COLLABORATORIES AS A VEHICLE FOR INVESTING IN THE IMPROVEMENT OF EDUCATION

REFLECTIONS ON THE ILLUMINATIVE CASE OF THE RESEARCH+PRACTICE COLLABORATORY

Mark St. John
With assistance from Jenifer V. Helms and Laura Stokes

This report is based on work supported by the National Science Foundation (NSF) under grant DRL-1626365.

Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

Inverness Research, a national education evaluation and consulting group headquartered in Northern California, has over 25 years of experience studying local, state, and national investments in educational improvement. http://inverness-research.org

Inverness Research * P. O. Box 313, Inverness, CA 94937 * Ph: 415-669-7156 * www.inverness-research.org

November 2018

ABSTRACT

The Research+Practice Collaboratory provides a compelling case that illustrates the ways in which the collaboratory structure—which is distinct from partnerships, centers, consortia, and other common structures—can make Grand Challenges in education "investable." The collaboratory structure, we suggest, has features that allow foundations (in this case, the National Science Foundation) to invest resources effectively in challenges that inherently require combined effort involving a range of expertise, varying perspectives, and even multiple disciplines. A collaboratory structure supports "collaborating laboratories" that are more autonomous than those in centers and partnerships, are more connected to shared theory and practice than those in consortia, and more powerful jointly than independently funded laboratories. Collaboratories, well designed, thus optimize the benefits of autonomy while at the same time achieving many of the benefits of collaboration.

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LEARNING FROM THE EXPERIENCE OF THE R+P COLLABORATORY

The National Science Foundation (NSF) makes investments that seek to strengthen STEM[1] fields and STEM education in the United States. NSF investments in STEM largely support research projects that generate knowledge—running the full spectrum from basic to applied. In its STEM education research investments, NSF seeks to generate basic knowledge about learning and teaching, but also more recently the Foundation has placed an emphasis on knowledge that is directly and practically useful to education practitioners as well as to those designing and implementing improvement efforts in education.

The Research+Practice Collaboratory (RPC) (http://researchandpractice.org/) is one such NSF investment. The RPC seeks to strengthen STEM education by addressing a fundamental challenge that education shares with other disciplines: the gap between research and practice. All too often there is a large disjuncture between the findings of academic research studies and the day-to-day realities and problems of education practitioners.

The R+P Collaboratory aims to contribute useful knowledge to three spheres of the education enterprise:

- For practitioners. RPC activities develop local research-practice partnerships (RPPs) where the collaborative work of researchers and practitioners create practical knowledge, tools, and resources for a broader practitioner audience, as well as enriching the local improvement effort.[2]

- For educational researchers and organizational leaders in education. The RPC develops knowledge about the ways in which researchers and practitioners can work together for mutual benefit, with a special focus on how to design and implement productive research-practice partnerships.[3]

- For national leaders and foundations. The R+P Collaboratory serves as an unusual example and illuminative case of using the ***collaboratory structure*** to organize an initiative that seeks to address a "grand challenge" for the education field.

[1] Science, technology, engineering and mathematics.

[2] See the RPC website (http://researchandpractice.org/), as well as those of the local RPPs for information, evidence, and examples of tools and resources: *https://www.exploratorium.edu/education/california-tinkering-afterschool-network; http://interactivestem.org/,* and *http://stemteachingtools.org/about*

[3] See http://researchandpractice.org/whatwedo/ for more information on forming RPPs. Inverness developed case studies of the RPPs, focusing on their design and functioning. http://inverness-research.org/2018/07/30/portfolio-research__practice_collab/

This paper addresses the RPC's contribution as an experiment in using a collaboratory structure. As a complement and contrast to other papers about the RPC, this report portrays the essential and defining features of the collaboratory structure and discusses its promise as a structure for investing in the improvement of education.

Investing in the improvement of education

Since the Sputnik event in 1958, multiple national agencies (e.g., NSF, NASA, Dept. of Energy, Dept. of Education) have sought ways to invest federal dollars to strengthen STEM education across the United States in both formal and informal domains[4]. Funding agencies have pursued multiple strategies to catalyze widescale improvements in STEM education, ranging from curriculum and professional development, to systemic change initiatives, to improved standards, assessments, and accountability measures.

Federal and state agencies, along with private foundations, have made thousands of investments in these strategies, most often in the form of grants and contracts for relatively short-term projects. These funders have funded these short-term projects with the goals of catalyzing local change, sparking innovations, and in other ways creating improvements that are meant to be institutionalized and/or more widely replicated.

In our more than 30 years of studying such investments, we have come to appreciate how important—and how difficult—it is to *design* investments which can actually bring about long-term wide-scale improvements in both the formal and informal educational systems. There are several reasons for this difficulty:

- The United States educational system (formal and informal) is large, complex, decentralized, multi-layered, and largely locally controlled within state-by-state policies.

- There are many competing visions of the purposes of education and what comprises "good education." Hence the nature and direction of change that would constitute "improvement" is not uniformly agreed upon.

- There are thousands of potential "improvement targets" for investors. Deciding where to focus investments to maximize return on investment is a non-trivial challenge.

- The level of investment made by foundations in educational improvement is typically very small compared to the scale of the systems they are seeking to strengthen or change.

- The educational system largely lacks an improvement infrastructure, that is, the capacity to design and implement high quality improvement efforts.

[4] Formal domains include K-12 schools and higher education institutions, while informal domains include STEM-oriented projects in media, museums, zoos, youth groups, videogames, and other out-of-school contexts.

