COMBINING RESEARCHERS' AND PRACTITIONERS' INTELLIGENCES FOR STEM IMPROVEMENT

A STUDY OF THE LOCAL LABS OF THE RESEARCH AND PRACTICE COLLABORATORY

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I. INTRODUCTION

The Research and Practice Collaboratory (http://researchandpractice.org) was funded by the National Science Foundation to bring research and practice together in effective ways to address core problems of STEM improvement. The Research and Practice Collaboratory (RPC) supported projects in three states—California, Maine, and Washington—that had the function of serving as "Local Labs" for the RPC. While these labs worked independently on specific, local STEM improvement problems, RPC leaders (all of whom were co-PIs of the RPC) held themselves to shared conjectures (cite) about their work and its outcomes, convened multi-lab inquiry groups to probe cross-cutting issues, and met regularly to envision and plan RPC strategies and products.

Each Local Lab was formed explicitly as a research-practice partnership (RPP), with dual purposes: 1) Address local problems of practice and producing usable, evidence-based knowledge for STEM improvement, and 2) Serve as existence-proofs of research-practice partnerships that thrive in a variety of institutional configurations. The Local Labs individually and the RPC as a whole also aimed to produce knowledge products—e.g., tools, slide decks, webinars, articles, and so on—that would contribute to the field, both to support STEM improvement and also to promote and support research-practice partnerships as an effective way to make research more valuable to the improvement of practice.

Inverness Research documented the formation of the Local Labs for the RPC and produced a detailed case study of each site.[1] The case studies aim to portray distinctive features of the design and work of the Labs as research-practice partnerships, as well as the multiple benefits of the partnerships. This paper looks across the cases to distill key findings and reflections.

Framing concepts for the Local Labs

Leaders of the RPC envisioned the Local Labs as **research-practice partnerships** (RPP) that would engage in a process of design-based implementation research (DBIR). This approach to improving education differs substantially from traditional educational research, where researchers identify important research questions and design studies to generate theory and pedagogical principles (sometimes using classrooms as laboratories, sometimes not), and where practitioners apply those to practice. Research-practice partnerships organize researchers and practitioners into non-traditional relationships and roles, and design-based implementation research serves as an approach that changes the research process and purposes.

[1] See http://inverness-research.org/2018/07/30/portfolio-research__practice_collab/.

Coburn, et al., (2013) discuss cases of research-practice partnerships among universities and school districts. She identifies five major ways in which research-practice partnerships "differ from the conventional ways researchers and district leaders work together." Research-practice partnerships are arrangements that:

1. Are long-term
2. Focus on problems of practice
3. Are committed to mutualism
4. Use intentional strategies to foster partnership
5. Produce original analyses. (p.6)

Within the Coburn taxonomy of district-university partnerships there are three types. One of them is "Design Research," which is characterized as being "similar to engineering research" in that "the aim is to build and study solutions at the same time in real world contexts. It usually focuses on developing and testing instructional activities and curriculum materials, while investigating how they can best support student learning" (p. 12).[2]

Penuel[3], et al. (2011) introduced **design-based implementation research** (DBIR) as having key features that imply the kinds of partnership elements that Coburn defines, as well as serving the multiple purposes of generating theory *and* fostering change in classrooms and even systems:

> ***What distinguishes this approach from both traditional design research and policy research is the presence of four key elements: (a) a focus on persistent problems of practice from multiple stakeholders' perspectives; (b) a commitment to iterative, collaborative design; (c) a concern with developing theory related to both classroom learning and implementation through systematic inquiry; and (d) a concern with developing capacity for sustaining change in systems.***

The Local Lab cases provide examples, or existence proofs, of these non-traditional ways to organize and conduct studies aimed at STEM improvement.

Overview of the local labs' accomplishments

Why so carefully document the design and functioning of the RPC local labs? The initial impetus to do so—with an emphasis on design and functioning—stemmed from the Collaboratory leaders' idea that research-practice partnerships need to be known about not merely because they are non-traditional, but because they may comprise part of the solution to the long-standing and long-recognized problem of the gap between research and practice, which often

[2] Others are 1) "Research Alliances," where independent research groups study questions of importance to the district and funnel findings back to the district. Research alliances do not involve the collaborative design/implementation component. And 2) "Networked Improvement Communities," which are larger networks of districts engaged in rapid cycles of testing to identify solutions to problems in multiple contexts.

[3] Bill Penuel, University of Colorado, was a Co-PI of the RPC.

manifests as a gap between theory and implementation. In the quest to make research more relevant and valuable to improvement, the forming of partnerships that connect research with practice—that combine the intelligences that span these worlds—can be seen as a rational approach. By documenting how this non-traditional approach works and what it takes, we hope to contribute knowledge to the field.

However, learning about the design is only important if the non-traditional arrangement functions to generate knowledge and practices that have value. Leaders of Local Labs have generated a number of knowledge products, articles, and studies to explain and disseminate the benefits of their work[4] —and the work of the labs continues. Accomplishments that Local Lab have documented include:

- Improvements in teachers' confidence and knowledge for teaching STEM subjects.
- Changes in teachers' classroom practice that are aligned with NGSS vision and approaches and that promote more equitable learning opportunities. These include:
    - Engaging students effectively in argumentation, explanation, modeling, and engineering design
    - Making their classrooms more student-centered
    - Engaging their students more in scientific and mathematical talk
    - More effectively engaging English learners and other at-risk students in classrooms and after-school programs, including the addition of social-emotional dimensions of learning
- Improvements in student engagement and learning, including their scientific and mathematical reasoning, as well as their confidence, risk-taking, and other social-emotional outcomes.
- Providing professional learning that teachers value and put to use.
- Institutionalization of new approaches in participating districts, with scaling to additional districts in some areas.
- Deepening researchers' understandings of what works to promote positive educational change.
- Enhancing teacher educators' and district leaders' insights about, and repertoires for, supporting instructional improvement.
- The creation of a new framework for after-school education that promotes equity through multiple facilitation strategies.
- Development and dissemination—locally and nationally—of widely used resources for professional learning.
- Delivery of MOOCs, conferences, and workshops on STEM improvement solutions and tools, as well as on ways to structure research-practice partnerships.
- Increased university capacity to conduct research in partnership with schools and to conduct a wider range of studies.
- Increased leadership capacity within schools, districts, universities, and informal science institutions to collaborate on research and improvement efforts.

[4] See for example, http://researchandpractice.org/ and http://learndbir.org/.

For a fuller summary, see the Appendix.

Developing the cases

In our documentation of the design and functioning of the partnerships, we addressed these questions:

- What were the key elements of design and operation that enabled the RPPs to form and to evolve in productive ways? How and why were those elements important?

- What can be learned from these three cases? What are the implications for linking research and practice?

Data collection focused on how the local labs were formed, how focal problem areas were defined, how practitioners and researchers interacted to carry out the work, and how the work and partnerships have benefited both researchers and practitioners. For each case, data collection concentrated on the first two years of the partnership. To capture how the partnerships had evolved near the time of report writing, we conducted follow-up interviews to form an epilogue for each case. Data consisted primarily of interviews designed to document the multiple perspectives of the participating researchers and practitioners (and sometimes the teachers they worked with in programs) over time. We also observed a small number of key activities. Case narratives were member-checked and revised through three cycles of data collection.

The Cases

California lab The California Tinkering Afterschool Network (CTAN), brought together practitioners (leaders, directors, facilitators, and line staff) working in the afterschool domain with educational researchers from the Exploratorium. CTAN was officially led by the Exploratorium in San Francisco, with the following primary partners: Community Science Workshops (in Watsonville and Fresno), Discovery Cube (Discovery Science Center) in Santa Ana, and Techbridge in Oakland. A primary purpose of the CTAN RPP was to involve the voice of practitioners in testing and adapting research findings relevant to the afterschool and Tinkering contexts, and designing, implementing, and studying STEM-Rich Tinkering opportunities in afterschool settings that served traditionally under-served youth. *See also: https://inverness-research.org/2018/07/30/portfolio-research__practice_collab/ and https://www.exploratorium.edu/education/california-tinkering-afterschool-network.*

Maine lab Education Development Center (EDC) formed a partnership with the Auburn School Department to focus on early math learning and the use of technology, contextualized by a state-supported one-to-one iPad program in the primary grades. The partnership connected pre-K-2nd grade teachers and administrators in Auburn with researchers from EDC and two universities, University of Southern Maine and the University if Maine at Farmington. The partnership concentrated on developing shared visions of practice, designing and studying interventions to address key problems in math learning, and documenting RPP practices and promising early math instruction practices for dissemination in the field. *See also: https://inverness-research.org/2018/07/30/portfolio-research__practice_collab/ and http://interactivestem.org/.*

Maine "1.0" EDC initially approached the Maine Physical Sciences Partnership as a partner. Various interactions among leaders in the key organizations continued for well over a year, including meetings to discuss mutual interests, a workshop on DBIR, and exploratory data collection related to supporting teachers with video cases. Ultimately the partnership did not form and EDC initiated the partnership with Auburn. The Maine PSP was halfway through a 5 year grant and it proved too challenging to add the partnership layer onto it. Challenges included merging research shaped by partnership norms and DBIR practices with more traditionally designed research already underway, and the inability to identify a problem focus of mutual interest and benefit. (This narrative appears as an appendix in the Maine Interactive STEM case*:* *https://inverness-research.org/2018/07/30/portfolio-research__practice_collab/*.)

