (Bruneel et al., 2010). But we also needed to consider what the particular barriers specific to this team might be.

Our intervention in this regard consisted of a series of three stages. First, external facilitators Hirsch and Lash-Marshall and the facilitative team leader Nomura reflected on the specific nature of the Green Composite Materials research challenge. Second, at the group's first official gathering, Lash-Marshall presented to the group an overview of the barriers we had identified in our survey, and facilitated a dialogue in which, based on their own experiences, research team members identified additional barriers to interdisciplinary collaboration and collaboration across SUNY campuses. Third, at a subsequent meeting with industry partners and representatives from SUNY's Technology Transfer Office, this dialogue was expanded to identify additional barriers to academic-industry collaboration and research translation.

In all three cases, barriers were first presented as being experienced by researchers in a broader context to begin with, and then were narrowed down to the specific experiences of individuals as part of the research team (see Table 2 for a summary of barriers identified in these discussions).

Because this research effort is closely concerned with the development of materials that may generate value within an industrial context, the set of barriers having to do with intellectual property and issues of trust (also identified by Bruneel, et al., 2010) came to the fore. In one way or another, researchers identified trust and intellectual property issues at each of the three meetings. The existence of these barriers reflects people's concerns – often based on past experience – that the ideas and/or intellectual property they share in the context of a group effort will be used by other team members or by the institutions or interests other team members represent in ways that do not fully honor peoples' contributions. As expressed during the facilitated discussion, trust issues are often a reflection of negative associations with past research teams or institutions, as well as of more general pre-existing bias or reputational issues related to specific institutions or individuals. In some cases, there is a sense on the part of researchers that the presence of people whose main agenda is institutional advancement can erode one's freedom to share one's best ideas.

Barriers to collaborative efforts can be significant when the majority of team-members do not know about each other or each other's work prior to collaboration, as was the case with most members of the Green Composite Materials group. Indeed, there was an attitude of skepticism regarding collaboration among many of the team-members at the first meeting. The opportunity to voice concerns in a safe space was a valuable exercise in itself, and was a step towards the development of strategic operating agreements designed to address them, detailed in the next section.

Table 2: Barriers to effective research collaboration identified by the GCM Network

		Scale of Barrier to Effective Research Collaboration	
		Micro–level	**Macro–level**
Type of Boundary Being Crossed	**Disciplinary**	• Lack of understanding of disciplinary differences • Lack of Trust, including an unwillingness to share one's "best" ideas with other researchers • Negative associations with interdisciplinary collaboration based on past experiences • Pre–existing biases or reputations of specific individuals • Large group size makes collaboration difficult	• Lack of Trust/ rivalry across research institutions • Pre–existing biases or reputations of institutions • Time and flexibility needed for interdisciplinary research not supported • Promotion & Tenure structure does not incentivize interdisciplinary collaboration
	Sector (Academia / Industry)	• Issues communicating across different audiences and education levels • Problems coordinating meeting times • Industry partners often engaged after research problem has been defined • Perceived lack of appropriate engagement (from partners on both sides) • Lack of mutual respect • May require new models of project organization and management	• IP & Licensing • Different criteria for defining success/failure of a project • Cost of ideas/pilot projects (who will pay?) • Difficulty finding feasible funding opportunities to support research partnerships between academia and industry • Difficulty of finding collaborators

Step 3: Writing Strategic Operating Agreements

If not addressed at the beginning of the collaboration, barriers related to trust and intellectual property have the potential to limit the creative efforts of a group. If people don't share ideas freely, new ideas – and new combinations of ideas – will not be forthcoming (see also the discussion regarding issues of trust in Keestra, 2017, this volume). Similarly, if people aren't given the opportunity to share their concerns or issues, new policies or protocols won't be developed to respond to them. In order to address up front issues of trust having to do with protection of intellectual property, Nomura worked with the SUNY Research Foundation to develop an appropriately worded non-disclosure agreement and asked each member of the research team to sign it before discussing any ideas or initiating any collective work. This served as an initial filter of people's willingness to abide by these terms in the team's formative stages.