The latter difficulty—lack of sufficient internal capacity for system improvement—means that funders often seek to invest in external or intermediary organizations that have relevant expertise and have potential to interface with the education system. The loosely coupled layers of the education system, along with the wide array of semi- or fully autonomous intermediaries, do not form a unified infrastructure that supports improvement. Rather, they form a large, complex, and ever-changing institutional ecosystem. As a consequence, the investment challenge is a complex design problem with multiple dimensions. Funders must decide:

- Where in the educational system to focus their investments, e.g., higher education, K-12 education, early childhood education, informal learning, STEM education, computer learning.
- What to invest in, e.g., standards, assessments, professional training, curricula.
- Who to invest in to do the improvement work, e.g., regional labs, universities, state agencies, district leaders, informal science organizations, educational improvement non-profits.
- How to structure that investment, e.g., projects, partnerships, networks, centers.

We have learned that funders and others can easily underestimate the complexity of this design problem.

Focusing on Grand Challenges

A recent movement to spur innovation and focus investments has been to identify **Grand Challenges** for a field.[5] Grand Challenges transcend ordinary research questions; they seek to identify fundamental questions and deep structural issues that are blocking progress in a particular field. Grand Challenges identify problems where solutions are feasible but also where achievement of those solutions will require multiple, sustained research and development efforts over many years. The benefit of focusing on grand challenges is that they can provide shared focal points for foundations, researchers, developers and practitioners; they can stimulate interest, passion and common investment; and their solution will significantly advance the field by removing critical barriers and stimulating new imaginative innovations.

A special 2013 edition of *Science* magazine[6] was dedicated to "grand challenges in science education." A team of experts posed 20 Challenges, a set of problems and opportunities facing science education on a global level. Identified Challenges ranged from "Enabling students to build on their own enduring, science-related interests" to "Shifting incentives to encourage education research on the real problems of practice as they exist in school settings."[7] It is this

[5] "On April 2, 2013, President Obama called on companies, research universities, foundations, and philanthropists to join him in identifying and pursuing the Grand Challenges of the 21st century." From: https://obamawhitehouse.archives.gov/administration/eop/ostp/grand-challenges

[6] *Science,* Vol. 340 (6130), April 2013.

[7] Bruce Alberts, Editorial, *Science* Vol. 340 (6130), April 2013, p. 249.

Grand Challenge—the shifting of research toward real problems of practice—that is the focus of the R+P Collaboratory.

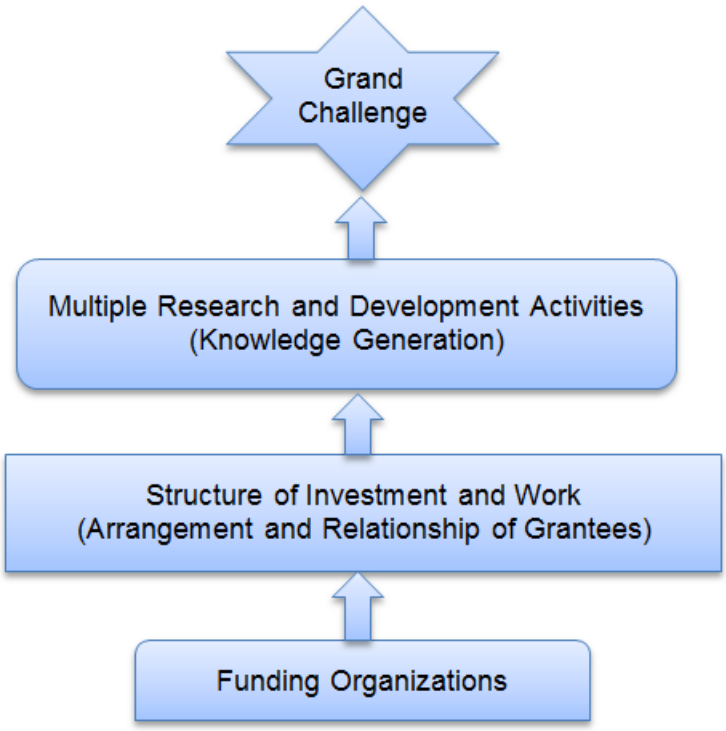
Structuring investments to address Grand Challenges

In science, NSFs investments in Grand Challenges have by necessity involved lengthy collaborative research arrangements. Studying climate change, gravity waves, or dark matter all require long-term investments in multi-disciplinary collaborative endeavors. More specifically, addressing Grand Challenges requires:

- A broad mandate and public visibility to focus attention on solving the problem
- The best expertise in the nation (or world) committed to and focused on the resolution of the challenge
- Institutional and technological capacity
- Sustained resources for cumulative work over many years
- Multiple perspectives interacting to formulate the problems to be addressed and to define the nature of the desired solutions.
- Independent explorations, as well as communication, sharing, mutual learning, and collaboration

Grand challenges require multiple steady sources of support for the ongoing work of setting research agendas and the pursuit of multiple lines of inquiry. The work needs to be structured so that it taps the expertise of the most expert institutions and individuals, while also remaining connected, coordinated, and mutually generative. All of this means that investments in a grand challenge need to be carefully structured.

Figure 1. The structuring of investments to address grand challenges



Common investment structures

How should foundations structure their investments in improvement? Should they make multiple competitive grants? Fund large centers? Form networks? Support consortia? We find that foundations and their advisors are rarely able to articulate the affordances and constraints of the structures they choose to support. Our studies of several dozen investments have revealed key characteristics of the most commonly used structures.