Washington lab The RCP-supported research-practice partnership in Washington State was launched as a collaboration between two projects: the Partnership for Science and Engineering Practices (PSEP), a state-funded Math-Science Partnership, and the Research Plus Practice (R+P) project at UW. The PSEP supported groups of teachers working together to adapt their existing science curriculum to the Next Generation Science Standards. District partners in the PSEP were Seattle Public Schools and the Renton School District. Through the UW R+P project, the researchers aimed to collaborate with the PSEP to add direct value to the PSEP work, develop research-practice relationships around problems of practice involved in teachers' changing practices to meet the new NGSS, and generate usable knowledge for the districts and for the field. *See also: https://inverness-research.org/2018/07/30/portfolio-research__practice_collab/ and http://stemteachingtools.org/about.*

II. KEY ELEMENTS OF DESIGN AND FUNCTION

Our cross-case study probed for features of design and function that contributed to the success of the partnerships and that were shared by all three labs. Critical features fell into two broad dimensions: the relationships that formed the partnerships, and the nature of the work, which combined researchers' and practitioners' intelligences for improvement. Additionally, the organizing structure of the Collaboratory strengthened the work of each lab, as well enhancing their contribution to the field beyond the sum of the parts.

A. RELATIONSHIPS: FORMING THE PARTNERSHIPS

Research-practice partnerships run counter to typical practice in education. The RPPs that formed the local labs of the RPC had the advantage of strong precursors that gave them a running start, including experienced leaders committed to their success. Those leaders ensured that each partnership included several key ingredients that sustained the partnerships and made them productive.

Forming the research + practice partnership required *continual deliberate effort* to build a trusting relationship among researchers and practitioners. This effort was initially led primarily by the researchers.

This section breaks down the several elements of partnership formation that contributed to the success of the partnerships. Leaders did not merely assemble these elements at the beginning and assume they would cohere; rather, they devoted continual, purposeful effort to tending them. In other words, these partnerships do not "form"; rather, they were continuously "forming."

1. A running start

Just as a delicious meal requires good recipes, the recipes are not sufficient with the presence of good food. The partnerships began with rich ingredients in place.

Each of the partnerships that thrived began with four important elements: a particular worldview about educational research, enough leaders and partners with boundary-crossing (or "dual citizen") skills, prior working relationships among key players, and membership in the national R+P Collaboratory.

"Worldview" about research

Research-practice partnerships represent (and assert) a value-proposition within the broader field. These cases reflect the work and accomplishments of a subset of researchers who share certain values about research and the contributions of practitioners. A leading researcher at

one lab explained how a "theoretical worldview" about the value of collaborative research for "understanding the phenomena" drives these researchers. Further, this researcher positions researchers who believe in collaborative research as being in a "different world" from researchers who believe in the more positivist methods of experimental control and protection against bias:

> ***Some of it is just your underlying kind of theoretical worldview. What do you believe about research? I think there are researchers to this day who live in a different world, who would be adamant that the thing that you build in a collaboration should be studied by someone else exclusively. I hear people say things like that and makes absolutely no sense to me, but it is about control and bias and all of those kinds of things that matter to their worldview, and that I think are way less important in some ways than understanding the phenomena.***

Boundary-crossing skill

Boundary-crossing aptitude and skill are known forms of human capital that contribute to the formation and efficacy of RPPs. One or more of the key leaders of each partnership acted as skillful "boundary-crossers," i.e., people who are comfortable and effective in the cultures of research and practice. We observed greater numbers of skilled boundary crossers based in research or intermediary institutions than in districts and schools; however, in each of the three cases, at least one practitioner with these skills served in a key leadership or coordinating role.

Leaders saw these labs as opportunities to provide newcomers to RPPs with experiences and relationships that could expand their professional repertoires. Where potential key players did not have prior experience with this kind of R+P relationship—for example, the university researchers in the Maine case, or one of the district leaders and some graduate assistants in the Washington case—RPP leaders recruited with some attention to openness to this way of working and also took care to acculturate team members.

We came to refer to these boundary-crossing players as "dual citizens" because they were more than citizens of one culture who could travel easily to another. In fact, many of them had "lived" in both cultures; several were practitioners who had become researchers, but there was also a researcher who became a practitioner. These combined, or "hybrid," pasts gave them working multi-cultural knowledge enabling them to interact with members of each culture. Even more importantly, they could convene practitioners and researchers for productive dialogue across the cultural divide; they were diplomats as well as translators and ambassadors.

Together, the R+P "worldview" and these "dual citizen" skills contributed a high level of leadership capacity to formation of the local labs

Relationship history

Familiarity gained through prior working relationships enhanced these leadership capacities and further advantaged formation of functional partnerships. The labs were developed through the leadership of key researchers that served as PIs for the R+P Collaboratory; thus, they had the advantage of being launched by people already holding strong visions and aptitudes. For example CTAN built upon earlier work to establish a RPP at the Exploratorium. Similarly, the Washington PSEP project formed a second, expanded generation of RPP work stemming from an earlier UW-Bellevue school district RPP[5]. The Maine partnership was facilitated by a PI of the Research + Practice Collaboratory who had a prior working relationship with the participating district as well as existing interest in the proposed focal area.

In the one partnership that did not thrive[6], leaders lacked prior relationships around joint interests; exploratory conversations stalled out before a mutually appealing joint project could be framed. Thus the cases that thrived—three of four—started in very fertile soil, enriched by experience and intentionality.

Cross-lab relationships and interactions

Together, the three labs operated as a cross-institutional networked research community within the host R+P Collaboratory. Membership in the RPC connected the local partnerships to one another and to multiple other RPC activities—cross-cutting inquiry groups, PI retreats, on-line check-in meetings, summits and workshops on research-practice partnerships and methods, and joint communications and publications efforts. Getting this validation and learning with one another afforded benefits to the local partnerships.

2. Essential ingredients added to the relationship

While the RPPs had the advantage of being formed by researchers with these worldviews and relationships, there was no guarantee of their success.

Research leaders marshaled their experiences to add three essential ingredients to ensure the success of the RPPs: Earning trust, enacting a stance of service to practitioners, and pacing research in a practice-sensitive way.

Listening and "getting it": Researchers must earn practitioners' trust

Trusting relationships are the foundation of research-practice partnerships. Beyond the prior working relationships, successful local labs shared emphasis on broadening and sustaining trust.

[5] The UW-Bellevue partnership served as a case study for the 2013 Coburn, et al., white paper on RPPs for the William T. Grant Foundation. Gallagher and Penuel collaborated with Coburn on a chapter in Fishman, et al., 2013.
[6] See the appendix to the full Maine case. http://inverness-research.org/2018/07/30/portfolio-research__practice_collab/.

Each case is replete with quotations and examples from both researchers and practitioners, and all of them cohere into a powerful message: **Given tradition and the inherent difference in stature between researchers and practitioners, the onus is on the researchers to earn the trust of the practitioners. Moreover, trust is ever fragile and must be sustained through continual deliberate effort.**

Whether they are in the research or practice world, all participant share awareness of RPPs as cultural phenomena marked by status differentials. This from a researcher:

> ***The researcher is the stranger and I think the burden is on the stranger to promote trust, coming into a close-knit community. The burden is on the stranger—it just is.***

And from a practitioner:

> ***I would even say something like, 'explicit measures to build trust have to be built into every aspect of every interaction' and it has to be constantly on the mind of the researchers because they are coming in with a loaded power dynamic.***

Earning trust equated with equalizing "voice"—which often meant amplifying practitioner voice and turning down the volume of researcher voice. Amplifying the voices of the traditionally silent involved conscious effort. Both researchers and practitioners alike commented that practitioners could be "passive" at first because they are so unaccustomed to this form of engagement. In one case, for example, the teachers expected the researchers form the hypothesis, but the researchers insisted upon the practitioner voice:

> ***There were a couple of meetings that were kind of tough because it was definitely working out the research, and a lot of [us] practitioners just wanted for them to tell us what to do. We were like 'can't you just write the hypothesis?' But they said 'no, we can't, because we're deciding this together.'***

This offers further evidence that the onus is often on the researchers and their vision to change the norms of dialogue.

Practitioners across the cases shared clear views about the qualities of researchers who earn their trust and warrant their effort to raise their voice: they are researchers who "listen" and "get it":

> ***So often you hear teachers or others who are working with researchers say, 'oh yeah this researcher is coming to observe but they don't really get it'.***

Quotes and examples from the cases suggest that "listening" and "getting it" involve being able to grasp and take into account the practitioners' point of view, ideas, and conditions. All three cases show that researchers without practitioner background of their own can earn trust by showing the ability to "listen." One practitioner in the Washington case provided an enlightening counter example of researchers who didn't "get it": They were a high-profile,

nationally respected research group that wanted to test new NGSS materials in the district but could not accommodate the realities of the district schedule, budget, or existing science improvement strategy. The researchers' deafness to the practitioners' efforts to find a workable middle ground cost them the research opportunity.