Subsequent to the identification of barriers at their initial meeting, Lash-Marshall and Hirsch facilitated, specifically for the Green Composite Materials group, a set of strategic operating agreements designed to help the group start formulating research problems and strategies for addressing them. This entailed, initially, asking members of the GCM group to share some of their experiences on interdisciplinary research teams and any concerns they had regarding this new effort. By sharing personal experiences and stories, the group began to build trust and develop a shared vision of how they would structure their collaborative process to avoid these barriers and not repeat negative experiences. During this discussion, the facilitators took notes directly onto a power-point slide so that the team could see their comments included and validated by the experiences of others in real time.

During a break after the discussion, Hirsch and Lash-Marshall worked together to organize peoples' concerns and articulate them in terms of three principles that could address the larger set of concerns emerging from the discussion. After engaging in additional discussion to refine them, the group agreed on the following principles: 1) cultivate trust and respect for intellectual property, 2) be an active participant, and 3) generate shared value. The group then used the principles to brainstorm a set of associated actions that would uphold the principles. Table 3 shows the strategic operating agreements, which consists of a complete list of principles and associated actions. Once generated, these agreements are available for subsequent meetings, and for new members, to provide a baseline for how the team functions. They are also revisable and updatable.

Table 3: Operating Agreements – Collaboratively Defined Principles and Actions

Principles	Associated Actions
1. Cultivate trust and respect for intellectual property	–No one will submit an individual proposal based on group ideas –All participants will sign a non-disclosure agreement before attending their first meeting –Group members will make explicit which ideas are personal intellectual property and which are available to the group –Group members will be transparent in the communication of plans for publications, proposals, patents, etc. throughout the process –Intellectual property includes ideas, networks and industry contacts
2. Be an active participant	–Group members will keep lines of communication open, which means • Articulating when reservations or conflicts arise to allow for proactive action • Being honest when one's schedule will not allow full engagement. –Group members will share materials, equipment and student research opportunities
3. Generate shared value	–Identification of a thematic research area for group focus will be made through a collective decision process –The group will collectively determine criteria for impartial selection of projects to receive funding –In addition to intellectual and commercial goals, the group will identify societal benefits of ideas and intellectual property generated through collaboration

Step 4: Developing Collaborative Visualizations of the Research Process

In addition to barriers related to trust and incentive systems, barriers related to difficulties in communicating across disciplinary and organizational boundaries came to the fore in both the survey research and in meetings of the Green Composite Materials research team. Successful interdisciplinary and transdisciplinary communication entails a broad set of challenges that researchers have engaged from a variety of dimensions (e.g. see Falk-Krzesiniski, et al., 2011; Winowiecki, et al., 2011; O'Rourke & Crowley, 2013). Our efforts in this dimension drew on previous experiences with the use of collaboratively developed visualizations to foster group learning and encourage fruitful discussion[4]. From a theoretical perspective, a collaborative visualization functions as a "boundary object" in that it affords the creative engagement of people working on different sides of a social or intellectual boundary in a shared thinking process (Star & Griesemer, 1989).

Lash-Marshall and Hirsch worked with Nomura and the Green Composite Materials group to develop a series of diagrammatic visualizations intended to support the team in creative and coherent communication about the process of the collaboration itself. Following the logic of Keestra's discussion (2017, this volume) this visualization strategy makes explicit and visible some elements of the group's understanding of the research process that were previously implicit, thus allowing for that understanding to be discussed and iterated. The visualization represented in Figure 1A**,** made by Hirsch and Lash-Marshall prior to the first in-person group meeting, helped provide a basis for initial strategizing about effective team development and for envisioning the process and outcomes of the Green Composite Materials collaboration. Using Figure 1A, the group discussed specific challenges related to disciplinary differences and lack of trust within the group, and explored how a "collaborative research community" would function.