- A Project is a grant awarded to an institution, group, or even individual to accomplish a specific set of proposed tasks. Projects typically are tightly-defined, one- to five-year efforts with a relatively narrow focus and short-term goals. Examples include creation of a new professional development program, assessment, or set of instructional materials. Projects can build capacity—knowledge, leadership, other assets—but that is not their primary purpose. Most projects are awarded to groups with an established threshold of existing capacity and are aimed at direct service and immediate "impact," are meant to be catalytic, and have self-limiting life spans.

- A Partnership is an arrangement where two or more entities participate equally in the proposed work, each benefiting from working with the other. Partnerships allow individuals or entities to combine their resources and labors in a win-win arrangement. Examples of

partnerships include Math Science Partnerships (MSP), which connect a university and school system. Timespans for partnerships are variable.

- A Center is an arrangement for creating capacity for ongoing improvement in and strengthening of a domain or field. Centers are intended literally to exist at (or to form) the center of a field or domain (e.g., the Center for the Advancement of Informal Science Education). Functions of a center include: producing, collecting, distilling and sharing knowledge relevant to the domain or field; connecting and organizing leaders and resources across a domain or field; shaping and advancing policy; and advocating for growth and funding of the domain or field. Centers should be seen as long-term investments. Examples include the Centers for Learning and Teaching and Centers for Ocean Sciences Education Excellence.

- An Institute is an organization formed around particular purposes or ideas. Often research, education, and communication are central to their missions. Institutes may have a broad purview (the Aspen Institute) or a narrower focus (The Doug Engelbart Institute). They may be part of a university or self-standing. In general, they are meant to be continuing, autonomous organizations that attract their own sources of support.

- A Network is characterized by structures of nodes and links. Nodes can comprise individuals (Everett, 2011) or organizations (Barletta, et al., 2018). Networks may be open or closed, and they vary in the tightness and direction of flow among nodes and links. Networks can support the collaborative learning needed to scale an approach that has been proven successful, and can support capacity building across a field or domain. Examples include the National Writing Project, the Carnegie Math Pathways, and the National Informal STEM Education Network.

- Consortia involve looser, more autonomous affiliations based on an agreement to contribute to an enterprise that is beyond the resources of any one member. An example in education is the Consortium to Promote Reflection in Engineering Education (CPREE).

THE COLLABORATORY STRUCTURE

This report focuses on a different type of structure—the ***collaboratory***—which has a long history in the funding of Grand Challenges in sciences and engineering. The example of the RPC, we believe, makes the case that the collaboratory structure can be used to similar advantage to address grand challenges within the field of education.

What is a Collaboratory?

The invention of the term has been attributed to William Wulf, who as president of the National Academy of Engineering in the late 1980s and early 1990s became interested in the

potential of virtual collaborations in science. "Laboratories without walls" became a commonly used term.

In 1993, a National Academy of Sciences committee studied the notion of collaboratories and produced a report: *National Collaboratories: Applying Information Technology for Scientific Research*. This report included a recommendation to initiate a research program that would investigate "how to build, operate, and use collaboratories in support of science." Subsequently, a group of researchers formed the *Science of Collaboratories* (SOC) project to understand "the technical and behavioral principles that can lead to better, more successful design of collaboratories in the future."[8] The SoC operated through the mid 2000s. Through survey and case study work, SOC researchers developed a definition of collaboratory and identified the components of collaboratories that contribute to their success.

The literature on collaboratories, much of it generated by the SOC studies, describes collaboratories as structures that enable distributed individuals or groups to work on common problems or questions, share instruments and/or data, and have the potential to create new knowledge that would not otherwise be possible. Many collaboratories in science and engineering revolve around a particular (often very expensive) instrument that researchers could not access were it not for the collaboratory.

Dormans (2009), in a review of work in social sciences, argues that the collaboratory structure offers a number of affordances to research. He cites this excerpt from a review conducted by Olson et al. (2008):

> ***Collaborative research makes it possible to tackle research questions that would otherwise not be feasible to address (Thagard, 1997; Wray, 2002). Researchers work together because there are questions they want to investigate that they cannot undertake alone. In addition, funding agencies, which must respond to the needs of society and the political environment, have encouraged collaborative research. (Olson et al., 2008: 2)***

Dormans adds, "According to Finholt (2003: 22), the critical element of collaboratories might be the opportunity they allow for encounters, discussions, and sharing of ideas. Thus… a collaboratory is also an organizational entity that supports rich and recurring interaction around a common research focus among researchers who are both known and unknown to each other."

Olson, *et al.,* (2005) suggest that researcher readiness to collaborate is essential to a successful collaboratory. Other "must-haves" of high functioning collaboratories include:

- The collaboratory culture must be organically collaborative.

[8] Science of Collaboratories. http://soc.ics.uci.edu/. The SOC website inventories hundreds of collaboratories, their start dates and primary function, from the late 1980s to 2009. Most of the literature is based on examples from the sciences and computing, although a few are from the social sciences and education.

- Participants' motivation to work together must include having the right mix of skills required to achieve the goal and engaging in joint work that is enjoyable and productive.
- Participants must trust each other to be reliable, to produce high quality work, and to have each other's best interests at heart.
- The goals of collaboratory members must be aligned with the mission of the collaboratory.
- Participants must have a sense of group self-efficacy, i.e., the belief that they can achieve their goals despite barriers.