All three cases underscore the fragility of trust. One long-time collaborating researcher spoke of "the many, many opportunities that you have to foul that up" and the need to "bend over backwards to be respectful." A practitioner with experience as a go-between in her district said that even after laying groundwork, "a researcher can still just blow it in the first sentence that they speak or the way they listen to people or don't listen to people."

Trust-building strategies

In all of the successful labs, partners entered into months-long series of discussions aimed building trusting relationships by listening to practitioner voice and moving toward shared purpose. These vignettes illustrate two concrete strategies.

Getting started through Value Mapping

At its kick-off meeting, leaders of the CTAN partnership engaged the assembled researchers and practitioners in an exercise, called Value Mapping, to explicitly recognize that educators and researchers might operate within different value systems and practices, and have different languages and experiences. Value Mapping was seen as a means to avoid tacitly adopting the values of only the researchers. To begin the Value Mapping activity, group members named the concerns and interests that had brought them together, then shared why these were important both personally and professionally. The group then took the initial research questions for CTAN and identified related sub-questions that each partner could address in a particular way. Participants were given time to process the questions and think about their responses before writing them on poster paper. Following was a discussion during which all were welcome to share their answers and ideas. To account for individuals who may not have felt comfortable sharing their thoughts in a whole group setting, everyone was given private time to write again. A gallery-walk then allowed each person (anonymously, if preferred) to identify which three ideas they thought were most important. Finally, the group sorted ideas into themes. Later, these themes became useful to forming data codes, but at the kick-off meeting, the Value Mapping functioned to surface and honor the perspectives of all partners.

See *Value Mapping: An activity for surfacing power dynamics and diverse perspectives in research-practice collaborations*. http://researchandpractice.org/wp-content/uploads/2015/11/Value-Mapping_Nov2015.pdf.

Sustaining trust through a disciplined approach to shared leadership

The Washington PSEP partnership formed a leadership team that included key players from each organization—both school districts, the university, and the Institute for Systems Biology. The team met quarterly to reflect and plan next steps. Structured into each agenda was a discussion designed to air and address each perspective and need. Described by one of the practitioners:

> *We have tried to become more formalized, in a sense of being more disciplined, to make sure that we are paying attention to each other's needs, and one thing is in our quarterly leadership team meeting now… one of the standing items is, so go around: are you individually and personally getting your needs met in a partnership, and is your institution getting its needs met in a partnership, or how are we helping you with that, and then also collectively are our partnership needs being met? We make sure that we give sufficient time to talk through each of those. And we kind of commit to each other, and not just to the health of the partnership, but helping each other's problems to the extent that we can.*

This kind of deliberate tending of the relationship ensured that the partnership remained a "win" for all.

Researchers enacting a stance of service to practitioners

A second key ingredient was that researchers put effort into being of service to practitioners. Sometimes this stance of service meant being helpful in unpredictable ways that may or may not have related directly to the collaborative work. Here a researcher explains to hypothetical colleagues in academia what it means to be a partner:

> ***I think it is the part that we have to tell to our colleagues about what it means to really partner, and it includes just a number of things that I don't think are always understood, from providing coffee when the district can't figure out to spend money to get coffee for teachers, to offering to put together slides for the board meeting when some grumpy board member is asking about science or math…there is a bunch of that kind of stuff going on, all of the time.***

In all three cases, practitioners described ways that the researchers helped them by serving as a conduit to relevant research—sharing a good article, adding a new topic to a workshop, offering well-vetted web links. One school administrator talked about the value of this role:

> ***…their ability to provide the resources and the strategies that the teachers need and in a way that translates the academia, the current research going on, into what our teachers can actually use in the classroom …[researcher] has been a great conduit.***

Researchers at all three sites deliberately stood in service to strengthening both the practice and the partnership:

> ***We are really cognizant that often times research doesn't help the communities that are***

> ***researched. We are interested in small ways that we could do short cycles of sharing back … in order to actually inform practice and just help out. It is not just about the research, it is also about building relationships.***

In sum, to earn trust and form relationship, research leaders at each lab developed and enacted multiple strategies:

- Creating structures that amplified practitioner voice and expected sharing of all perspectives
- Paying careful attention to power dynamics and ensuring shared decision-making
- Acting in ways that demonstrated service and value to practitioners.

Ground-laying efforts occupied several months to a full year at the three labs, with researchers prioritizing relationship over productivity. One researcher said, "I think it is fair to say that we have spent a lot of the [first] year in a dance to try to figure out what the research agenda can be." Further, this deliberate effort at relationship formation did not constitute merely the initial phase in the labs' evolution. On the contrary, ongoing effort was required to sustain the partnerships over time.

B. THE WORK: COMBINING INTELLIGENCES FOR IMPROVEMENT

Processes of forming relationships did not take place in a vacuum of substance. In fact, trusting relationships formed and strengthened around efforts to define foci of interest, to investigate, and to make meaning.

Designing the implementation research work so that it was productive and preserved the partnerships involved continual attention to two principles: ensuring that the work was of mutual interest and benefit to researchers and practitioners, and hybridizing central processes of inquiry.

1. Ensuring mutual interest and benefit

Research-practice partnerships differ from the traditional "consent" relationship by forming around mutually beneficial effort.

Shared interest in a problem domain

Just as the RPPs did not form among strangers, they also did not form on a *tabula rasa* with respect to focal areas of interest in the improvement of education. Rather, the partnerships formed around some degree of shared prior interest in specific domains, e.g., implementation of NGSS, tinkering in after school programs, and math learning related to technology. Broadly shared interest brought potential partners to the table.

Jointly defined focal problem

Led by researchers from a more traditional worldview, that same interest could as easily have paved the way for a researcher-defined study with practitioner consent. The DBIR approach, however, emphasizes that, within the broader domain, the specific "problem of practice" that motivates a research effort is to be "negotiated" rather than framed by the researcher. Negotiating foci for study involved a wide variety of processes over time: meetings such as the "values mapping" described earlier, repeated observations of classrooms and debriefing with teachers, listening to teachers in professional development workshops, looking for alignment with school- and district-based improvement initiatives, and so on.

Part of the purpose is to preserve trust and commitment based upon the promise of mutual benefits. A practitioner in one of the cases put it this way, implying that "groundwork" involves the blend of substantive focus and relationship the work depends upon:

> ***Understanding that the researcher and the practitioner are actually looking for a problem that you both care about really sets the groundwork for the rest of the project. That seems like a really important first step that I have learned from this project.***

Another purpose has less to do with trust and more to do with the nature, quality, and value of the knowledge that is gained from the inquiry. Researchers in these labs believe that their research will be better—more valuable to both theory and practice—if they concentrate on problems of relevance to active practitioners and engage practitioners in the inquiry. This is the "worldview" described earlier. In the comment below, a researcher distinguishes between typical research planned by the researcher and this different approach, which focuses on practitioner-generated problems within the broader domain:

> ***We have been paying attention to what are these emerging problems of practice that we have seen that teachers have been talking about, or we identified them, that kind of rose to the surface, and we want to respond to those and address those rather than to say nope, we have done our plan, we just [follow it] and repeat all 3 years.***

Researchers in all three cases referred to the ways that practitioner input provided "nuance" to research questions and identified "more specific" practices to test in the classroom. The Maine case offers a powerful example of how the teachers sharpened the research focus by sharing their observations about the role of student talk as they experimented with iPads in math.

It is not as though the researchers do not have *a priori* research questions or plans at hand; in fact, they must have these in order to win grants. However, as one researcher put it, they "re-wind" their thinking and engage with practitioners until problems that reflect practitioner reality come to the surface.

Practice-sensitive pacing and flow of the research agenda

To preserve mutual benefit, decision-making about next steps for research stemmed from collaborative dialogue, not by following a pre-established timeline. Key leaders gauged when and how to move forward by assessing trust ("We looked at, 'Have we achieved enough rapport to take this work the next step?'") and by ensuring that the inquiry yielded meaning to practitioners. Here a researcher describes how the research was paced to fit teachers' work cycles.

> ***Another key strategy has been the pacing of the process, moving along slowly enough that the groups had time to deeply explore areas they were interested in, to try things and learn from them, and to head down paths that developed along the way. The partnership was structured so that the fall work would allow for teachers and researchers to engage in joint exploration, so that by the time spring came, it was a joint decision about what would be explored in depth going forward.***

Negotiating value and relevance involved ongoing effort to balance the broad with the local—to advance the research such that it would be responsive and relevant to the local contexts, while also meeting the goals of the larger project and the RPC.

2. Hybridizing the inquiry

In our analysis of the cases we many times used the term "hybrid" to refer to the many people involved who have a mixed background in research and practice. Here we use to term to refer to the many facets of how research and practice *combined* in these cases.

Research processes designed to engage researchers and practitioners as learners together permitted the combining of specific knowledges and capacities to learn—i.e., intelligences—on problems of practice.