The visualization process also allowed the group to co-develop the scope of their work with an eye to its relevance to industry, and to articulate short and long-term goals, with the ultimate aim of creating a "Center" for green composite materials research (see the right side of Figure 1B). All eight team participants engaged enthusiastically with the development of the updated visualization and agreed to use it – in combination with the operating agreements – as a framework to describe their group when inviting potential industry partners to join.

[4] See, for example, Feed back – future feed, a project Hirsch participated in through a connection made with other SUNY faculty through the Networks of Excellence Initiative (feedbackfuturefeed.wordpress.com).

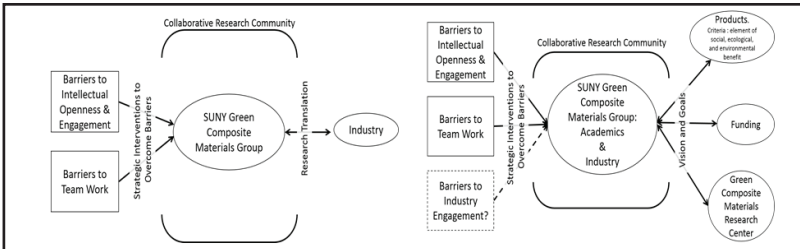

Figure 1: Systems representations of the collaborative research process. A. The initial visualization represented barriers to the collaborative process among academic team members; B. The second visualization highlighted the importance of including potential industry partners in the process of formulating the problem, and expanded the range of potential outputs of group efforts.

As described above, the first meeting included academic partners only. This allowed team members to establish relationships and build trust before engaging industry partners. At a second meeting specifically designed to facilitate academic-industry collaboration, the group of SUNY researchers met with initial industry partners, and Nomura presented this visualization with the inclusion of "barriers to industry engagement" as a point of discussion.

Although industry partners expressed desire to have been engaged earlier, the group was nevertheless able to engage in productive dialogue regarding possible additional barriers related to academic-industry partnerships, and updated the diagram accordingly (see Table 2). Based on the specific input from those industry partners in attendance, a key shift in the updated model of the Green Composite Materials group was that industry became part of the collaborative research team (as in Figure 1B). This shared visualization of industry *within* the research network served as a basis for solidifying the operating agreements as a sort of "contract" for being part of the group and catalyzed a discussion on why academic-industry partnerships had not always been successful in the past (see Jacob, et al. 2000). As in the first team meeting, a discussion of past barriers and experiences provided a baseline for determining how this group could develop a better collaboration.

Conclusions

Was the strategic intervention successful? This was a pilot study in which we sought to develop a generalizable model, and there was no control group. Of particular note, however, is fact that the Green Composite Materials group reached a unanimous agreement on the allocation of research funds (see Figure 2). This is additionally telling in that the allocation was unequal

with respect to the institutions and individuals involved, and nevertheless seen as providing the best benefit for the group as a whole. This agreement on the allocation of research funds indicates that the group was able to establish a genuine team mental representation of the project as a whole (see Keestra, 2017, this volume), and that the group members were able to make their individual contributions part of that larger understanding –rather than vice versa. These successes occurred, furthermore, for a group that 1) had not worked together previously and 2) from the outset had a significant, and potentially difficult, set of barriers to overcome (as summarized in Table 2, above).

Additionally, the group identified short- and long-term funding opportunities to generate continued support for the work and for the achievement of their ultimate vision. As further evidence of success, two of the three projects seeded by the Green Composite Materials group obtained additional funding from the New York State Energy Research and Development Authority (NYSERDA) as well as from industry partners. While some of the success is surely a function of the individuals who composed the team and of the unique synergies that developed among them, the experience of the Green Composite Materials group provides a useful model for understanding the role of strategic intervention in collaborative efforts that include industry partners as part of the research team.