The Example of the Research+Practice Collaboratory

In 2012, the NSF included in its RFP a call for a STEM Education Resource Collaboratory within the Math-Science Partnership (MSP) solicitation:

> ***The MSP program also seeks to fund one RETA project for a STEM Education Resource Collaboratory that will focus on: (a) gathering and synthesizing knowledge from STEM educational research that can be meaningful for K-12 practitioners, drawing upon varied sources of research, including that which has been supported by NSF's Directorate for Education and Human Resources, particularly the past and current MSP portfolio; (b) designing innovative mechanisms of actively disseminating research-based findings to STEM educational practitioners and researchers; (c) providing approaches for practitioners and researchers to consider translational research in order to implement the ever-evolving research on effective K-12 STEM educational projects, programs, and practices; and (d) engaging educational practitioners and STEM education researchers and social/behavioral/economic sciences researchers in identifying areas of mutual interest for further educational research.*** *(Emphasis in the original.)*

Three final proposals were submitted, and the grant was awarded to what is now known as the Research+Practice Collaboratory (RPC). The Principal Investigators (Bronwyn Bevan of the University of Washing (the Exploratorium at the time of the grant); Bill Penuel of the University of Colorado, Boulder; Philip Bell of the University of Washington; Joni Falk of TERC[9]; and Barbara Berns and later Pamela Buffington of EDC) were known to one another as having key expertise and interest in the focus of the solicitation, along with a shared particular interest in creating partnerships between researchers and practitioners as a means to achieve the goals.

The Partners

The Exploratorium, known for its leading work in informal STEM learning, led a local laboratory that explored equity-oriented tinkering in afterschool programs. Bevan, who had been working on ways to bridge the research-practice gap in informal science learning, formed a team of researchers and practitioners in San Francisco Bay area informal learning institutions to study different approaches to equity in afterschool learning.

[9] TERC's initial role was to lead the development of a web-based collaboration space and archive. TERC left the Collaboratory near the end of Year 2. See the Challenges section below.

The Education Development Center is known for its work with school systems, curriculum, and understanding problems of practice at all levels. The EDC local laboratory, led by Buffington in the final three years of the effort, involved a partnership with elementary teachers, school and district leaders, and university researchers to explore early math learning iPads[10].

At the University of Washington, Bell formed a local laboratory around the co-designing of a district-wide STEM curriculum. With teams of university faculty and graduate students, teachers and district leaders, this lab worked to implement a new vision for science that centered on STEM practices.

Penuel, an expert in research-practice partnerships, spearheaded the work at the University of Colorado, Boulder, designed to create formal and informal opportunities for researchers to learn about Design-Based Implementation Research (DBIR) approaches to collaborative research partnerships.

As a partner in the collaboratory, Inverness Research brought knowledge of informal and formal education improvement work and capacity to conduct case studies of the labs and the collaboratory itself.[11]

SRI served as the external evaluator of the collaboratory with the mandate of studying its contributions to the field.

THE GRAND CHALLENGE: BRIDGING THE GAP BETWEEN RESEARCH AND PRACTICE IN STEM EDUCATION

In education as in other fields such as medicine, there has been much discussion of, and attempts to resolve, the problem of the "gap" between research and practice. In particular, there is concern about what seems to be little contribution by research toward helping practitioners solve the problems of practice they face on a daily basis.

In education, many factors contribute to this gap. First, the research enterprise is largely carried out by researchers in universities and specialized research labs without significant involvement of school systems or informal institutions except as test-beds. Universities as institutions operate according to policies, incentives, and multiple other structural and cultural elements that do not align well with those of school systems; thus, researchers and practitioners do not interact as members of a unified profession. For example, the incentive for many researchers is to meet publication standards refereed against university research standards rather than school system utilization standards. Thus, exchange of research knowledge functions in a somewhat closed loop.

[10] EDC's initial attempt to create an RPP did not succeed. See the Challenges section below.
[11] Inverness developed written case studies of each of the three local labs. http://inverness-research.org/2018/07/30/portfolio-research__practice_collab/

Standards, curriculum frameworks, textbooks, and assessments, along with teacher professional preparation and development programs, are the components of the education system that administrators and teachers encounter, employ, are held accountable to. While these are the primary vehicles by which educational research gets translated for use in practice, the quality of those translations can vary according to the state and local policies that dictate the choices of what teachers use. Further, many practitioners are not able to discern the research basis of these translations.

In short, the institutions of researchers and practitioners are governed by different rules, and there are few incentives or effective mechanisms to meaningfully connect their worlds.

The RPC's stance: Adaptation rather than adoption

Modeled on recent developments in the medical field, the Research+Practice Collaboratory took a stance that shifts the effort to bridge research and practice from adoption to adaptation. Adaptation allows for the recognition that the institutional divide represents a cultural gap, and that translating research to practice should be reframed as cultural exchange. From the RPC proposal, which drew on the work of Palinkas, et al. (2009) and Palinkas (2010):

> ***Such exchanges—characterized by collaboration and adaptation—have been effective at changing practices in clinical settings where knowledge products of researchers are taken up, adapted, and implemented, and in research settings where practitioner knowledge is integrated into the design and conduct of research.***

The RPC team also identified design-based implementation research (DBIR) as an approach to generating knowledge that would be directly usable in practice. A principle of DBIR is that the focus of the research should be on a "persistent problem of practice." In the case of the RPC, this problem was the gap dividing "research-based evidence and evidence-based practice" in STEM education.

The Collaboratory designed its work to achieve three goals: 1) expanding awareness of and access to usable knowledge generated through research and practice in dialogue with one another, 2) creating forums for critical engagement across research and practice communities, and 3) developing and studying new models of research-practice collaborations that can lead to transformational and sustainable change in STEM education[12].