Combining perspectives and knowledges

An over-arching idea that helped hybridize the inquiry in all three cases was to position everyone explicitly—researchers and practitioners—as "learners." Comments like this show up in each case: "Everybody put on the hat that we were all going to be learners in the endeavor and find out together." With this conceptual level playing field established, leaders made an effort to combine the best of both researcher and practitioner knowledge so that the sum would be greater than the parts, just as we want hybrid animals and plants to combine strengths. This comment reflects the kind of hybridizing effort, common to all three cases, that generates "a new understanding":

> ***We are really trying to figure out how can researchers bring their expertise in terms of the literature that they read or the research that they have done in the past – and how can practitioners bring their expertise in terms of the daily experience in their different spaces –***

> ***and share the knowledge in a way that is accessible to both sides, of both worlds, and develop a new understanding of the work.***

Forming shared language

Embedded in the hybridizing of knowledges was development of shared language, including greater use of common language and sometimes new coinages. In Maine, for example, leaders used classroom video to prompt the formation of "working language" so that teachers and researchers could "talk about the problem better":

> ***We were purposeful about using video and opportunities for them to work together, and "we" means math education researchers and practitioners, to kind of develop that shared understanding. It wasn't that any one of us was saying, this is the way it should be, but instead, we said, "Let's watch the video, what do we notice, what do we know."***

Cases include anecdotes where new coinages that arose in these hybridized dialogue settings became a cultural short-hand reflecting the new combined understanding.

Research settings that combine intelligences

All three labs designed settings for work that invited this hybrid inquiry. These settings may have looked typical—they were classrooms, professional development workshops, planning meetings, research meetings—but the RPP leaders altered the spaces normatively so that they combined perspectives, interests, and goals of both practitioners and researchers.

These vignettes offer three examples.

The classroom as a site for combined inquiry

The Washington partnership involved a large number of teachers in a curriculum adaptation and professional development project. A sizable team of UW faculty and graduate student researchers played a number of roles in the partnership. One inquiry process involved "deep dives" into practice; these were one-on-one inquiries where graduate student researchers worked in partnership with a small number of teachers to explore problems of implementation of new curriculum on NGSS practices. The researchers took care not only to establish a trusting relationship (through listening and respecting their work) but also to hybridize the inquiry. Here, a researcher describes how she engaged teachers to "work on something together":

> *When it comes to working with focal teachers, I try to sit down with them before I come into their classroom and say, 'now, what are you curious about or what do you want help with?' so that we can be working on something together.*

The researcher also made transparent her observations of the classroom and promoted joint meaning-making by sharing field notes with the teachers and inviting them to add to them. Further, the researchers interview the teachers to document the challenges they faced and what they observed in their classrooms. These strategies added teacher knowledge to the meaning making and kept the researchers' eyes on real problems of practice.

School-based co-investigation teams
In the Maine partnership, EDC researchers worked with teachers over the school year on cycles of experimentation. Over the fall, teachers formed tentative hypotheses-based on their classroom experiences and on readings provided by the researchers-about what types of classroom strategies with iPad apps could lead to improved math learning in early grades. Over the months, teachers noticed that students seemed to reflect more critically on their own work solving math problems when they used an audio-recording tool. They then refined their several hypotheses and settled on one to test during the rest of the school year: When students record and review explanations of their thinking when solving mathematical problems, student engagement in mathematics and learning will improve. Teachers worked together with researchers to design strategies to test.

Partnership leaders designed 30-day iterative Plan-Do-Study-Act cycles in which teachers reflected upon, refined, and re-implemented the group-designed strategy. Working as school-based co-investigation teams, teachers and researchers met monthly to examine student data and artifacts, discuss what they were learning and what questions arose, and to jointly plan the next round of implementation. EDC also continued to provide professional learning opportunities for the teachers, at their request.

Tool-building as a means to hybridize codification of research-based knowledge
Researchers in all three labs put effort into creating tools designed to help practitioners put research-based knowledge to use in classrooms. Tools included "practice briefs," video resources, and facilitation protocols. The tools focus specifically on the problems of practice shown in the labs' inquiries to be important to practitioners as well as researchers. The tools combine user-friendly references to relevant research as well identification of practices shown in the labs to be effective in addressing the problems. Thus the tools not only link research to practice, but they combine the intelligences of researchers and practitioners working together on improvement.

Here a researcher offers a perspective on how these research + practice tools form a different kind of "analysis" from that of typical academic research, with researchers and practitioners "making sense together":

> *The creation of tools has been a really iterative process… that also has been a kind of routine that hasn't existed in other research projects that I have been on, and it is a form of analysis. It is people making sense together and negotiating what is important here - 'why is this equity-oriented?' Or 'why are these little moves within facilitation something that we want to express and talk more about with other facilitators or share more broadly?' Those conversations take place to create tools that will help practitioners. They are a kind of research analysis. Not an interview, not an observation, but somewhere in-between.*

Over time, co-investigation in these settings generated an experience of shared professional culture. This comment from one of the cases reveals evolution of practitioners' stance from outside to inside participation in the inquiry.

> ***Early on, the teachers and principals asked, "Who are the researchers? What is the research you are doing?" And that shifted to, "What are we doing?" and now it is, "We want to look at this." There's been an evolving level of understanding of the partnership to where everyone understands that we are co-planning this, we are collaboratively designing and testing things.***

Differentiated responsibilities within the hybrid setting

Hybridizing the investigation did not mean everyone did everything. In particular, researchers respected the fact that, while research formed a significant proportion of their professional responsibility, the same was not true of practitioners. One of the researchers' challenges was to engage the practitioners without overburdening them, that is, to optimize practitioners' available attention. For example, inviting teachers to review and add to researchers' field notes proved too heavy a burden to be done more than occasionally. Effective strategies including hybridizing *existing* work structures, for example, re-designing professional development sessions so that practitioners shared reflections on practice, helped iterate draft tools, examined student artifacts, and in other ways contribute their thinking to the work.

Here a practitioner comments on how a researcher respected the differential responsibilities:

> ***What I really love about working with [the researcher] is that she says, 'you don't have to write anything, I will write it and I will just talk about it with you'. She is saying, 'obviously your time is important and obviously you have this job that you have to do but because your ideas are so great, I really want to incorporate them into a piece of written work that I can produce, which is part of my job'.***

Here a researcher describes how hybrid settings do not asking people to be what they are not, but do ask everyone to contribute what they can:

> ***I really do think with my whole heart that it is a solid case of how researchers and practitioners can co-design and pull off large-scale system support and change without asking anybody to be something they are not. Everybody gets to sort of fill in where they see they can.***

In sum, local labs designed "hybrid" spaces that combined the intelligence of researchers and practitioners. Engaging in shared work in these spaces served multiple functions— maintaining trust, forming new professional relationships, jointly identifying problems, refining hypotheses, permitting broader interpretation, trying a range of solutions, and forming transferrable knowledge.

C. AFFORDANCES OF THE COLLABORATORY AS SUPPORT STRUCTURE

While the labs operated autonomously, their membership in the Collaboratory provided affordances not normally available to independent labs. The Collaboratory served a "hub" function in a number of ways that enriched the work of each lab and enabled them as a group to make a larger contribution to the field.

Convening local lab directors as Co-PIs

The Collaboratory PIs—along with key members of their staff and often both evaluation teams[7]—met for 2-3 days annually to reflect on their work, to strategize about challenges, and to plan. Between these in-person meetings, the group held monthly calls that emphasized progress reports from each lab and the evaluation groups, as well as check-ins on joint projects, such as the conjecture mapping and inquiry groups.

These joint meetings and frequent touch points kept the lab PIs well enough informed about one another's work that they readily found synergies and learned from one another. One lab director, for example, told of another PI offering access to new analytic expertise and of: "There are a range of different connections and synergies in the sense that our connection to [Co-PI]'s team has allowed us now to do social network analysis, which we haven't done historically." This CoPI added, "I am very excited about the [local lab in another state] work and where it has been evolving…there are lots of parallels, lots of good things that could be learned both directions."

Local lab PIs felt that these enhancements to their work wouldn't have been possible had the labs been independent.

Engaging PIs in shared conjecture mapping

The Collaboratory PIs practiced Sandoval's (2014) technique of mapping conjectures as an approach to making design research more systematic. Conjectures are statements of how theoretical ideas should manifest as design and how designs should function to produce outcomes. The PIs worked jointly over the course of two years to formulate and refine conjectures about the Collaboratory as a whole. In addition, each local lab was expected to formulate conjectures linked to their own theories, designs, and outcomes.

Local lab PIs reported that conjecture-mapping as a group for the Collaboratory had real value. One PI said explained how the joint process held the autonomous groups to "social accountability" as well as kept shared research questions in view:

[7] SRI served as summative evaluator, Inverness Research as formative evaluator and documenter of the labs.