The four-step intervention described here may be one of many paths to successful collaboration across discipline and sector. The results of the efforts described here, however, clearly indicate that the additional time and resources spent in facilitating research collaborations can provide value by fostering trust and nurturing connections in such a way that individual researchers are able to take a group perspective instead of remaining isolated contributors. Although this is a precondition to subsequent output, it is not always a visible process, and thus is not always valued in current systems of incentives and rewards. Finding ways to value and invest in the less visible aspects of the collaborative research process may allow for more fruitful– and enjoyable – collaborative efforts.

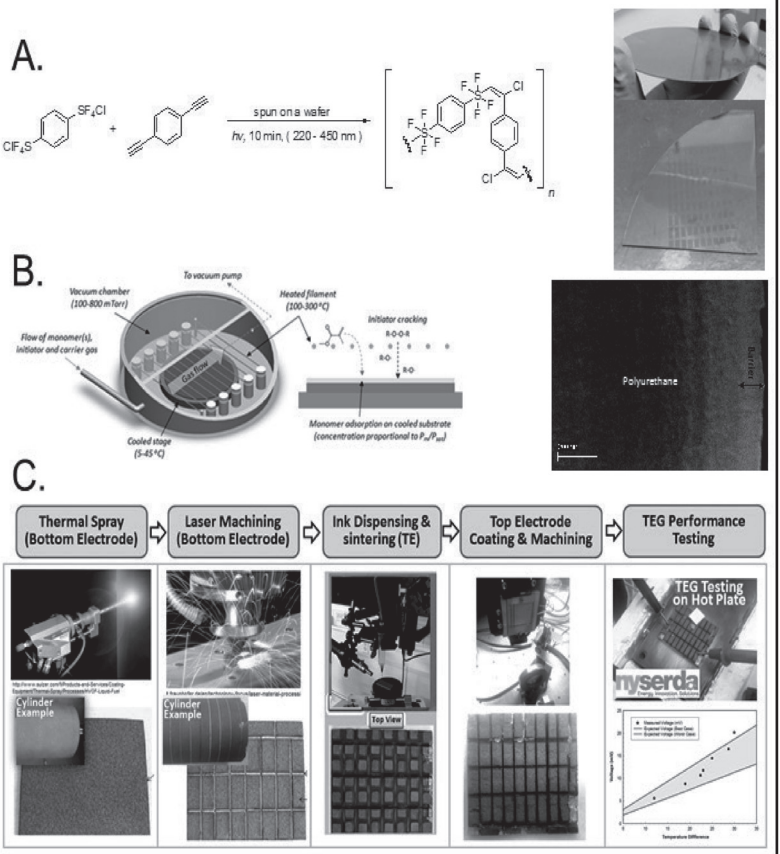

Figure 2. Academic-Industry collaborative projects generated from Green Composite Materials Workshops. Three projects emerged after discussion among academic and industry partners:

A. Developing new photosensitive monomers to lower the energy of polymerization reactions.

B. Developing methods to UV cure conformal coatings to protect electronic components from various environmental exposures as well as provide a means of mitigating tin whisker failure in Pb-free electronics.

C. Developing hybrid additive manufacturing methodologies through UV curing to better produce thermoelectric generators (TEGs). These devices aid in the recovery of waste heat from industrial processes to generate electricity.

***Acknowledgements*:** This research was conducted as part of the Research Foundation for SUNY Networks of Excellence and supported through the 4E (Energy, Environment, Economics, and Education) and Materials and Advanced Manufacturing (MAM) Networks of Excellence (Grant 67400). The authors are grateful to the members of the Green Composite Materials Research Team for their collaborative efforts and to Barry Bozeman for his comments on an earlier draft of this paper.

Biographical Notes: Whitney Lash-Marshall is currently an Adjunct Assistant Professor at the State University of New York College of Environmental Science and Forestry. This published work was completed as part of her post-doctoral research position managing our project on collaborative interdisciplinary research in SUNY. A systems ecologist by training, her research and teaching strive to bridge disciplinary boundaries to develop more effective approaches to the study and management of complex social-ecological systems (SES). She holds a Ph.D. from SUNY ESF in Environmental and Natural Resource Policy where her research focused on conservation and natural resource management in complex landscapes, including Puerto Rico and Costa Rica. She has served as Executive Director of the Baltimore Woods Nature Center since January of 2017 and continues to participate in the design and delivery of strategies to overcome barriers to communication and collaboration in inter- and transdisciplinary research teams and community groups. She may be reached at wglash@esf.edu.