Binding the strategies together was the key principle of converging the lenses of researchers and practitioners. At multiple levels and in multiple forums, the Collaboratory sought ways to create activities and tools that would connect research to practice (and researchers with practitioners)—and to do so in ways that would disrupt the status quo of researcher-practitioner (and research-practice) relationships. For this purpose, the RPC deliberately

[12] From the RPC Implementation Plan.

brought together like-minded researchers to work together towards an explication of the possibilities afforded by the cultural exchange approach.

Key design features of the R+P Collaboratory

A number of overarching features framed the effort and the structures that PIs developed to undertake it.

Orienting principles

- Autonomy and collective action. PIs inquired into the ways the Collaboratory structure could support a productive set of literally ***collaborating laboratories***. Each laboratory was funded to focus its inquiry on locally identified problems of practice and generation of knowledge to solve local problems. At the same time, the Collaboratory functioned as an entity in and of itself, with its own mission, funding, and identity. Thus the Collaboratory directly promoted the unique interests and expertise of the individual labs while focusing the work on the Grand Challenge.

- A focus on specific domains within STEM. The Collaboratory identified relatively narrow domains to initiate the local lab inquires: cross-setting learning, cyber/computer-assisted learning, and STEM practices. PIs believed that these were critical to tranformative CCSS Math and NGSS implementation and also vulnerable to weak implementation. Robust research-practice relationships could generate knowledge, tools and resources to be utilized in those areas.

- Emphasis on issues of diversity, equity and inclusion. A focus on equity functioned as both a goal of and a means to increase integration of research and practice. Over time the discussions became more explicit and the tools produced became more directly related to promoting greater equity in process and outcomes.

- Inquiry and conjectures. The Collaboratory formulated a shared framework for inquiry into the problems of bridging the gap between research and practice. At the beginning, the RPC created "conjecture maps" (Sandoval, 2014) to guide their inquiry into research-practice partnerships. In the first 2 years, RPC PIs put considerable effort into outlining shared conjectures about outcomes that would reflect productive interactions between research and practice. The intent was to use the conjectures to map both individual local lab inquiries and to frame the RPC's collective knowledge generation. The process of working through the conjectures also brought values to the surface and created a process of mutual learning across the laboratories.

Multiple types and levels of activity

The Collaboratory sought to promote research-practitioner interactions through multiple strands of work. Each strand interacted with and complemented the other. By targeting "retail"

and "wholesale" levels, the activities formed a kind of vertical integration, allowing the Collaboratory to work on the ground in educational settings, to engage leading researchers and practitioners, and to interact with national professional and policy leaders.

- The local labs served as ground-level efforts to create integrated partnerships of researchers and practitioners targeted to a range of local problems. These labs worked from principles of DBIR to focus on problems of practice arising from practitioners' observed and voiced needs, and engaged practitioners in making meaning from research and framing the development of tools and resources.

- The Collaboratory focused a great deal of their resources and energy on the collaborative design and development of a range of resources and tools intended to be useful to practitioners, to researchers, to educational leaders, and to policymakers.

- Higher-level activities, such as multi-day inquiry group meetings, brought together leading-edge researchers and practitioners from across the local labs to foster critical exchange of ideas and perspectives. Outcomes of these meetings—insights, R+P practices, templates for knowledge tools—strengthened the collective output of the Collaboratory as well as informing local work.

- Workshops and webinars brought together faculty, post-docs, and graduate students from around the country to orient them to practices of collaborative research involving practitioners. In this way, the RPC hoped to disrupt tradition by habituating early career researchers.

- Some activities focused on professional associations networks (PANs) to raise awareness and add value to their own efforts to better connect research and practice. For example, the RPC built long-term relationships with leaders of professional associations (e.g., NSTA) and policy groups, (e.g., CCSSO) to build awareness and add value to their efforts to bridge research and practice. For these and other groups, RPC PIs sponsored conferences and hosted meetings on RPPs and DBIR, as well as opportunistically responding to opportunities to make presentations at network association meetings.

- A communications team focused on various channels, such as web site development and social media, for sharing the work of the collaboratory and fostering greater engagement with the field.

Continued focus on capacity building

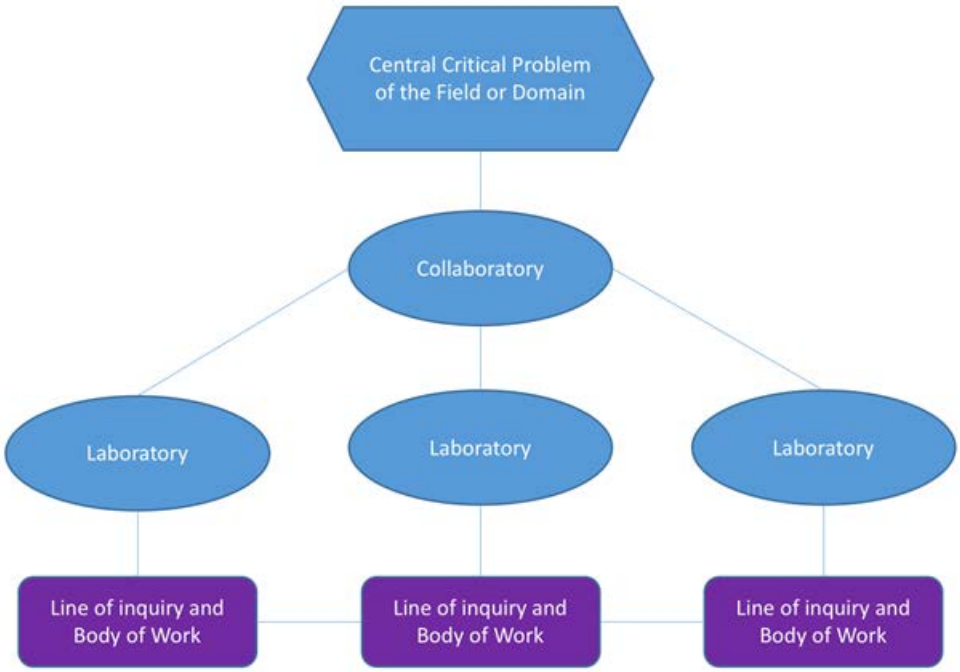
The Collaboratory not only concentrated multiple research efforts on bridging research and practice, but it also prioritized capacity building in the field as a primary contribution of their work. Through workshops, seminars, professional meetings, presentations, publishing, and distribution of tools through web sites, they worked continuously to make the field more