> ***I think it is really important that we do it at the project level because there is an audience there that we feel accountable to and that helps us keep the research agenda alive…when we do invest time as a [Collaboratory wide] group, there are certainly moments that help us identify critical data that we should be collecting for example or a pattern that is emerging that we want to get really systematic about, or to help clarify where, what one adaptation site is doing is very different than what another adaptation site is doing... Just the sort of professional, the social accountability of articulating what it is that we are learning in these complex moving sites in relation to a core set of conjectures that we all believe are valuable.***

Eventually the local sites did form conjecture maps of their own; however, the joint process held more value for the local labs than the individual process. It was more difficult to replicate the process of conjecture-mapping for the local lab work, especially in the early years when the PIs felt pressed to do the relationship building and adaptations necessary to enact the R&P partnerships. One person said, "The wanting to be there in the field and the immense amount of time that it takes to be in the classroom and to coordinate that keeps us from prioritizing the conjecture work."

Sponsoring cross-lab Inquiry Groups on cross-cutting topics

One of the Collaboratory's broad strategies for "disrupting and transforming the status quo" of research-practice relationships was framed as Critical Engagement. This strategy aimed to foster "practitioners' understanding of and value for research and researchers' understanding of the realities of practitioners."[8] Activities for this strategy included inquiry groups that brought together researchers and practitioners from all of the Local Labs around cross-cutting issues that arose from or leveraged work of the Local Labs. Each meetings took place over 1½ - 2 days, with each of the three local labs hosting them in their states. Each held out the expectation that the participants' inquiries into the issue at hand would generate the grist for some kind of product, e.g., a white paper, a collection of practice briefs, a short report, or a toolkit.

Convening members of all labs around issues that were central for an individual lab, but were also cross-cutting, had value for all members of the Collaboratory because they broadened the shared knowledge base across labs, deepened the improvement work at individual labs, and formed new social capital across the country among researchers and practitioners with shared values about research and practice as well as shared interests in STEM improvement. The cross-lab inquiry groups modeled and provide more experience with practices of cultural exchange across the worlds of research and practice, along with generating concrete knowledge products reflecting the combined intelligences.

Inquiry group meetings focused on these cross-cutting issues and products:

[8] From the original proposal to NSF.

- STEM practices (with an NGSS lens). This inquiry—which involved two meetings 6 months apart led by the Washington lab—generated list of the most challenging and critical STEM practices to teach as well as practitioners' needs for addressing them. These created an agenda for the production of STEM Teaching Tools. (*http://stemteachingtools.org*)

- Cross-setting learning (formal and informal, in-school and out-of-school). The meeting on this topic, led by the CTAN lab—focused on programs, studies, ideas, tools, challenges and questions related to cross-setting learning, the potential of the work, and resources needed for implementation. The discussion generated ideas and material for a white paper and for the R&P website (http://researchandpractice.org). Also, participants' experience with a strategy of "value-mapping" generated interest in an inquiry focusing more specifically on equity.

- Equity-oriented facilitation of learning. This inquiry group, held a year after the cross-setting learning group, focused on focused on four questions arising from the first meeting: What does equity in afterschool science look like? What forms of professional development are needed to support the teachers? What kinds of tools can support programs and improvement efforts that are needed for professional development? And, what do we mean by equity, anyway? Participants worked on ideas for developing tools that would help educators build a new "facilitation muscle" associated with more equitable access to learning STEM. Out of this meeting came the report, "Equity In Out-of-School STEM Learning: Professional Development Needs and Strategies" (http://www.informalscience.org/sites/default/files/20150429_RPC_IG_Equity.pdf).

- Interactive technology. This meeting, led by the Maine group, focused on implementation and support of interactive technology use in early math learning. The participants generated design principles as well as areas for further investigation. Two reports arose from this inquiry: http://interactivestem.org/wp-content/uploads/2015/06/Interactive-STEM-Report-Inquiry-Group-2014.pdf and http://interactivestem.org/wp-content/uploads/2015/07/Interactive-STEM-Report-Guidelines.pdf

Promoting collaborative dissemination efforts

Leaders of the local labs collaborated frequently on papers, conference presentations, webinars, meetings with key policy makers (e.g., The Council of Chief State School Officers (CCSSO). While these dissemination activities included STEM improvement ideas, they concentrated primarily on making the case for the designs, functions, and outcomes of research-practice partnerships. The collaborative work contributed to the Collaboratory's mission of building broad field awareness about RPPs as an arrangement that could generate more relevant and valuable knowledge for STEM improvement. Just as importantly, the collaborations fostered cross-fertilization of ideas across the labs as well as strengthening the human capital resources of "hybrid" educators.

III. BENEFITS TO PARTICIPANTS

The local RPP labs supported researchers in practice-informed research and engaged practitioners in research-informed professional growth opportunities. Both researchers and practitioners experienced a number of benefits.[9]

A. Benefits to practitioners

Small numbers practitioners were directly involved with researchers in each of the labs. The positive impact on them, however, was substantial.

Practitioners engaged in the RPP work gained direct access to research and to researchers, which provided them with immediate and longer term benefits. Practitioners also gained leadership capacity that has empowered them as professionals.

Access to research

Practitioners gained research-based knowledge they put to use in their practice. This knowledge came in many forms: directly from the researchers through feedback on their work, through hand-picked materials the researchers gathered for them on request, through relevant, timely professional development sessions and classroom support for innovative teaching, and through research summaries prepared for practitioner use in PLCs, board meeting, staff meetings, and other scenarios.

Furthermore, because practitioners were involved in defining the new practices they would testing, they were more engaged and motivated to make significant changes in their teaching. One researcher commented, "Teachers are more excited to try these strategies because they have been there from the beginning to come up with them."

Some school administrators reported that the experience shifted teachers' stance toward their practice so they "have become researchers themselves," being able to design, try, implement, adjust instruction, observe what's truly effective and have conversations about it.

Practitioners also gained new professional relationships with researchers, social capital that has expanded their access to a wide range of resources and opportunities over time. The epilogue of one case includes this example:

> ***The partners continue to work together as opportunities arise and stay in touch via periodic conference calls. This has given practitioners the advantage of having ready access to research, resources, researchers, and other forms of professional support. One participant referred to this as "having a researcher on speed dial."***

[9] Our study did not independently document the multiple benefits summarized in the Introduction. Here we spell out benefits revealed by our case studies of the local labs' design and functioning.

Leadership capacity

Practitioners, whether teachers or administrators, gained leadership capacity in the form of greater confidence and knowledge. Some sought opportunities to spread dialogue about innovative practices across their institutions. Each case includes examples of practitioners positioned for professional advancement because of these projects. Those already in leadership positions benefited from the increased stature that the research partnerships imparted to their improvement work. One person commented, "Had we not been part of this project, we would be lacking in a certain legitimacy, and would also be missing an important avenue to get our ideas out into the field."

Practitioners gained commitment to a partnership approach to research and gained sophistication in navigating the world of research, enabling them to better define the kinds of research relationships they want. One practitioner commented, "Having the researcher really embedded in our work expanded our idea of what is possible, in terms of how you can interact with researchers." Another said, "From hearing about … how other people do research, I think this partnership is something really new. It is an important model for getting real information from marginalized voices into the field."

B. Benefits to researchers

Researchers benefited directly in a range of ways, whether they were well established or starting out in their careers.

Working in partnership with practitioners helped researchers gain new skills and stance toward their work, and it gave researchers greater confidence that the knowledge they share with the field will be valuable.

It is important to remember that academics are researchers *and* teachers: they are teaching the next generation of researchers and preparing the next generation of teachers. Thus what they gain from this work can have effects beyond how they conduct their own research.

Researchers gained a richer seedbed for their own learning with the addition of practitioner perspective. Here an experienced researcher explains how a partnership approach improves the quality and value of research:

> ***I feel more sure about what we are finding and saying because it is a group that is saying it; it is the researchers and the teachers. I feel like it makes the findings more connected to practice and maybe more doable for teachers, because the teachers are engaged in the research.***

An experienced researcher who was new to working in partnership with practitioners suggested there is no going back to the old worldview:

> ***Working with folks the [local lab] has impacted the way I think about all my future work and collaborations. I can't imagine conducting research that isn't RPP in the future.***

Early career researchers gained increased commitment to collaborative, improvement-oriented research, as well as skills of trust-building, boundary-crossing, and designing hybrid settings for shared inquiry. They are entering academia well equipped to engage in this kind of work.

Both new and experienced researchers gained new professional ties with practitioners as well as with like-minded researchers. One professor who had grown isolated from practice believes the new relationships with practitioners will strengthen her own work as teacher educator: "I really want my students to learn some of the things I am learning from these teachers."

IV. IMPLICATIONS FOR FIELD-BUILDING

Building research-practice partnerships is not simple. Even in the R+P Collaboratory, with all PIs and staff pre-disposed in favor of such partnerships, three succeeded and one did not survive. These studies produce a number of lessons learned and provoke broader reflections for the field about the design and functioning of research-practice partnerships.

Research-practice partnerships are arrangements grounded in core values

Particularly for the research side, what distinguishes research-practice partnerships is **the values position that collaborative research and its products are better**—more relevant, more usable, more grounded in reality—than research done in pure laboratory settings or with a positivist distance from the practitioner perspective. Creating a productive and lasting research-practice partnership requires that researchers value implementation-based research that combines research and practice perspectives for the purpose of generating knowledge of value to practitioners as well as to researchers.