Christopher T. Nomura, Ph.D.**,** is a Professor in the Department of Chemistry at the State University of New York College of Environmental Science and Forestry (SUNY-ESF), a member of the SUNY-ESF Center for Applied Microbiology, Syracuse Biomaterials Institute and Chutian Visiting Lecturer at Hubei University in Wuhan, China. He received his B.A. in Biology with honors from the University of California at Santa Cruz, where he studied immunology and physiology of elephant seals, and his Ph.D. in Biochemistry, Microbiology, and Molecular Biology at The Pennsylvania State University for his research on cyanobacterial electron transport proteins. From 2001 to 2006, he worked in the internationally recognized Natural Polymer Chemistry laboratory of Dr. Yoshiharu Doi at the RIKEN Institute in Japan. Since 2006, he has been a faculty member in the Department of Chemistry at SUNY-ESF. Dr. Nomura has published and co-authored more than 50 original articles in refereed scientific journals, including 3 reviews, 7 book chapters, and 5 patent disclosures. Dr. Nomura has a multi-disciplinary research group whose interests span the fields of metabolic engineering, protein engineering, microbial physiology, molecular microbiology, biochemistry, synthetic chemistry, and polymer chemistry. He received the SUNY-ESF Exemplary Researcher Award in 2011 for his contributions to the field of biopolymer production and has received special recognition for his mentorship of student researchers. Dr. Nomura has worked with researchers through the Research Foundation of SUNY Networks of Excellence to foster collaborations between faculty and industry partners. Dr. Nomura's research programs have been sponsored by DOE, USDA, NIH, NSF, NYSERDA, and The Research Foundation of SUNY. He may be reached at ctnomura@esf.edu.

Kimberly Eck, M.Ph., Ph.D., has served as the Director of Research Development at the University of Tennessee, Knoxville since 2016. In this role, she and her team provide proposal development services for major proposals, lead capture management and federal relations, and build research capacity and form new collaborations through innovation programming. Her career in research development began in 2007 working for a small consulting firm. She went on to work for the Research Foundation of the State University of New York and Geisinger Health System in a similar capacity. In her career, she garnered support for proposals securing nearly $200M in external funding. Dr. Eck's Ph.D. is in epidemiology. She has an appointment as an Adjunct Assistant Professor at the University of Tennessee, Knoxville Department of Public Health where she enjoys teaching graduate students. Dr. Eck also serves on the Advisory Council of the Tennessee Governor's foundation for Health and Wellness, the investment committee for Knoxville United Way, and acts as Chair of the Southeast Region of the National Organization of Research Development Professionals. She may be reached at eck.kimberly@gmail.com.

Paul Hirsch, Ph.D., is Associate Professor in the Department of Environmental Studies at SUNY Environmental Science and Forestry. He received his Ph.D. in Environmental Policy from the Georgia Institute of Technology; his M.S. in Conservation & Sustainable Development from the University of Georgia Odum School of Ecology; and his B.S. in Biology and Society from Cornell University. Dr. Hirsch is a Board Member with the Association for Interdisciplinary Studies; Fellow with Planet Forward at George Washington University, and Fellow at The Center for Organization Research and Design at Arizona State University. Dr. Hirsch's scholarly work on navigating the trade-offs between conservation and development has been cited over 500 times. Other research areas include cross-boundary environmental problem solving, research collaboration, science in the policy process, and the inclusion of marginalized perspectives in decision-making. In addition to his scholarly work, Dr. Hirsch designs and facilitates workshops, dialogs, and training sessions on transdisciplinary communication, engaging science and values in decision-making, and strategic thinking amidst complex dynamics. Organizations he has worked with include Cornell Cooperative Extension, Onondaga Environmental Institute, Town of Dewitt, New York State Department of Environmental Conservation, Tanzanian Department of Wildlife Management, Peruvian Society for Environmental Law, Center for Natural Resources and Environmental Studies in Vietnam, and Worldwide Fund for Nature. Paul is the corresponding author for this article. He may be reached at pahirsch@esf.edu.