inclined and more capable of recasting the ways that research can interact with practice. All of this varied work and production was tightly focused on addressing the challenge of bridging research and practice.

Generalizing from the R+P Collaboratory

The work of the Collaboratory generated knowledge about collaboratories as an organizational and funding structure as well as knowledge about bridging research and practice. Our model of the collaboratory structure is illustrated in the diagram below:

Figure 2. A Collaboratory Model



In this model, a collaboratory is formed to address a grand challenge (long-standing critical problem) in the field by identifying, supporting, and connecting individual laboratories working on facets of the challenge. Each individual lab is committed to pursuing its own line of inquiry and body of work, while also being committed to supporting one another, learning from one another, and contributing to the broader effort of the collaboratory as a whole. The collaboratory hub organization helps support individual labs, fosters sharing and critical review, and represents the work of the labs to the field.

THE PERCEIVED BENEFITS OF A COLLABORATORY STRUCTURE

The role of Inverness Research was not to assess the R+P Collaboratory's efficacy or contributions to the field; that task was assigned to SRI. In our many rounds of interviews of PIs and observations of their work over several years, however, we learned much about how the Collaboratory has benefited its members and generated value for the field. What follows is a brief summary (in their own words) of the perceptions of the Collaboratory leaders about what made the Collaboratory distinct and beneficial as a structure and context for their work.[13]

Comparative advantages of the collaboratory structure

- Individual researchers and their labs gain broad access to knowledge and opportunity through collaborative work with other labs.

  The different staff members in each of these laboratories have different perspectives on the work and that adds value. For example, if we are doing work that is close to practice in classrooms, we can connect to people in different labs with, say, an expertise in informal education. You can learn about examples there that you can bring to your setting. So this illustrates how some of the ideas and problems you encounter scale beyond your own setting.

  We advance our own thinking… For example, about how research practice partnerships are supposed to be different than other research projects…

  There are multiple ways we can leverage other people's experiences and expertise… I get to see themes that wouldn't necessarily occur to me if I weren't exposed to their work… or get feedback on challenges we might have.

- Collaboratories offer degrees of freedom and opportunities not found in individual research projects, centers, and other contracted structures.

  We get to do some things in the Collaboratory that we can't do in these other contexts, because of the funder, or the context we work in… The fact is that this is different, more free, than a contract or grant.

  'Collaborating laboratories' is a good image. It replaces the bad parts of being a Center… I think we were trying too much be a center a year or two ago when there were some forces moving us to become fully coordinated… But now the way it works with collaborating laboratories is to have some level of assumption that we are working in a shared space and so when we come and talk with each other about what we each are doing, we are actually talking with each other as opposed to past each other.

[13] Quotations in this section are from collaboratory members, primarily the Co-PIs. Many of these leaders have extensive experience with centers, networks, partnerships and other investment structures.

> ***In the Collaboratory there is flexibility of the funding within a certain constraint that is really different than an individual project constraint. That allows you to be opportunistic with your partnership development, which I think is actually a positive… We are able to say, 'oh wow, there is some energy around this idea, let's follow it, let's spend some time here and let's invest in this.' And that is not your typical research project that has a well-defined, or at least mostly defined, scope to it.***

- The Collaboratory created a unique infrastructure for communication across multiple labs and from the labs to the field.

> ***I definitely think that the communication in our collaboratory is unique. Having a little [communications] infrastructure once we reorganized was really powerful and I am really missing it now [at the end of the grant]. I really feel its loss, especially managing social media. We decided not to replace [the key person overseeing communication], and just use that funding to back things up, but I really miss that.***

- The Collaboratory functions as a more visible entity which can leverage support and combine expertise.

> ***The Collaboratory provides us with opportunities to develop additional relationships that can move the work further. For example, with the PIs we have opportunities to look for additional funding and different environments to leverage the work… We can also bring own networks to address a particular problem or involve them in a new collaboration.***

Generating greater value for the field

- The Collaboratory structure builds internal capacity that can extend into the field both locally and more broadly.

> ***[The Collaboratory] is a really powerful model because in the work that we do, we not only create these additional deeper relationships, but we also help build the capacity of schools and districts…We have created partners who can establish and maintain networks that then can be used for additional opportunities for improvement. Once that network has been created, then you can really use that network of people and relationships to move other work forward. To me it creates a longer life of the work and extends it over time.***

> ***Three or four years ago, the 4 PIs could have given that talk about research and practice, but now we have probably 25 to 30 people who could do that—whether they are people from within the [local lab] teams or people that we have collaborated with. We now have evidence of why those ideas are important, and details on how to do it, and many players who can talk about it.***

- The Collaboratory has produced multiple examples of RPPs and high utility research through its several labs, which promotes greater legitimacy in the field.