Research-practice partnerships require, and continue to build, professional capacity for "hybrid" research

As egalitarian arrangements, research-practice partnerships run against the norm. These cases suggest that the onus is on the research side to amplify the practitioner voice and include practitioner perspective in inquiry. Thus these partnerships likely require leadership by researchers with particular core competencies.

Through their work in research-practice partnerships, **both researchers and practitioners gain dual perspective and boundary-crossing skill.** Researchers listen to and become more sensitive to practitioners' realities, and practitioners adopt a more inquiring stance toward their teaching and toward ideas coming in from the outside. Working in partnership builds new forms of professional capacity.

Research-practice partnerships can thrive in a variety of organizational configurations

There was substantial variation in the types of institutions involved in the three labs and in the roles of the players in them: large and small school districts, R-1 and teaching universities, a variety of informal learning institutions, education reform intermediary organizations. These variations suggest **there is little limit to the types of organizations that can form and participate in RPPs**. What is important is that the RPPs bring together organizations that have either (or both) of the research and practice function as well as the core values related to partnering in order to combine the two.

Sustainability and spread

Research-practice partnerships need to be sustained and to spread in order to fulfill their potential. The case epilogues show that all the labs have continued well beyond the initial two years. How they have evolved offers promise for the participants and for the field.

Sustainability

Every lab has continued its work but none of them have continued it in the same way. All of the work has evolved or "morphed" into new projects. The projects include many of the same key leaders, are shaped by new funding, and they are branching out from the original work in logical ways. CTAN has launched a new RPP they believe is stronger than the first one because of practical lessons learned. Similarly, EDC, the facilitating organization for the Maine RPP is better positioned to start new work with partners having benefited from the experience. The partnership in Seattle continues to evolve as it transitions into a next generation of state support. These examples suggest that sustainability does not imply institutionalization *per se*: there are some new people, different funding sources, new goals and products, different organizations as partners. Rather, **sustainability requires adaptive leadership capacity**—particularly the ability of key leaders to seek out new funds and interested partners.

This evolving work grows from and continues to build the needed capacities for research and practice partnerships. Those capacities seem to include two core elements: human capital (the particular skills to form the trusting relationships and design the mutually beneficial hybrid work) and social capital (the professional ties that cross the researcher-practice divide). With regard to the social capital, we can see in all three cases that the professional respect that develops through the research-practice work is lasting; it is not confined to the one project where it formed. Those who form relationships try to find new, good ways to keep working together.

Spread

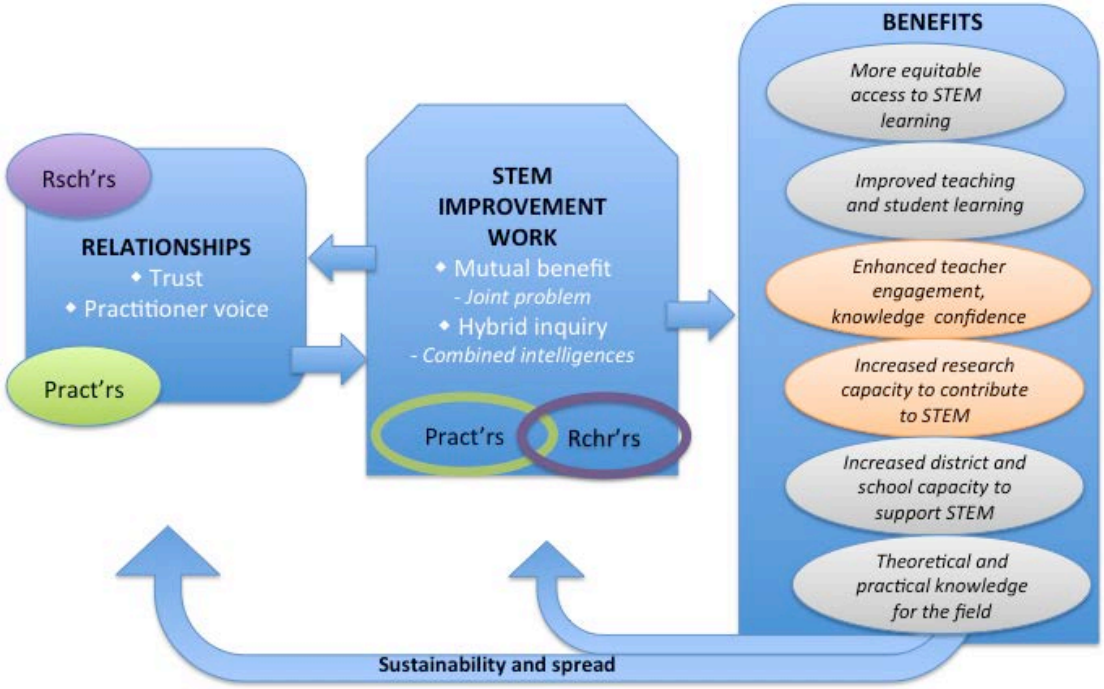
The cases demonstrate **two routes to spreading the values, skills, and products of research-practice relationships**. One is simple mobility of participants. Mobility may be the "upside" of turnover. Graduate students move on, leaving behind a hole in one partnership while bringing their values, skills, and professional networks to new institutions. School administrators and teachers change districts, leaving a gap in leadership in one place while bringing new knowledge and new expectations for research to other places. Filling the gaps left behind requires enculturation of new people, which further expands the pool of professionals with shared values and skills.

The cases also suggest that joint dissemination of RPP work can enhance the visibility, and perhaps ultimately the stature, of this form of research. When researchers and practitioners present jointly—at professional associations for researchers or practitioners—they spread not only the fruits of their collaboration, but they also make visible the values that underlie the RPP relationships.

V. AN EMERGING CONCEPTUAL FRAMEWORK

Below we display a conceptual framework that is emerging from our study of the design and functioning of the research-practice partnerships of the RPC. The framework reflects the partnerships as relationships that permit a type of STEM improvement work that combines the particular intelligences of researchers and practitioners for the benefit of both, which ultimately results in STEM improvement that benefits students, capacity-building among researchers and practitioners and their institutions, and valuable knowledge for the field. Their presence in the educational landscape builds field capacity to sustain and spread new arrangements that combine the intelligences of research and practice to address problems of practice.

Figure 1. An emerging conceptual framework for research-practice partnerships



Successful research-practice partnerships require the **formation of particular relationships** among practitioners and researchers. These relationships are values-based and counter-normative, requiring sustainable trust, amplification of practitioner voice, and a stance of service to practitioners as the primary interest, with other interests (e.g., theory development, policy change, system capacity) present but not dominating. Absent relationships with these qualities, there may be research but there is no research-practice partnership.

These relationships permit and give rise to **improvement work that blends the knowledge and learning capacities—the intelligences—of researchers and practitioners**.

Continual, **deliberate attention of those in relationship must go into the design of the improvement work** so as to ensure mutual benefit and hybridization of the settings for inquiry. Furthermore, **participating together in this kind of improvement work contributes strengthening of those relationships**.

Such **partnerships generate multiple benefits**.[10] Practitioners gain new access to research, a new stance toward researchers and their own practice, and grow in their leadership capacity. Additionally, they change their practice in ways that provide more equitable opportunities and

[10] Our study verified benefits teachers and researchers; other benefits were documented by the local labs and/or by the SRI evaluation.

deeper learning for students. Researchers gain new confidence in the quality and value of the knowledge they share with the field, as well as new stances and skills for research. Both researchers and practitioners benefit from new professional ties that bind them across the research-practice divide. These ties, the practical lessons learned from working in partnership, and the products and other benefits help sustain the work and spread the skills and values that define it.

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APPENDIX

Summaries of Local Lab Results And Accomplishments

To accompany this paper, PIs drafted summaries of the accomplishments of the Local Labs. Also see *http://researchandpractice.org*, *https://www.exploratorium.edu/education/california-tinkering-afterschool-network*, *http://interactivestem.org/*, *and* *http://stemteachingtools.org/about*.

1. CALIFORNIA TINKERING AFTER SCHOOL NETWORK (CTAN)

The focus on equity-oriented facilitation in Making in CTAN led us to ask the following question: How does high quality equity-oriented facilitation in after school tinkering support learning outcomes that are valued in the school day? This question was important to us because of the goals of the after school programs to support young people's success both in terms of their current school careers, and in terms of their possible future directions.

To pursue this question further, we formed a new research-practice partnership with a charter school in Oakland California. Educators from the Exploratorium Tinkering Studio co-developed bi-weekly (year one) and weekly (year two) after school tinkering programs. We collected data on a weekly basis and then met, monthly, with after school educators to review the data, discuss different after school program approaches, and begin to articulate a framework that could be used to design for, foster, or document learning outcomes from equity-oriented tinkering programs.