References:

Bauer, H.H. (1990). Barriers against interdisciplinarity: Implications for studies of science, technology, and society (STS). *Science, Technology, & Human Values, 15*(1), 105-119.

Bozeman, B., & Boardman, P.C. (2003). Managing the new multipurpose, multidiscipline university research center: Institutional innovation in the academic community. *IBM Endowment for the Business of Government*,

Retrieved February 2016, from http://archive.cspo.org/rvm/reports/reports_docs/IBM_Centers.pdf

Bozeman, B., & Corley, E. (2004). Scientists' collaboration strategies: Implications for scientific and technical human capital. *Research Policy, 33*(4), 599– 616.

Bruneel, J., D'Este, P., & Salter, A. (2010). Investigating the factors that diminish the barriers to university-industry collaboration. *Research Policy, 39*(7), 858-868.

Corley, E.A., Boardman, P.C., & Bozeman, B. (2006). Design and the management of multi-institutional research collaborations: Theoretical implications from two case studies. *Research Policy, 35*(7), 975-993.

Dieleman, H. (2017). Transdisciplinary hermeneutics: A symbiosis of science, art, philosophy, reflective practice, and subjective experience. *Issues in Interdisciplinary Studies, 35,*170-199.

Falk-Krzesinski, H.J., Contractor, N., Fiore, S.M., Hall, K.L., Kane, C., Keyton, J., . . .Trochim, W. (2011). Mapping a research agenda for the science of team science. *Research Evaluation*, *20*(2), 145-158.

Fiore, S.M. (2008). Interdisciplinarity as teamwork: How the science of teams can inform team science. *Small Group Research, 39*, 251-277.

Forester, J. (2009). *Dealing with differences: Dramas of mediating public disputes*. New York, NY: Oxford University Press.

Fox, H.E., Christian, C., Nordby, J.C., Pergams, O.R.W., Peterson, G.D.& Pyke, C.R. (2006).Perceived barriers to integrating social science and conservation. *Conservation Biology, 20*(6), 1817-1820.

Frodeman, R., Klein, J. T., & dos Santos Pacheco, R. C. (Eds.). (2017). *The Oxford handbook of interdisciplinarity* (2nd ed.*)*. Oxford: Oxford University Press.

Gewin, V. (2015). Collaborations: Recipe for a team. *Nature, 523*, 245-247.

Golde, C.M., & Gallagher, H.A. (1999). The challenges of conducting interdisciplinary research in traditional doctoral programs. *Ecosystems, 2*(4), 281-285.

Gray, B. (2009). Enhancing transdisciplinary research through collaborative leadership. *American Journal of Preventative Medicine, 35*(2), S124-S132.

Hicks, C.C., Fitzsimmons, C., & Polunin, N.V.C. (2010). Interdisciplinarity in the environmental sciences: Barriers and frontiers. *Environmental Conservation, 37*(4), 464-477.

Hirsch, P. D., Brosius, J. P., O'Connor, S., Zia, A., Welch-Devine, M., Dammert, J. L., . . .McShane, T. O. (2013). Navigating complex trade-offs in conservation and development: An integrative framework. *Issues in Interdisciplinary Studies, 31*, 99-122.

Hord, S.M. (1992). Facilitative leadership: The imperative for change. *Office of Educational Research and Improvement (ED)*, *Washington D.C.* (Retrieved October 2015 from http://eric.ed.gov/?id=ED370217)

Jacob, M., Hellström, T., Adler, N., & Norrgren, F. (2000). From sponsorship to partnership in academy-industry relations. *R&D Management, 30*(3), 255-262.