> ***I do more big-picture talks, not specific study results, which is a different genre of talk. The Collaboratory gives some concrete ideas and examples for landscape pictures of this work, like what does it mean to engage professional associations. We have sustained engagement, we get to know the politics of the organizations and work with them over time… The ongoing-ness of the partnership is what makes it different.***

CHALLENGES INHERENT TO COLLABORATORY STRUCTURES

Our study seeks to inquire into the extent to which the collaboratory structure—as exemplified by the RPC—represents an optimal arrangement for the funding of Grand Challenges in education. Our analysis would be incomplete without recognition that the collaboratory structure presents challenges. In fact, Dorman (2009) emphasizes that if there is one piece of advice emerging from the literature on collaboratories, it is "not to underestimate the challenges and problems accompanying such an enterprise… Academic collaboration is difficult to organize, it is difficult to sustain and there aren't that many successful examples around."

The R+P Collaboratory faced many of the issues and struggles that other collaborative research efforts have also faced. Many of the more difficult questions faced by the leaders of the Collaboratory can be seen as inherent tensions of design. From the Collaboratory experience we have identified the design choices and tensions that any collaboratory is likely to encounter:

1. Identity, governance, and control. From the outset, there were questions around the extent to which the R+P Collaboratory's work should be centralized, *i.e.,* the degree to which individual lab activities should be overseen and shaped by a consensus of the PIs *vs.* the degree to which the work should be left to the discretion of the member labs. Also, there was a continuing question about the allocation of Collaboratory resources: What percentage of resources and work were to be allocated to the hub organization, and what percentage to support the member labs to do their individual work?

Governance structures and practices had to evolve and be refined continuously. Eventually the vision of collaborating laboratories connected by a central hub became a productive and useful metaphor for organizing the Collaboratory. This process involved conflict and struggle. In fact, an original PI abandoned the Collaboratory over a dispute about the design and control of the Collaboratory website and communication strategy. Other issues to be dealt with by the collaboratory included questions that revolved around distribution of funds, product credit, and website location and control of content.

Overtime, the role of the central hub became clarified around the following functions:

- Representing the work of the member labs to the broader field
- Advocating for research practice partnerships more broadly
- Creating an internal forum for sharing and reflecting on the work of the individual labs
- Coordinating the work of members in sub-projects

- Organizing collaboratory-wide events for others to learn about the grand challenge
- Designing and implementing a communication and resource dissemination strategy
- Organizing regular meetings and retreats for collaboratory members

Those roles, however, did not limit local labs' autonomy to represent the collaboratory, advocate for RPPs more broadly, and develop web sites to host their own tools and resources.

2. Collaboratory goals and local agendas. The Collaboratory faced a kind of paradox of its own making. On the one hand, the Collaboratory PI group held strong values about the importance of equity, equal voices, and being highly responsive to local perspectives and needs (problems of practice). On the other hand the Collaboratory was funded by NSF to generate knowledge about research and practice that could be useful to the nation as a whole.

This tension manifested itself, for example, at the level of the local labs where researchers wanted to address a given challenge (*e.g.*, equity in informal learning) and yet at the same time wanted to shape the research work they were doing in the field around the felt needs of practitioners, which may or may not have aligned perfectly with the foci of interest to the Collaboratory. This required two levels of work—one that was highly responsive to local interests, and the other at a meta-level that required the generation of knowledge and production of generalizable resources flowing from the local work.

3. Membership: The interaction dynamics between individuals and between organizations. The initial group of people and institutions forming the nucleus of the collaboratory need to be well matched. Many decisions have to be made through some sort of consensus process. The question of adding additional members (or dropping members) is likely to emerge. Ultimately, people involved in a collaboratory need to trust and respect each other, perhaps even like each other. Forced, awkward, or unnatural collaborations will probably not evolve into successful arrangements.

4. Authority dynamics between research and practice. The Collaboratory, with its focus on bridging research and practice, worked very hard to make sure that researchers' language, viewpoints, experiences, and professional status were not privileged in the interactive spaces where they came together with practitioners (*e.g.*, inquiry groups, local labs). The Collaboratory was itself a research effort, and thus potentially subject to the same "failings" as other research efforts, particularly in terms of intellectual authority, use of jargon, and so on. At times members of the Collaboratory found themselves challenged to "walk the walk" as well as "talk the talk" in terms of its own operations. Ultimately, it became clear that the two domains of research and practice were not completely symmetrical *vis a vis* the mission of the Collaboratory. The Collaboratory put more effort into and was much better positioned to influence researchers and the research domain—that is, to try to change the culture and perspective of researchers—than to shift practitioner perspectives of research. Nonetheless, within the local labs, a number of practitioners who were most deeply involved in the work

reported gaining new insights into research as well as more comfort and confidence in their own professional voices[14].

5. Shared theoretical vision and framework. There is nothing inherent in the notion of a collaboratory that all members share a common approach and perspective as they focus on a Grand Challenge. Because of the composition of this group of member organizations and the power of some Collaboratory leaders, this Collaboratory evolved toward a shared and perhaps radical approach to bridging the gap between research and practice. In fact, they more or less jointly rejected the notion of "translating research to practice" as described in the NSF RFP. Rather, they sought to develop and promote the idea of cultural exchange and interaction between researchers and practitioners in the very doing of the research. While not a huge source of conflict in the R&P Collaboratory,[15] different perspectives and approaches could be a problem in other collaboratories where members do not share a unified view.