This framework was refined over the course of 12 months, and integrated into a MOOC offered on Coursera. Importantly, the framework built on prior work at the Exploratorium, but highlighted key social and emotional learning dimensions valued by CTAN educators as well as educators at the charter school. Specifically we addressed how students' cultural and personal resources were leveraged, how their creative agency was deployed, and how their critical thinking and problem solving was fostered through iterative processes of design.

The framework serves as a core module within the MOOC which reaches an average of 20,000 teachers each year.

2. WASHINGTON: PARTNERSHIP FOR SCIENCE AND ENGINEERING PRACTICES (PSEP)

PSEP Results & Accomplishments

- **Vision-Aligned Improvements in Teacher Practice in Science Classrooms:** The NRC Framework vision for K-12 science education—that guided the development of the Next Generation Science Standards—calls for many significant shifts in teaching practice. Our partnership has worked for five years to build capacity of about 200 teachers across these two districts. We have evidence that many teachers have routinely engage students in the science and engineering practices (e.g., argumentation, explanation, modeling, and engineering design in particular). We have documented how teachers have shifted the focus of classroom activity to include more emphasis on learner-centered discourse for intentional purposes. We have evidence that

teachers more regularly engage in formative assessment and have developed initial capacity to design and interpret assessments focused on the three-dimensional view of learning in the vision. Finally, we have documented that teachers have increased their capacity to engage ELL students they serve in scientific sense-making.

- **Increased research capacity:** We brought a capacity for ethnographic documentation of classroom life to the research. We have increased our research capacity in order to sense these classroom shifts in the implementation project by developing and refining teacher-facing practical measure strategy focused on constructs of interest. We have also increased our research capacity to engage in social network analysis of resource sharing across teacher networks to document influence.

- **Meaningful District-Level Professional Learning in Science:** Many public school teachers will report that district-provided professional development often does not meet their professional learning needs. Over the past five years, we have broken that norm and engaged teachers in 80 hours of professional learning per year that most consider to be meaningful and relevant to their classroom practice and to the learning of the students they serve. We used a focus on curriculum adaptation to build teacher capacity in phenomena-focused instruction and cognitive and cultural formative assessment. They appreciate that the project engaged them in leveraging their expertise to guide the work of implementing the new vision while also supporting them in new professional learning. They report the benefits of receiving professional resources to support their learning and work—which they report sharing with colleagues. Many teachers also appreciated development of cross-building relationships with other teachers as a unique outcome of the model.

- **Capacity for Collaborative Design by Researchers and Practitioners:** After five years, the partnership has built its expertise and routines to engage in the co-design of professional learning experiences for large groups of teachers. This is a stark change from where the group started in our collaborative work—where we outsourced much of the initial PD work. Now, we engage in collaborative design and enactment of PD routinely across the two districts—and we bring this knowledge base to other groups. This is also notable in that we have built and maintained this capacity in the face significant staff transitions over the course of the partnership. The work has also become increasingly centered on issues of equity and social justice—as the partnership developed a shared equity focus and related design capacity to engage in such work.

- **Development of Broadly Used Professional Learning Resources:** The partnership routinely developed strategies and tools related to realizing the new vision. These tools were co-designed by researchers and practitioners around problems and opportunities of educational practice. Importantly, these tools were refined through use across a range of contexts. Many of them came to be shared across national networks of science educators through the STEMteachingtools.org web site. In this way, the PSEP partnership served as the crucible to develop tools and solutions that can be adapted and used at relatively broad scale—and disseminated through our professional association partners and networks.

3. MAINE: INTERACTIVE STEM

Within the first year of the collaboration, the RPP in Auburn began to yield signs of strong shifts in the knowledge, practices, and views of all partners, including students. Data providing evidence of these shifts include teachers' online log entries; partner surveys; monthly PLC meetings' group sharing; classroom observations; student screencasts; email correspondence between teachers and EDC or university faculty partners, and interviews with17 key participants. With the input of Auburn teachers and principals, EDC and the university researchers created coding schemes for the qualitative data to identify major themes that emerged in the group's early analyses.

Results

Below we describe emerging changes in learning and practice among the partnership's researchers, administrators, teachers, and students based on preliminary analyses of project data. Some results have been described in the project's 2016 annual report to NSF; other results will be published in a chapter of a book titled *Rethinking Research and Practice,* edited by Bronwyn Bevan and Bill Penuel and to be issued by Routledge in 2017. The last section describes how the work we have conducted with the original cohorts in Auburn have begun to spread more widely.

Deeper insights among project researchers of "what works" to promote educational change. The EDC team came to the partnership with deep experience working collaboratively with educational stakeholders in a wide variety of settings. Participating in the RPC project, however, pushed the EDC team to work with Auburn educators to truly "figure things out together." The approach led to some of the highest levels of teacher engagement that team members have experienced. A second-grade teacher shared that "the collaboration has been one of the best professional development experiences I have had" (Maislen, 2016). The district superintendent observed: "The way [EDC] designed [the work] really had [the teachers] feel ownership in it… They were investigating things together in a safe environment… You could see the confidence in those who participated" (Interview, June 17, 2016). These types of responses have helped EDC team members and the university partners come to believe that mutualistic collaborations have the potential to facilitate powerful changes in the professional practice of school educators.

Enhanced tools and insights among university faculty partners for teacher education. Both university faculty partners have been sharing knowledge and resources generated from the project with the pre-service and in-service teachers that they teach. One faculty partner has written that the project "has helped my own teaching practice because I am able to see that what I believe to be best practices, based on previous observations, practice, and research, does have impact in classrooms. I am able to use this information when I teach my pre-service teachers." She has been sharing classroom videos and student screencasts from Auburn, and having her undergraduate students create and critique their own screencasts. One of these pre-service teachers feels she is learning from the experiences in Auburn, writing: "Students [in Auburn] are being trained to self-assess so that they can understand what they are learning and the purpose of it... By learning to explain [using *Explain Everything*], students can easily see where they need to develop in their work to make things make sense." The learning that is emerging from the partnership is therefore spreading to a new generation of teachers.

Altered views among school leaders of ways to promote school improvement. Interviews with school leaders suggest that the partnership has had profound effects on their views of mathematics learning and how schools should approach educational improvement. One school principal described the iterative cycle of "giving us some information [and] then setting up the process of implementing [a strategy] and talking about it and really picking it apart" as more valuable and empowering than traditional professional development approaches (principal #4634, interview, February 1, 2016). She observed that "because you guys certainly don't have all the answers either," having classroom educators examine student work and teacher practice with researchers "has been really what brings [our work] to that next level." She also stated that even after project funding ends, "the whole process is something we could always continue." Another principal came to believe that schools and researchers must work in partnership for educational improvement to occur:

> *I've been in education a long time. When I first started we really relied on the "experts" to tell us what we needed to do. And it's really clear to me now that moving forward we have to work collectively in partnerships such as this one to figure out how to best use technology and how to maximize learning for students… There's so much now to know and you really need to bring together all of the experts together. We're all experts in what we do (principal #4739, interview, March 11, 2016).*

Shifts in confidence, knowledge, and classroom practices among teachers. Project data suggest that the teachers who participated most actively in the partnership's work developed a stronger understanding of the research process and greater confidence in their abilities to serve as co-creators of research knowledge. A second-grade teacher said she had an "epiphany" once project team members began to present group findings at regional and national conferences: "You actually couldn't do what you do if it wasn't for us" (teacher #8500, interview, March 2, 2016). A first-grade teacher said the partnership inspired her to become a math coach. She stated that prior to joining the partnership, "I don't think I would have [considered] a role as a math coach," but she found that "the co-investigative model was so valuable." She realized: "We could do this with all teachers. I don't have to be the expert, but I now have this pool of resources and information that I could help share with others, and [we could] really be a collaborative group [examining] what's working, what's not working. And modeling that kind of situation with other staff" (math coach #8928, interview, January 27, 2016).

Project data also indicate that the teachers in the partnership developed new understandings of how to support mathematical thinking among young students. Classroom observations revealed that over time, teachers stopped asking students to use iPad apps for drills and instead encouraged students to choose visual modeling apps as aids for mathematical problem-solving. Once the group began to test its screencasting hypothesis, teachers stopped asking students to use their iPads quietly with headphones and instead encouraged them to record and share their mathematical thinking with teachers and peers. Auburn educators have cited a number of significant shifts in their thinking about mathematics learning and teaching and their own instructional practices due to their participation in our co-investigation work. We provide some examples below.

The project has helped many teachers understand the importance of mathematical communication. One teacher said: "Honestly, in the past, I'd never really thought about how important

it is to have [students] explain what they're… thinking. So it has been huge for me… an eye-opener, and a changer, in how I teach my kids" (#8300, Gr. K, Cohort 1). Another teacher explained: "[The project has] upped our ante for conversations about math… whereas before you would get a couple kids raising their hands and wanting to participate, now everyone is making their video and recording their thinking" (#8693, Gr. 2, Cohort 1). By using the recording strategy, she explains that she gains insight into all her students' thinking and can provide more informed guidance about how to support the learning of individual students.