Jakobsen, C.H., Hels, T., & McLaughlin, W.J. (2004). Barriers and facilitators to integration among scientists in transdisciplinary landscape analyses: A cross-country comparison. *Forest Policy and Economics, 6*, 15-31.

Keestra, M. (2017). Meta-cognition and reflection by interdisciplinary experts: Insights from cognitive science and philosophy. *Issues in Interdisciplinary Studies, 35*, 121-169.

Klein, J. T. (1990). *Interdisciplinarity: History, theory, and practice*. Detroit, MI: Wayne State University Press.

Lélé, S., & Norgaard, R.B. (2005). Practicing interdisciplinarity. *BioScience, 55*(11), 967-975.

Killeen, T. (2013). *Re: Networks of excellence* [Memorandum to SUNY Campuses]. Albany, NY: State University of New York. Retrieved December 7, 2015, from:https://www.suny.edu/about/leadership/board-of-trustees/meetings/webcastdocs/3%20-%20Networks%20of%20Excellence%20Framing%20Document.txt

McAdam, T.R. (2015). SUNY 4E – Breaking with tradition to increase collaboration. *SUNY RF News*. Retrieved December 8, 2015, from http://www.rfsuny.org/RF-News/ESF-NoE---Composites/Name-18630-en.html

Menken, S., & Keestra, M. (Eds.). (2016). *An introduction to interdisciplinary research: Theory and practice*. Amsterdam: Amsterdam University Press.

McEvoy, J. (1972). Multi- and interdisciplinary research: Problems of initiation, control, integration and reward. *Policy Sciences, 3*(2), 201-208.

Newell, W. H. (2001).A theory of interdisciplinary studies. *Issues in Integrative Studies*, *19*, 1-25.

O'Rourke, M., & Crowley, S. J. (2013). Philosophical intervention and cross-disciplinary science: The story of the Toolbox Project. *Synthese*, 1-18.

Perkmann, M., Tartari, V., McKelvey, M., Autio, E., Broström, A., D'Este, P., . . .Sobrero. M. (2013). Academic engagement and commercialisation: A review of the literature on university–industry relations. *Research Policy, 42*, 423-442.

Powell, W. W. (1996). Inter-organizational collaboration in the biotechnology industry. *Journal of Institutional and Theoretical Economics, 120*(1), 197-215.

Repko, A. F., Szostak, R., & Buchberger, M. P. (2017). *Introduction to interdisciplinary studies*. Thousand Oaks, CA: Sage Publications.

Roy, E.D., Morzillo, A.T., Seijo, F., Reddy, S.M.W., Rhemtulla, J.M., Milder, J.C, ...Martin, S.L. (2013). The elusive pursuit of interdisciplinarity at the human-environment interface. *BioScience, 63*(9), 745-753.

Schwarz, R. (2006). Using the facilitative leader approach to create an organizational culture of collaboration. In S. Schuman (Ed.), *Creating a culture of collaboration: The international association of facilitators handbook* (pp. 281-303*)*.San Francisco, CA: Jossey-Bass Publishers.

Shockley, K., Lash-Marshall, W.G., Friedman, K., & Hirsch, P. (2017). Distinguishing collaboration from contribution in environmental research: The essential role of collaborative problem formulation. *Journal of Environmental Sciences and Studies, 7*(2), 336-345.

Star, S. L., & Griesemer, J. R. (1989). Institutional ecology,"translations" and boundary objects: Amateurs and professionals in Berkeley's Museum of Vertebrate Zoology, 1907-39. *Social Studies of Science*, *19*(3), 387-420.

van Rijnsoever, F.J., & Hessels, L.K. (2011). Factors associated with disciplinary and interdisciplinary research collaboration. *Research Policy, 40*, 463-472.

Winowiecki, L., Smukler, S., Shirley, K., Remans, R., Peltier, G., Lothes, E., . .