What turned out to be a source of struggle in this Collaboratory was the degree to which and the ways in which the Collaboratory could formulate a shared framework for investigating the grand challenge. Initially, the leading idea was to use Sandoval's (2014) method of forming "conjectures" to frame their individual design-based research partnerships so as to allow cross-lab summaries and aggregated research results. The conjecture process proved to be impractical and the conjectures received less attention as time went on. There were differing views ultimately about the value of the conjectures:

> ***The conjectures are clumsy, and we still struggle with how to use them in an elegant, light touch way… I do think that we are in agreement about the general nature of what we are trying to investigate, but we are not there yet in terms of understanding what [the conjectures] are revealing to us.***
>
> ***It was highly productive for us to go through the conjecture process, even if at the end we did not revisit them all the time… They did help us with our write-ups, and they did help us establish a shared framework and vision.***

[14] The cross-case study provides evidence for this statement.

[15] However, one initially planned local research-practice partnership failed in part because of a lack of comfort and confidence with DBIR principles; a change in the PI paved the way for a partnership more in line with the more powerful voices in the Collaboratory leadership.

SUMMARY THOUGHTS ABOUT THE COLLABORATORY STRUCTURE

The advantages of a collaboratory structure—**collaborating laboratories**—are many, including access to funding that might not be available to an individual lab, pooling of disparate expertise, sharing knowledge and results that can lead to new collaborations and lines of inquiry, greater visibility to the field, and wider dissemination channels.

For the field the R+P Collaboratory produced book chapters and journals; conference presentations, seminars, workshops and meetings; case studies; tools and resources, including an array of online resources. Locally, the Collaboratory worked intensively in several settings and contributed significantly to local improvement. And perhaps most importantly the Collaboratory contributed to building the capacity of the field (researchers, practitioners and policymakers) to re-think how research and practice can better engage and interact with each other.

In this section, we draw on our discussion of collaboratories as an investment structure to highlight their defining elements, their contributions, and their potential in the education domain.

Defining Features

Through our review of the research and our work with the R+P Collaboratory, we have developed our own working definition of the collaboratory structure as it functioned in this case:

> ***A collaboratory is a supported arrangement of cooperative, non-competitive laboratories with different expertise, perspectives, and lines of inquiry that work in collaboration as well as individually to address a Grand Challenge in the field. A collaboratory generates theoretical as well as practical knowledge to solve important problems, and through this work, develops the human and social capital required to continue to make progress on the challenge.***

These key features of the R+P Collaboratory reflect the affordances of this collaboratory structure:

- Created to attract and focus investments on a Grand Challenge—the gap between research and practice—which has hindered the improvement of STEM education

- Focused solely on that challenge to better understand its root causes and address them at multiple levels and in multiple ways

- Identified, connected, and supported the work of strong individual laboratories already working on that problem or could contribute to the solution of that problem

- Organized so that funding could be used to support each laboratory in drawing on its greatest strengths and pursuing its own work

- Designed ways to promote connection, sharing, critical review, and communication between the labs

- Supported emergent opportunities for labs to engage in collaborative research, education, and communication efforts

- Advocated jointly for the importance of the Grand Challenge problem, and for the work of the labs in addressing that problem

- Designed to be creative and opportunistic in finding ways to create more capacity in the field to address the challenge over the long term

The affordances of the Collaboratory structure: Implications for funders

Foundations, government agencies and other funders of educational improvement face a very difficult challenge as they develop their investment targets, theories, and structures. The case of the R +P Collaboratory serves as an illuminative experiment for NSF and others as they design future investments in educational improvement.

Our study of the R+P Collaboratory shows that the structure provides a number of affordances that other typical investment structures—such as center, projects, and partnerships—do not. A collaboratory has a scale and depth that give it potential to identify, define, and address Grand Challenges in the educational domain. The collaboratory structure implies a long-term (semi-permanent) organizational entity with stature, imprimatur, and capacity to make the challenge more visible and garner resources to address the challenge. A collaboratory can attract and leverage the best individual talent in the field to address that challenge, as well as arrange for a diverse range of expert laboratories to do individual and collective inquiry into the challenge. Through its work at multiple levels in multiple arenas, the "collaborating laboratories" can significantly enhance the national capacity to address a Grand Challenge through development of new theory, practical knowledge, expertise, leadership, and commitment.

The collaboratory structure affords foundations the opportunity to engage the strongest members in a field without 'silo-ing' them, without competitive limitations, and without diminishing their individual expertise. A particular advantage is that a collaboratory can optimize the strengths of the individual laboratories. Too often, center and partnership structures demand a degree of mandated collaboration that becomes over-centralization where the costs and constraints of working together outweigh the benefits. (We sometimes use the analogy of the three-legged race, where strong runners are tied together. The binds that connect them hamper the abilities of the individual runners.) Any collaboration can become over-prescribed. However, the collaboratory (when managed so as to overcome inherent

barriers), affords greater potential to maintain the strengths of individuals while also optimizing the benefits of connection.

While a collaboratory structure empowers individual leaders and labs, it also creates a new collective identity where the whole is more than the sum of the parts. This gives it the advantage over multiple individual grants. Thus we suggest that collaboratory arrangement creates an authentic win-win investment structure: the participating labs benefit from their involvement, and the collective effort of the collaboratory benefits from the work of each of the labs.

There are few opportunities in education for long-term, problem-focused, mission-driven, collaborative research initiatives in education. The education field, and STEM education in particular, has tended to focus on short-term catalytic efforts along with some broader capacity-building projects. The case of the R+P Collaboratory suggests that the collaboratory structure can function within education, as it does in science, to provide both short- and medium-term results as well as build ongoing capacity for future work. When carefully designed and managed, the collaboratory serves as a funding structure with greater affordances than other structures for addressing Grand Challenges in the improvement of education.

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