The project has helped teachers become more student-centered. By focusing on student thinking and communication, teachers have come to see the value in giving students greater agency in their own learning. "I'm trying harder to be less at the front of the classroom giving the instruction and trying to be more of a facilitator as students work through strategies… to allow the students to talk more" (#8693, Gr. 2, Cohort 1). A school principal (#4739) also describes a significant shift in the classroom culture of participating teachers. Due to the project, "teachers and students are working and learning together. There's less emphasis on right and wrong answers and all children are able to participate in math activities at their level. So students are less dependent on the teacher for answers. And they're more invested in their own learning."

Teachers have developed a deeper understanding of and appreciation for "productive struggle." Multiple teachers noted that using the recording strategy on a regular basis helped them discover the benefits of increased "wait time" and the importance of letting students work through mathematics problems on their own without intervening too quickly. This was a new realization that emerged from the work. As teachers began noticing students persisting, and "struggling" through problems in a way they had not previously, research was introduced that provided additional details about the phenomena they were observing in the classroom. A math coach realized: "It's not [about students] regurgitating what you told them to do." Instead, it's about "letting children… explore their own thinking." She observed that this shift can be difficult for primary level teachers, because "we're still coddling and motherly types," and "we don't like to teach in struggle." However, she came to understand that "productive struggle is where kids learn." Similarly, a school principal (#4739) said that due to the project, "What I've seen is that students are willing to take risks and engage in productive struggle… And for kids the end result is a better understanding of the learning process itself." A research-practice brief was created to further clarify and connect this research to what productive struggle looks like in practice.

For at least some of the teachers in Auburn, the project has been transformative. We have posted on our project website two blogs by participating teachers describing their experience with the Auburn Math Collaboratory. We quote from one teacher's blog:

> *As a second grade teacher I found the collaboration to be one of the best professional development experiences that I have had [emphasis added]. We would meet monthly and focus on developing mathematical thinking with effective questions, how to get students to share their thinking with their peers and in math congress and how to support students to become confident problem solvers, thinkers and risk takers. We*

> *shared math lessons by grade level and reflected on students' responses and what elements would constitute challenging, open-ended math tasks. We had access to Practice Briefs, articles by Catherine Fosnot, demonstrations of open-ended problems and monthly coaching opportunities.The sharing and reflecting was helpful because it gave us the opportunity to have discussions about key math ideas as well as students' misconceptions. We were able see our peers share their ideas and their students' learning as if we were right in their classroom. I would often take a lesson idea that was shared and try a new version with my class. Colleagues shared rubrics, sentence starters and students' videos. The videos were extremely helpful because we could follow students' thinking as it unfolded. Often students would self-correct as they were making their videos and revise their thinking. Students were engaged and eager to share their thinking. I saw my students gain confidence in solving problems not just to have the correct answer but to be a part of the process of solving the problem and deepen their understanding. One student told my principal, "It's o.k. if I don't have it all the first time because I'll see my mistake and I can change my strategy and go back and try it again." That's problem solving, right there!*

Shifts in mathematical learning among students. Educators in Auburn reported four major ways in which students benefitted from the work of the partnership and regular use of the iPad recording strategy. These findings have also been observed by EDC and university faculty partners during classroom observations.

The collaboratively-developed iPad recording strategy has helped to strengthen students' mathematical communication. Multiple teachers said that they observed strong growth in students' abilities to explain their thinking when solving mathematical problems through regular use of the recording strategy. One teacher shared: "In the past, my kids have said, 'Well, this is how I did it.' Or, 'I just knew it,' and they don't discuss anymore. This year, they're having discussions and talking about their thinking and responding to others" (Teacher #8405, Gr. 2, Cohort 2). Another teacher noted that use of the strategy has prompted her students to engage in independent conversations about mathematics, without her involvement. She reported:

> *I didn't realize how little I had students talking about math… And I'll find now just sitting on the carpet students will… be engaging in conversation while I'm writing something up on the board and it's about a math problem. And they're arguing with each other but being really reasonable and they're doing those things that we're practicing… (#8693, Gr. 2, Cohort 2)*

The strategy has helped to strengthen students' mathematical thinking and reasoning. Teachers and teacher leaders voiced a range of ways in which they saw improvement in students' numeracy and problem-solving skills from regular use of the recording strategy. One teacher said that the strategy had helped to promote flexible mathematical thinking among students: "The way they're thinking about solving problems is a lot different than they have in years past… they have multiple ways they're answering these questions, and then they're having discussions" (#8405, Gr. 2, Cohort 2). Other teachers noted students' increased capacities to listen to other students' mathematical solutions and to make connections with their own approaches. Participants also observed how the strategy promotes

student metacognition. A teacher said that when students record and review their own mathematical explanations, "a really big 'aha' is that kids will self-correct when they make a mistake" (#8500, Gr. 2, Cohort 1). A math coach further explained that when "they go back and listen, they can deepen their understanding, or be reflective in the sense of self-correcting… and within that piece, [they] may also clarify a misunderstanding."

The strategy has helped to promote positive socio-emotional outcomes during mathematics learning. A second grade teacher (#8693, Cohort 1) observed that by using the recording strategy, students have become more comfortable taking risks with their mathematical work because they know that they can edit and fix their screencasts before they share them with their teacher or peers. A kindergarten teacher (#8781, Cohort 2) observed that her students have realized that they learn from each other's screencasts. They are therefore "thinking of themselves as teachers" and feeling that "what I'm doing is worthwhile." Another kindergarten teacher (#8300, Cohort 1) noted that the recording strategy has helped her students review and feel proud of their own growth over time: "They love going back, and looking [at their screencasts], and seeing what they did and [thinking], 'What can I do now'"?

The strategy has promoted more equitable mathematics learning opportunities for students. Multiple teachers and administrators observed that the recording strategy promotes equity in mathematics learning because it gives all students opportunities to express and share their mathematical ideas and to have their thinking heard and discussed by others. A principal (#4634) observed that "you might have kids that have great thinking but they're not able to share that because they can't read or write like their typically developing peers. So it evens the playing field for some of those kids who struggle in other areas." Several teachers noted that the recording strategy provided ways for English learners, students with fine motor and writing difficulties, and more introverted students to engage in mathematical discourse. Other teachers observed that the strategy helped change and raise their expectations of their students. One teacher shared: "I have [a student who makes] video after video [with] Explain Everything. His are just right on and he's picking up using tools that I haven't even taught yet. And he's using them correctly and just a lot of really neat stuff from that kid that I did not expect" (#8781, Cohort 2).

How the work of the partnership has begun to spread more widely. We describe ways in which the knowledge and tools generated from the partnership's collective work have begun to spread to other schools in Auburn and across the state of Maine.

Spread within Auburn. During the two years when the partnership co-investigated the screencasting strategy, teachers collaboratively generated and shared classroom tools with each other to support strategy implementation. One example of such a tool is a "student screen recording checklist" developed by a second grade teacher and her students (see tools listed on Interactive STEM website interactivestem.org). The tool description explains: "After Colleen's class began making screen recordings and videos, she noticed that many students were unsure whether their videos were complete. She wanted them to know the characteristics of a quality video for these types of math assignments." She and her students reviewed videos that they had created and collaboratively generated a list of criteria which they though would make a video strong. Colleen's students used the

checklist as a guide when creating new screencasts and when reviewing and providing feedback on the work of peers. When this tool was presented in a monthly group meeting, teachers from other schools found the tool valuable and used it with their own students. Some worked with their students to customize the checklist further for their specific grade level and classroom context.

Project learning has also been expanding to other schools in the district. The math coaches and other teacher participants have shared project tools, strategies, and insights with other teachers during district-wide meetings. During the second year of the partnership, project learning spread to the elementary school with the highest percentage of English language learners in the district. Prompted by positive word about the partnership, the principal at that school worked with EDC and university faculty partners to provide a modified version of the project's professional learning component over a period of six sessions to all of her elementary staff, including regular classroom teachers, special education teachers, and English language learner specialists. This commitment enabled a broader range of teachers and students to have access to the resources and knowledge generated by the project.

Spread across Maine. In January 2017, the Maine Department of Education awarded a grant to EDC to continue, sustain, and expand the work that it began in Auburn with an expanded team of mathematics education partners from UMF and USM, and with teacher leaders who have emerged from the original partnership work in Auburn. Highlighting its focus on collaboration, the EDC team worked together with university partners and educators in Auburn to write the proposal for this new phase of work. Expanding to 22 primarily high-need elementary schools – including rural schools – and one additional grade, the team is working collaboratively to provide training for K-3 elementary teachers and special educators teaching mathematics, elementary teacher leaders, pre-service teachers at UMF and USM, and administrators focusing on the effective integration of technology in learning related to enduring mathematical practices and numeracy in early elementary grades.

Led by a design team, the project is concentrating on delivering a sustained, hybrid PD program for nine cohorts of in-service teachers from districts across the state. The design team is composed of staff from all the primary partner institutions: including three teacher leaders and three school principals from Auburn. Project activities include developing leadership capacity of teacher leaders from Auburn through mentorship from university and EDC partners and by co-facilitating professional development sessions. The project is also engaging administrators to support teachers and build sustainability, and using project knowledge and resources in experiences for pre-service teachers at UMF and USM.